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Original Research

Temporal and Spatial Evolution of Agricultural Facilities in Heihe River Basin Since Han Dynasty

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Abstract

In this paper, geography, history, and geographic information methods were comprehensively used to analyze the spatial and temporal changes of agricultural land, irrigation canals, water sources, and water conservancy facilities since the Han Dynasty in China based on remote sensing images, historical atlases, and word record materials. The results showed that agricultural land was mainly distributed in the upper reaches of the river basin and the southeast region. It rapidly increased from 614.32 km^2 to 6396.54 km^2 from the beginning of the Yuan Dynasty to the People's Republic of China, while the length of irrigation canals increased from 2051.78km to 3267.69km in this period. The total length of the water source remained unchanged from the Han Dynasty to the Republic of China, but increased from 2350km in the Qing Dynasty to 2514km in the People's Republic of China. Moreover, there were 12 water conservancy facility points in the Qing Dynasty, but only 3 facility points in the Tang, Song, and Yuan dynasties. We found that agricultural facilities in the Heihe River basin were mainly comprehensively influenced by natural and social economic factors. Temperature, precipitation, and water resources were the natural background elements of agricultural development and played a key role, while policy, military war, and population migration were important factors effecting the changes in agricultural facilities.

Keywords: Agricultural facilities, Spatial-temporal evolution, Spatial analysis, Historical period, Heihe River Basin

Introduction

Agricultural facilities constitute an essential resource for agricultural production activities and represent a crucial factor impacting human survival, habitation, and reproduction [1]. In ancient times, agricultural facilities played a more prominent role in shaping the conditions of people's mobility, habitation, and development. Since the Han Dynasty, China has experienced a long history of agricultural development, undergoing significant transformations across various periods, influenced by numerous factors [2]. The study of the historical evolution of agricultural facilities can enhance understanding of social development and the human-land relationship over time. This is also significantly important for the rational planning of modern agricultural facilities.

The Heihe River Basin is located in the arid inland of the Hexi Corridor in China, which has historically been one of the most developed agricultural, socially prosperous, and stable regions with the most complete agricultural facilities, especially since the Han Dynasty. It is also the earliest basin in northwest China where irrigated

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agriculture was developed on a large scale, but it is also an area where the contradictions in the development of soil and water resources have deteriorated dramatically [3, 4]. Records related to agricultural facilities in the Heihe River Basin were generally absent before the Han Dynasty, but they have been recorded since the Han Dynasty, therefore allowing the changes of agricultural facilities to be studied using document data and historical photographs [5-7].

Scholars have studied the changes in agricultural facilities in the Heihe River Basin, and most early studies focused on the entire western or northwestern section of the river, including many studies on agricultural facilities in the Heihe River Basin [8-11]. For example, Wang et al. discussed changes in migrant settlement, water conservancy, and agricultural and livestock industries in historical periods [12]. Wang et al. conducted a detailed analysis of the spatial and temporal changes and drivers of oasis settlement in the historical period of the Heihe River Basin [13]. Xie et al. reconstructed the spatial pattern of water resource utilization in the Heihe River Basin during the historical period by using literature, survey data, and satellite image data and found many ecological and environmental problems in the process of soil and water resource development during the historical period [4]. Wang et al. also quantitatively evaluated the intensity of human activities in the middle reaches in the Heihe River during the historical period based on historical documents and estimation data and found that human activities were significantly strengthened during the Ming and Qing dynasties and weakened in the Republican period [7]. Dong et al. analyzed the spatial and temporal evolution characteristics of oases in the Heihe River over the past 55 years using 16 periods of multi-source remote sensing images from 1963 to 2017 and found many common features that provide scientific references for studying agricultural development [14]. Xiao et al. assessed and studied water resource problems and watershed management measures in the Heihe River basin during the past 50 years using meteorological and field study data and presented several management solutions for the present [6]. Li et al. investigated historical grain production in the Hexi region through a large amount of survey data, and they also analyzed changes in agricultural facilities related to agricultural development, focusing on the agricultural layout of Zhangye City in the Heihe River Basin [8]. However, most research has focused on small areas such as counties and townships in the basin because of the literature and field survey data, which are more suitable for small-scale investigations. Besides, most current studies are based on a review of the literature, which also has some shortcomings such as unclear positioning, inaccurate area, and quantitative difficulty. Therefore, it is important to combine the literature, on-site examination, and modern satellite remote sensing technology together to scientifically, accurately, and objectively reflect the evolution characteristics of agricultural facilities of the Heihe River Basin in the historical period, as well as to spatially visualize and express the relevant combination.

This paper used multidisciplinary methodologies such as historical documentary evidence, remote sensing image interpretation, fieldwork, and archaeological inquiry to analyze the changes in location, scope, and area of agricultural land, irrigation canals, water sources, and water conservancy facilities, as well as their influence factors since the Han Dynasty. The results are useful for understanding the history of agricultural development in the Heihe River Basin and tracing the ecological and environmental problems caused by human activities in the historical period. It also has significant references to employing some reasonable measures for ecological restoration, environmental protection, and oasis development.

In this study, agricultural land primarily encompasses various types of farm land, such as dryland, irrigated land, and certain unoccupied residential areas. Irrigation canals specifically denote those irrigated by natural channels and artificial ditches in different periods. Water sources mainly refer to various natural rivers, artificial canals connecting different rivers, and natural water surfaces. Water conservancy facilities refer to agricultural relics, ancient rivers, and ancient lakes used for drainage and irrigation.

Material and Methods

Study Area

The Heihe River originates from the Qilian Mountains on the northern edge of the Tibetan Plateau, flows through the Zhangye Basin, Jiuquan Basin, and Jinta Basin, and finally injects into the territory of Ejin Banner in the Inner Mongolia Autonomous Region. It is the second largest inland river in China [15]. The Heihe River Basin is the second-largest inland basin in the northwest region of China, geographically located between 96°04′~102°00′E and 37°41′~42°42′N, with a total area of about 14.29×10^4 km^2, a total population of 1.425 million, and an irrigated area of 33.5×10^5 acres. The administrative boundaries include Qilian County in Qinghai Province, Sunan, Shandan, Minle, Zhangye, Linze, Gaotai, Jinta in Gansu Province, and Ejin Banner in Inner Mongolia Autonomous Region, totaling 10 counties (banners) [16]. The basin belongs to the mid-temperate continental arid climate, with a dry climate, scarce precipitation, and concentrated June-September strong solar radiation, and a large temperature difference between day and night. At present, the basin has formed major oasis areas such as Shandan-Minle, Ganzhou-Linze-Gaotai, Jiuquan, Jinta-Dingxin, and Ejin Banner. Among them, Jinta Oasis, Dingxin Oasis, and Ejin Banner Oasis are located in the lower reaches of the basin, while other oases are located in the middle reaches of the basin. The Heihe River has nurtured rich pastures in its upper reaches and nourished fertile farmland in its middle reaches, making Zhangye an important grain-producing area in western China (Figure 1) [17, 18].

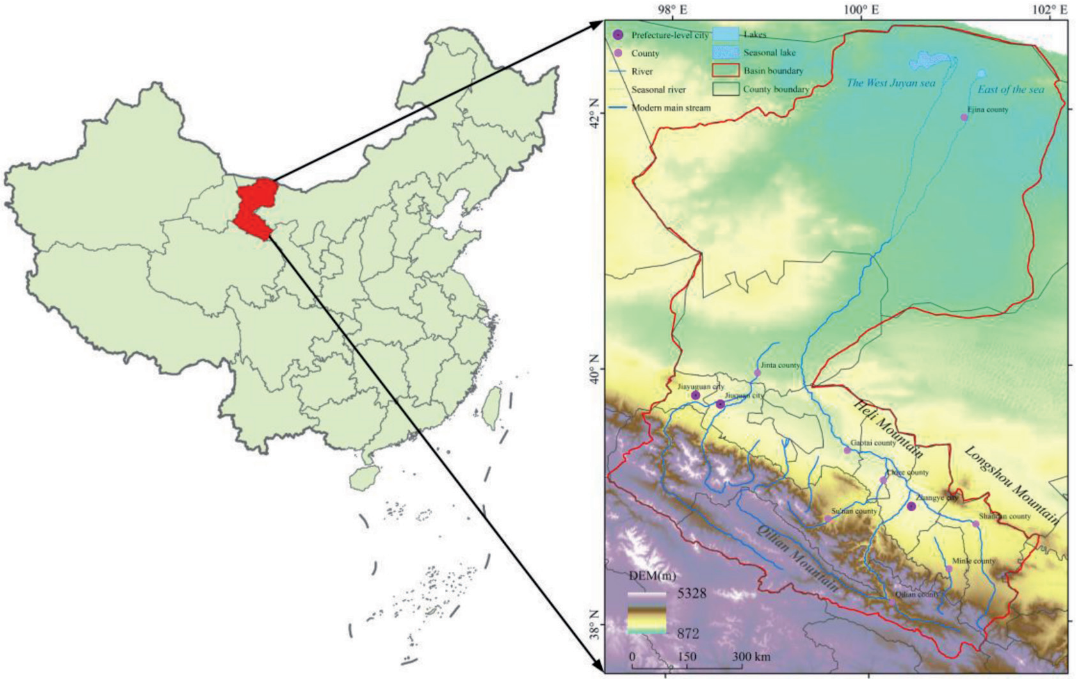


Fig. 1. Geographical map of the Heihe River Basin.

Date Sources and Date Processing

Remote Sensing Data

The use of historical remote sensing imagery is the most important data source for obtaining information on historical agricultural facilities in this study. The remote sensing imagery, together with topographic and soil data, can directly decipher the possible areas of agricultural facilities such as irrigation areas, ancient river channels, water sources, and water conservancy facilities [19]. In addition, high-resolution HD images were downloaded from Google Earth, and Keyhole satellite photographs with a spatial resolution of 2.7-7.5m, imaged in the 1960s, were acquired. Since the productivity of the time was relatively low and the transformation of nature had not yet reached a significant level, the Keyhole images have preserved the previous information well and are of great importance for the identification of ancient rivers and canals and are of great importance in the study.

Historical Documents

The historical data involved in this paper mainly includes historical documents, historical relics, and graphic materials. Among them, historical documentary data is the basic information for the reconstruction. Official publications such as History of the Han Dynasty and History of the Later Han Dynasty were collected in the study, and their records include information on the population, administrative establishment, and cantonment of the Heihe River Basin during the Han Dynasty [20]. Chinese historical sources have some records of major events of the early Han Dynasty, which are important supplementary materials. In addition, the city histories of Zhangye and Jiuquan and the county histories of each county were collected, containing accounts of events and relics from the historical period and correcting inaccuracies, which appear more objective and scientific, and are also important reference materials.

Historical Graphics

Historical map materials include historical maps and modern maps. Historical maps include "Historical Atlas of China" edited by Tan Qixiang, "Geographical History Maps of All Ages" edited by Ma Weilin (Qing Dynasty), and illustrations in ancient local chronicles. It can be used to obtain the administrative establishment of the Han Dynasty in the basin. Modern maps are mainly topographical maps of different periods, which can provide a basis for locating the distribution of settlements and the recovery of the course of the channel water system in historical periods. The Gansu and Inner Mongolia volumes of the Atlas of Chinese Cultural Relics contain information on most cultural relics, with detailed descriptions of their spatial locations, existence times, and scales, which are important basic information for the reconstruction of agricultural land. In addition, the time of the rise and fall of ancient city sites obtained by some scholars through testimony or dating means was collected in the study, providing a temporal basis for the recovery of the spatial distribution of agricultural land.

Site Visit Information

In order to verify the accuracy of the location of agricultural facilities in some of the literature and historical drawings, a site examination was conducted in the Heihe River Basin from May 2011 to July 2022. Some historical

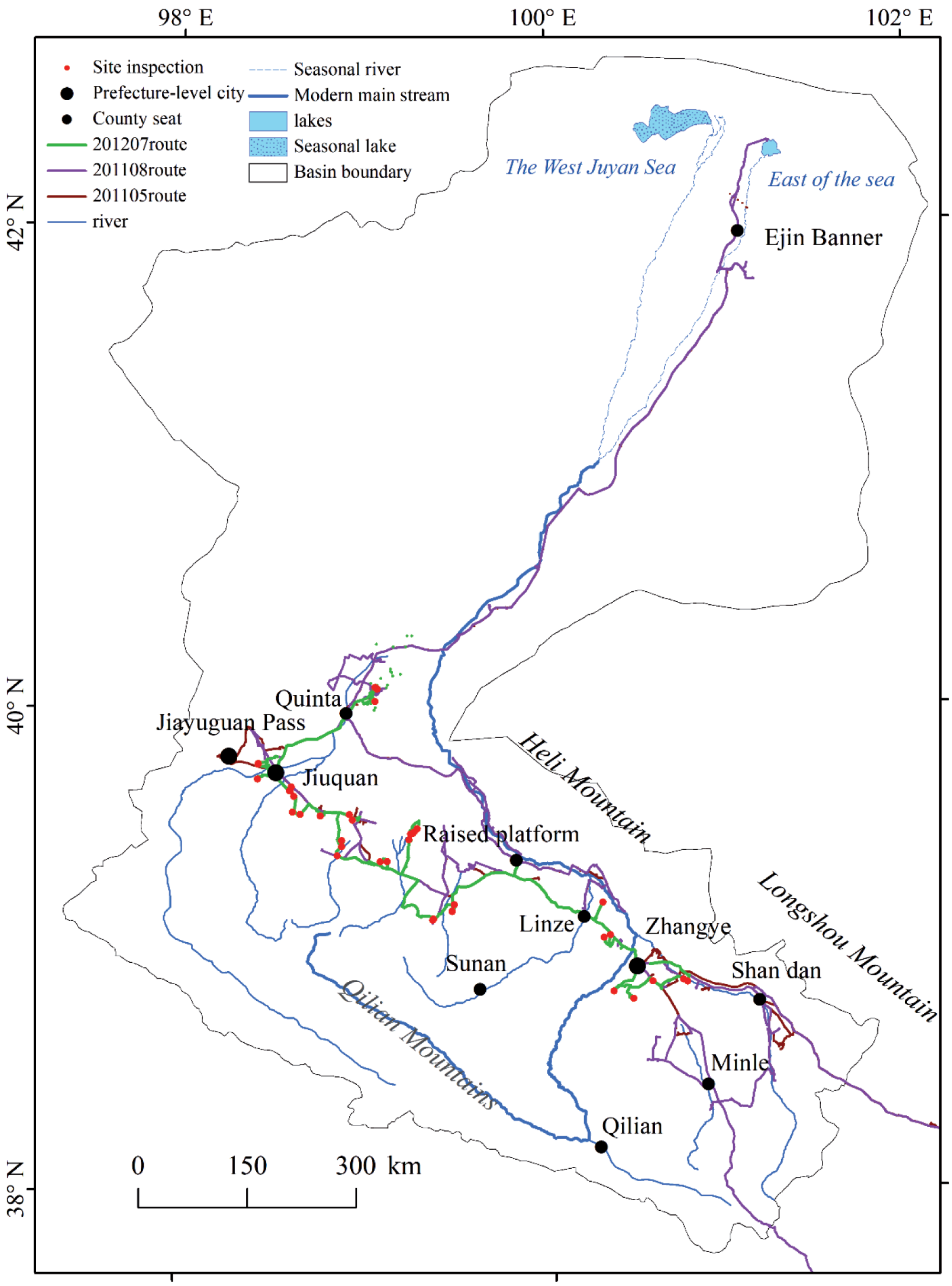


Fig 2. Field survey route.

sites were surveyed on site, and some more objective information on agricultural facilities was obtained, including the location of major water sources, the location and length of old irrigation areas, and the location of some water conservancy facilities. The main routes of the examination are shown in Figure 2.

Basic Geographical Data

The basic geographic data used in this paper mainly include: administrative boundary data of the Heihe River Basin since the Han Dynasty, municipal and county-level resident data, and agricultural land distribution data, the vector boundary data of the Heihe River Basin, ancient rivers and lakes data, channel data [21]. The soil type data of the Heihe River Basin collected so far is the 100,000 soil type data formed by the former Lanzhou Desert Research Institute of the Chinese Academy of Sciences around 1988 through various land type maps, soil maps, and field surveys, aerial film, and satellite film interpretation, which divided the Heihe River Basin soil into 8 soil classes. Crop using the Heihe River Basin boundary, which was provided by the National Earth System Science Data Center (http://www.geodata.cn/).

The collected DEM data are NASA's ASTER GDEM with a spatial resolution of 30 m, a global elevation accuracy of 20 m, and a horizontal accuracy of 30 m. The data are obtained from the International Scientific Data Mirror website of the Computer Network Information Center of the Chinese Academy of Sciences (http://datamirror.csdb.cn).

Data Processing

The spatial distribution of agricultural land, irrigation channels, water conservancy facilities, and water sources in different periods was obtained through manual visual interpretation through remote sensing images corresponding to periods after on-site verification in May, August 2011, and July 2012. 89.75% of the data were consistent, and the remaining data were modified for interpretation results. Besides, historical documents, historical maps, and county records of Heihe County and Han Shu Geography were compared with each other in the same period; the description was consistent and the correct range was determined, and the description was inconsistent with the repeated demonstration. The accuracy of collated data can meet the needs of this study.

Study Methods

Dynamic Analysis

The dynamic analysis model can not only reflect the change rate of ancient agricultural facilities, but also reflect the overall change characteristics of ancient agricultural facility types. The formula for calculating the dynamics of irrigation canals, agricultural land, etc. is as follows:

$$T_{\text{grid}_{T_2-T_1}} = \frac{\Delta U_{in} + \Delta U_{out}}{S_{grid}} \times 100\% \qquad (1)$$

In the formula: ΔU_{in} and ΔU_{out} are the expansion and retreat of agricultural land during the study period; S_{grid} is the grid unit area; T_1 and T_2 were the early and late stages of the study, respectively; Tgrid represents the dynamics of agricultural land change in the two phases in the study area, and the theoretical value range is [0,1].

Central Migration Analysis

Use the Average Center analysis tool in the Spatial Statistics Analysis tool in ArcGIS to identify the geographic center (or density center) of a set of elements. In this paper, the average centroid analysis tool is used to calculate the center points of various agricultural lands in each period, calculate their latitude and longitude, calculate the number of center points in different agricultural lands and water conservancy facilities, and quantify the results.

Spatial Overlay Method

In this study, the advantages of both vector data file formats and raster data file formats were utilized. During the stages of data preparation and preprocessing, the vector method was employed, enabling flexible modification, updating of information, and conditional combination calculations of intersecting information from multiple layers. For comprehensive analysis and calculation, the raster data format was adopted, ensuring both speed and accuracy. Based on the variations of agricultural land within different years and land use types, the change patterns of agricultural land were categorized into areas of increase and areas of decrease. These change patterns were primarily determined through overlay analysis of agricultural land boundaries from different sample years. By overlaying agricultural land data extracted from two adjacent sample years, areas that remained unchanged during that period were identified, and the areas of increase and decrease were determined by excluding the unchanged regions between subsequent and previous data periods.

Kernel Density Analysis

The kernel density analysis tool is used to calculate the density of elements within their surrounding neighborhoods. Kernel density is employed to visually express the spatial structure and evolutionary characteristics of canals, water sources, and water conservancy facilities. A higher kernel density indicates a denser spatial distribution of canals, water sources, and water conservancy facilities.

The formula for calculating the kernel density function is as follows:

$$\mathrm{f}(x) = \sum_{i=1}^{n} \frac{1}{\pi r^2} \phi\left(\frac{d_{ix}}{r}\right) \qquad (2)$$

In the formula, *f(x)* is the estimate of kernel density at *x*; *r* is the search radius; *n* is the total number of samples; d_{ix} is the distance between points *i* and *x*; Φ is the weight of the distance.

Statistical Analysis Method

Statistical analysis methods in mathematical statistics primarily study the regularities that exist in the relationships between local and global phenomena, as well as the various relevant factors in random phenomena. In this study, relevant statistical methods were employed to calculate and analyze the changes in ancient river channels and relic migration, changes in agricultural land area, length variations, and line density variations.

Results and Discussion

Spatial and Temporal Variation Characteristics of Agricultural Land

The spatial visual representation and mathematical statistical analysis of agricultural land in the Heihe River Basin at different periods since the Han Dynasty were performed using the GIS spatial overlay method (Figure 3). It was found that the agricultural land in the

Heihe River Basin changed significantly throughout the study period. Spatially, it was mainly concentrated in the southeastern part of the basin, and its changes showed a trend of decreasing and then increasing, and the overall area showed a trend of increasing. In different historical periods, agricultural land was distributed in the upstream, midstream, and downstream areas from the Han Dynasty to the Yuan Dynasty. While agricultural land was mainly distributed in the upstream areas, beginning with the Ming Dynasty. The Heihe River Basin had a better ecological environment in the early downstream areas that was suitable for agricultural development. However, the ecological environment deteriorated in the modern age, and the downstream areas became unutilized and bare land, unsuitable for agricultural land development and exploitation. In terms of quantitative changes, from the Han Dynasty to the Song Dynasty, the area of agricultural land in the Heihe River Basin decreased continuously from 1702.74 km^2 to 560.47 km^2, with an obvious trend of decrease. From the Yuan Dynasty to the People's Republic of China, the agricultural land in the Heihe River Basin expanded very rapidly and grew faster, with the area increasing from 614.32 km^2 to 6396.54 km^2. In the People's Republic of China period, the change rate of agricultural land area was greater than 2, indicating that the expansion rate of agricultural land in the Heihe River Basin was the fastest. Table 1 provides detailed statistics on the area and changes of agricultural land in different periods.

Spatial overlay analysis of agricultural land in the Heihe River Basin in each adjacent period since the Han Dynasty using the ArcGIS10.4 platform yielded the results shown in Figure 4 and Figure 5. It can be seen that the intensity

Fig. 3. Spatial distribution of agricultural land in the Heihe River Basin since the Han Dynasty.

Table 1. Changes in agricultural land area in the Heihe River Basin in different dynasties.

Time nodes	Total area(km^2)	Growth volume(km^2)	Growth rate(%)
Han Dynasty	1702.74		
Jin Dynasty	1114.62	-588.13	-34.54
Tang Dynasty	629.10	-485.51	-43.56
Song Dynasty	560.47	-68.64	-10.91
Yuan dynasty	614.32	53.85	9.61
Ming Dynasty	963.55	349.23	56.85
Qing Dynasty	1754.54	790.99	82.09
Republic of China	1917.17	162.63	9.30
The People's Republic of China	6396.54	4479.37	233.64

of agricultural land area change in the Heihe River Basin fluctuated greatly during the study period, but the intensity of agricultural land change varied in different periods. Among them, the dynamic attitude of agricultural land change was negative from the Han Dynasty to the Song Dynasty, indicating that the area of agricultural land in that period was decreasing, and after the Song Dynasty, it showed an obvious increasing trend, especially in two obvious increasing periods from the Ming Dynasty to the Qing Dynasty and from the Republic of China to the People's Republic of China. Figure 4 shows the change in agricultural land in two adjacent periods. It can be seen that agricultural land has increased and decreased in different historical periods, but its increasing trend is more obvious from the Qing Dynasty, and the increasing location is mainly concentrated in the upstream area of the Heihe River Basin.

To more intuitively represent the changes in agricultural land in the Heihe River Basin during the study period, this paper calculated the geometric centers of agricultural land in the Heihe River Basin in each period using the spatial statistics tool in ArcGIS. Meanwhile, this paper obtained the geographic coordinates and distances of the center points in each period, and the results are shown in Figure 6. It can be found that the location of the center of agricultural land in the Heihe River Basin changed significantly over time, with the center of agricultural land moving westward by 49.54 km from the Han Dynasty to the Jin Dynasty, and moving northward by 28.78 km from the Jin Dynasty to the Tang Dynasty. From the Tang Dynasty to the Song Dynasty, the center of agricultural land moved 158.77 km to the northeast. The center point of agricultural land moved 59.47 km to the west from the Song Dynasty to the Yuan Dynasty. The center point of agricultural land moved the most between the Yuan Dynasty and the Ming Dynasty, 162.57 km to the south. From the Ming Dynasty to the People's Republic of China periods, the center points were concentrated in the southern part of the basin, with less variation, and the distance between them was within 20 km.

The most important factors affecting agricultural land are temperature and precipitation, which are mainly related to the terrain and climate of the Heihe River Basin. It is characterized by a continental climate surrounded by mountains and far from the sea. The southern part is located in the Qilian Mountains, with more precipitation, a low temperature, and weak evaporation [7, 22]. The downstream area is extremely dry, with less precipitation, more wind, and a large temperature difference between day and night, which can directly affect the growth of vegetation, while precipitation and temperature can affect

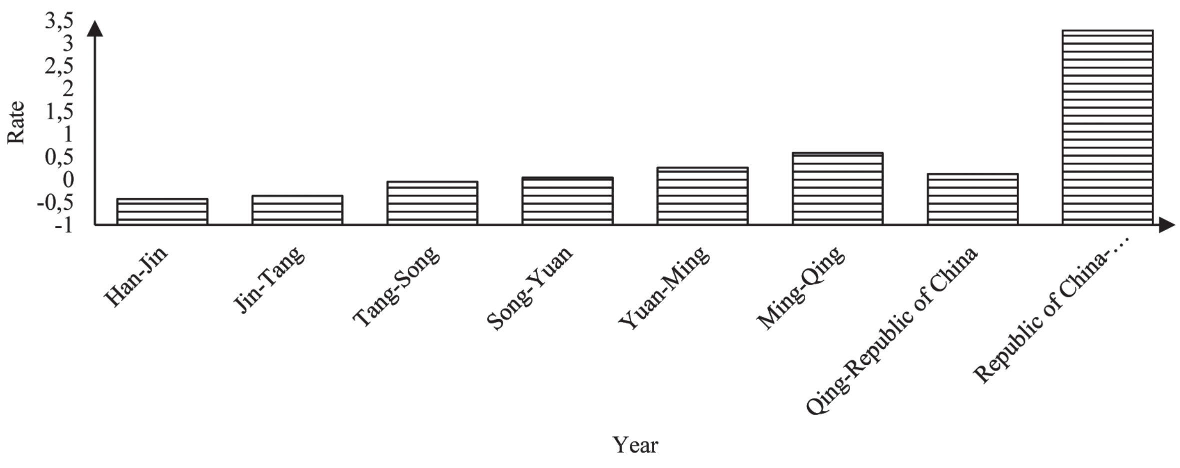


Fig. 4. Dynamic attitude of agricultural land change in the Heihe River Basin.

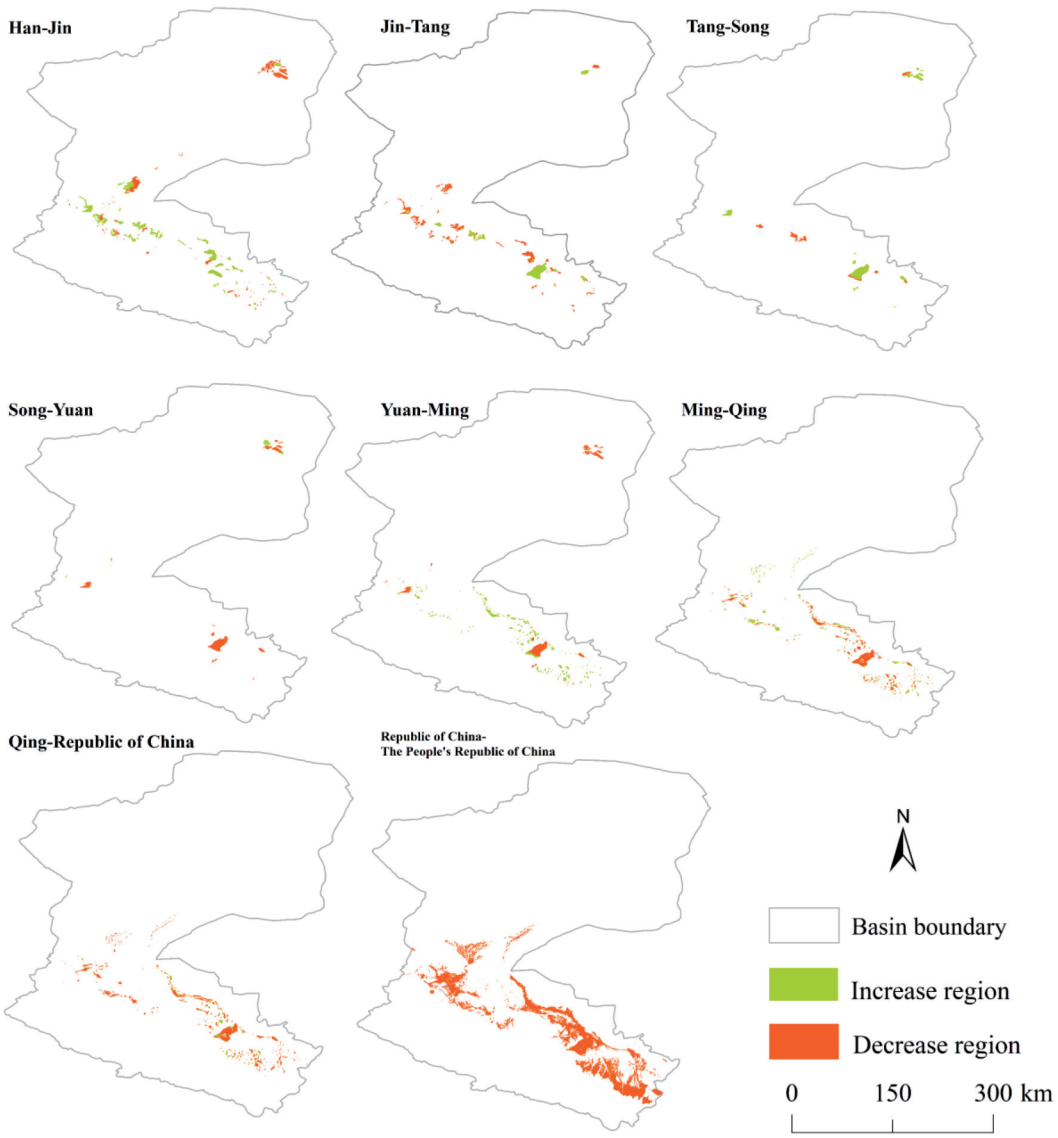


Fig. 5. Spatial changes of agricultural land in the Heihe River Basin since the Han Dynasty.

the temporal and spatial distribution of hydrology and water resources. As shown in Figure 7 and Figure 8, most of the precipitation in the middle reaches of the Heihe River fluctuates around 100mm, making it difficult to supply water to agricultural land. But in the upper reaches of the Heihe River Basin Qilian Mountain area, rain is rich and is the main source of agricultural land water supply. The variation trend of precipitation is basically consistent with that of farmland areas. Higher temperatures will also restrict the growth of vegetation. Under the synergistic effect of temperature and precipitation, the temporal and spatial changes of agricultural land were changed.

Spatial and Temporal Variation Characteristics of Irrigation Canals

Agricultural development is often inseparable from water resources, and irrigation canals, which convey water resources for agricultural production, are very important agricultural facilities. In this paper, the number of irrigation canals in the Heihe River basin in various periods was statistically analyzed by the nuclear density analysis method, and the results are shown in Figure 9 and Table 2. The study shows that the spatial distribution of irrigation canals in the Heihe River Basin gradually evolved from point-like distribution to surface-like distribution and constantly clustered in the southeastern part of the basin. The number and area of irrigation canals increased significantly during the Yuan Dynasty, and the spatial location was similar to the distribution trend of agricultural land. The number of irrigation canals increased slowly, and the length of irrigation canals increased from 98.96 km in the Han Dynasty to 165.30 km in the Song Dynasty, mainly due to the low level of social and technological development at that time, and the fact that the Heihe River Basin was located at the border with more social unrest, which led to the decrease of population, and thus the demand for agricultural facilities,

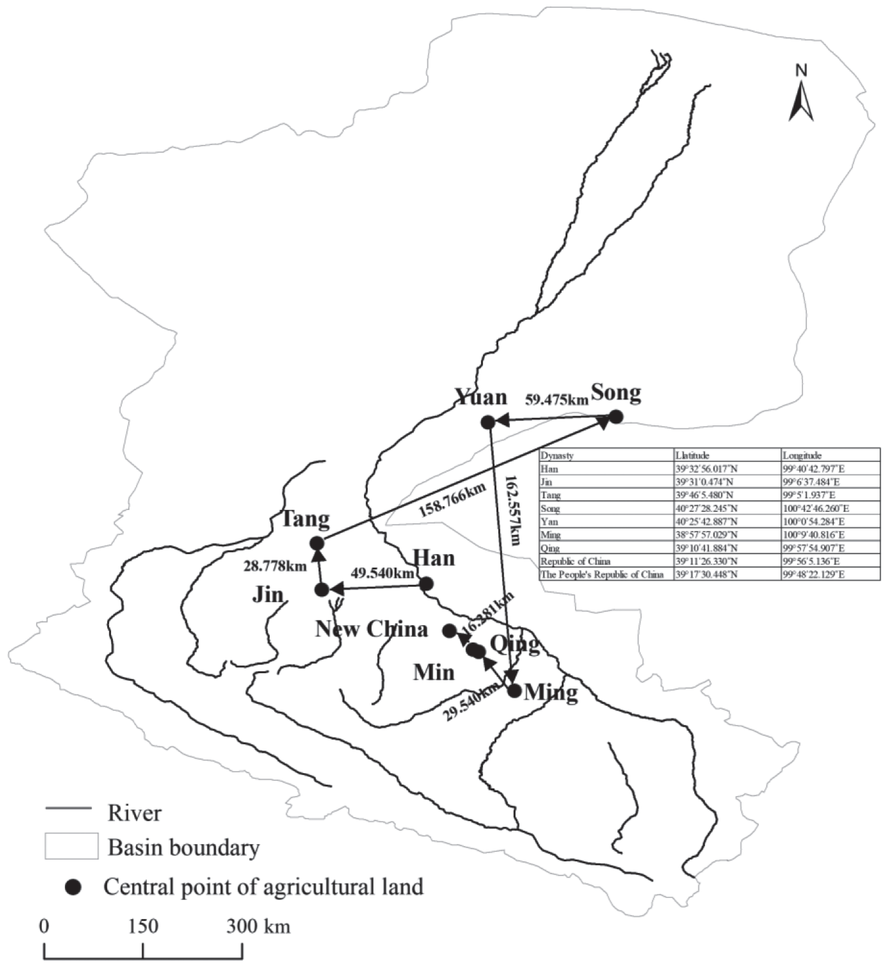


Fig. 6. Changes in the agricultural land centers in the Heihe River Basin since the Han Dynasty.

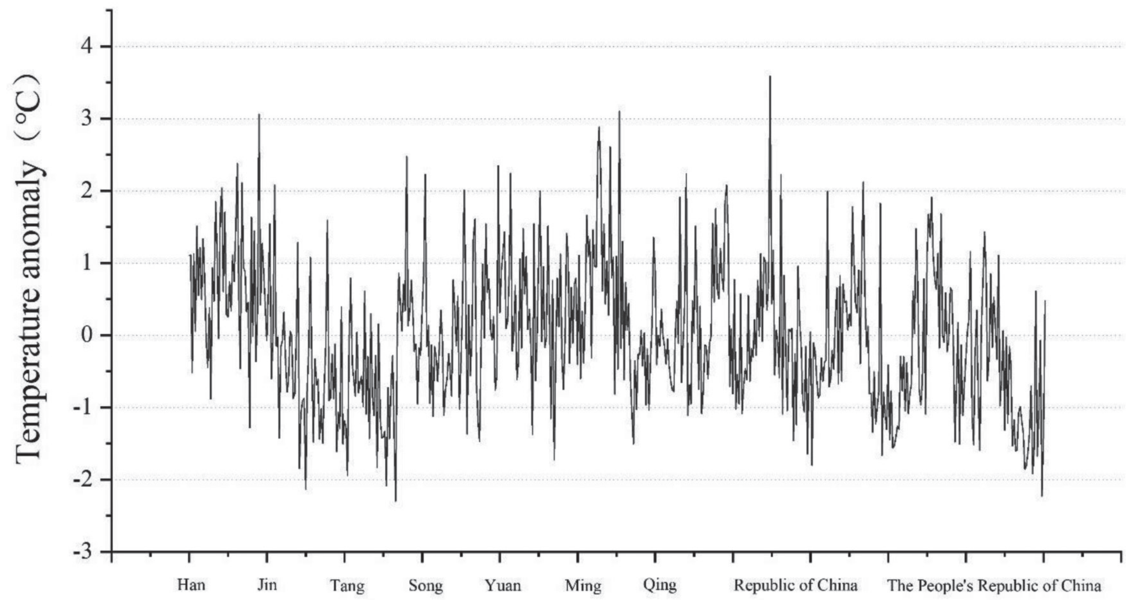


Fig. 7. Average annual variation curve of precipitation.

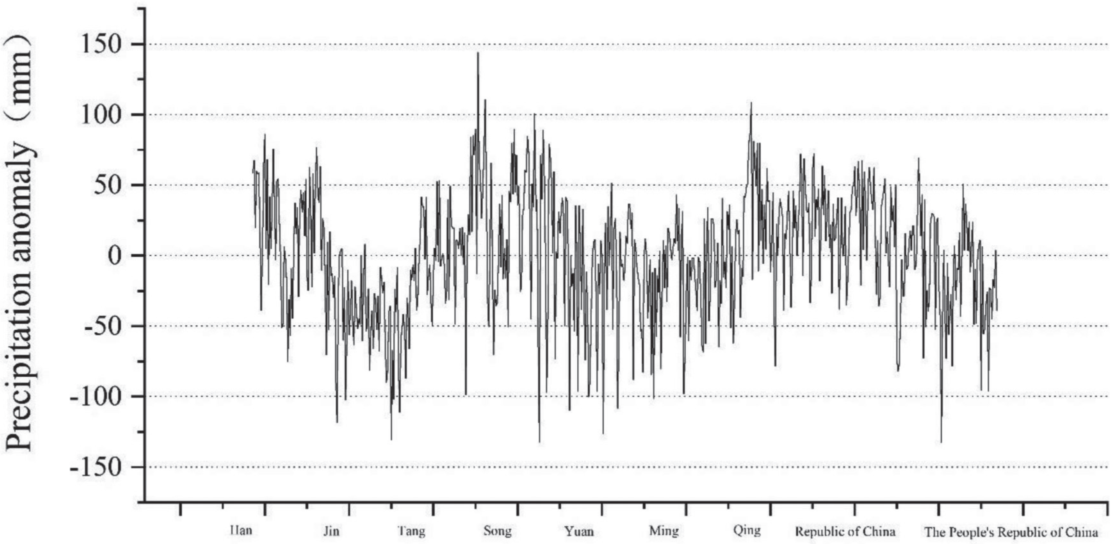


Fig. 8. Average annual temperature change curve.

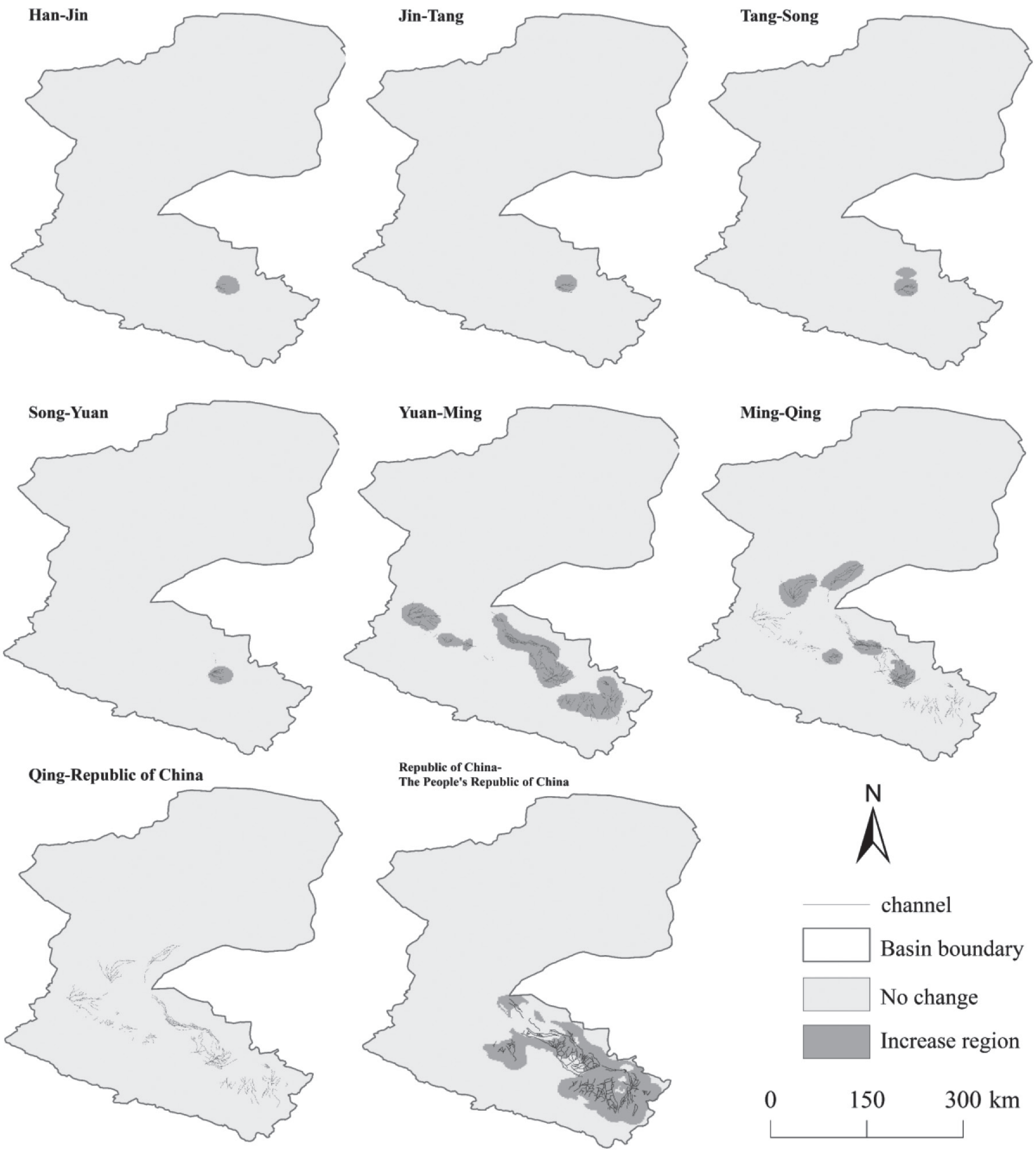


Fig. 9. Irrigation channel changes in the Heihe River Basin in different periods.

Table 2. Variation of irrigation channel length in the Heihe River Basin in different periods.

Dynasties	Length (km)	Length increase (km)	Rate of change (%)
Han Dynasty	98.96	—	—
Jin Dynasty	115.24	16.28	16.45
Tang Dynasty	129.84	14.60	12.67
Song Dynasty	165.30	35.46	27.31
Yuan dynasty	165.30	0.00	0.00
Ming dynasty	2051.78	1886.48	1141.26
Qing dynasty	3267.69	1215.91	59.26
Republic of China	3267.69	0.00	0.00
The People's Republic of China	2242.98	-1024.71	-31.36

such as irrigation canals. The demand for agricultural facilities, such as irrigation canals, decreased. From the Song Dynasty to the Yuan Dynasty, the population recovered, but the number of irrigation canals was basically the same as in the Song Dynasty because there were many uprisings and social unrest in the latter part of the period, so there was no major water development. From the Ming Dynasty to the People's Republic of China period, the length of irrigation canals increased rapidly, from 2051.78km to 3267.69km in the Republic of China period, the total length increased by 19.76 times compared with the Song Dynasty, mainly due to the rapid development of social and economic development in this period. The period of science and technology has been developed and has higher productivity, while social stability and the cultivation of high-yielding food crops drives a rapid increase in population. The number of irrigation canals also increased rapidly due to the expansion of agricultural land and the increasing demand for related agricultural facilities.

To deeply analyze the changes in the number of irrigation canals in the Heihe River basin in each period, statistical analysis of the nuclear density of irrigation canals in different periods was carried out in this paper, and the results are shown in Figure 10. It showed that the density of irrigation canals in the Heihe River basin shows a change characteristic of increasing and then decreasing with the passage of time. From the Han Dynasty to the Qing Dynasty, the density of irrigation canals in the Heihe River Basin increased from 0.082 to 0.520 and then decreased from 0.520 to 0.398 during the Republic of China to New China. In the Ming Dynasty, the density of irrigation canals increased from 0.211 in the Yuan Dynasty to 0.413, which was double the density of irrigation canals in the Yuan Dynasty, and reached its maximum density in the Qing Dynasty. During the period from the Republic of China to the People's Republic of China, the density of irrigation canals in the basin decreased due to the abandonment of some canals that had no irrigation function, the systematic optimization of the construction of irrigation canals in the basin, and urban expansion.

Changes in water resources can directly determine changes in river tributaries and irrigation channels. The paper statistically analyzed the annual variation characteristics of surface runoff from the Han Dynasty to the People's Republic of China for more than 2000 years. The results are shown in Figure 11. Most of the annual runoff is concentrated in the 10-20×109m^3/a fluctuation. Two troughs occurred in the Jin Dynasty and the Tang Dynasty, indicating that water resources decreased during this period, and the corresponding water sources and irrigation channels also changed significantly. However, in the Ming Dynasty, the Qing Dynasty, and the Republic of China, there was a small peak of runoff, which was consistent with the change of irrigation canals.

Natural disasters have a certain impact on the agricultural facilities in the Heihe River Basin, which can destroy the agricultural land in the region in a short time and even lead to a change of water source. Natural disasters in the Heihe River Basin mainly include earthquakes, sandstorms, hail, etc., which are mainly caused by climate change [4]. According to the statistics on the occurrence times of various disasters (Figure 12), drought and flood disasters occurred 251 times in the Heihe River Basin, of which 71 were waterlogged and 180 were drought [23]. It showed that the drought disaster is the main natural disaster in the basin. Drought and flood disasters in the river basin play an important role in promoting the spatio-temporal change of agricultural facilities and are also one of the main factors causing the change of social life.

Spatial and Temporal Characteristics of Watershed Changes

The kernel density analysis and dynamic calculus methods were used to analyze the characteristics of watershed changes during different periods. The results are shown in Figure 13, which reveal noticeable fluctuations in watersheds within the Heihe River Basin from the Han Dynasty to the establishment of the People's Republic of China. The main areas of change are concentrated in the upper reaches of the Heihe River Basin. By examining the locations of increased watersheds, it is evident that they were predominantly situated where rivers connect with agricultural land. The primary approach involved establishing connections between different water

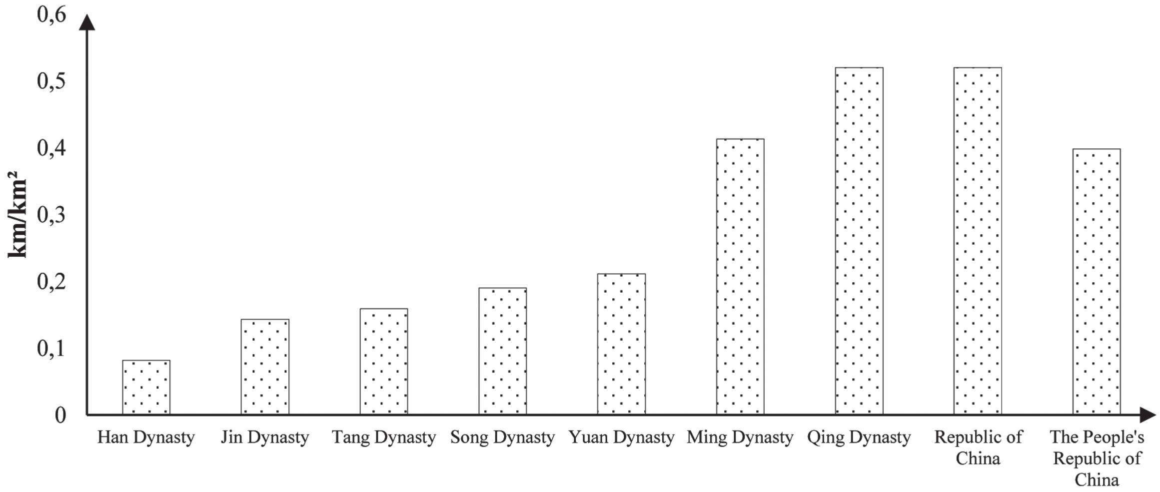


Fig. 10. Change in irrigation channel density in the Heihe River Basin.

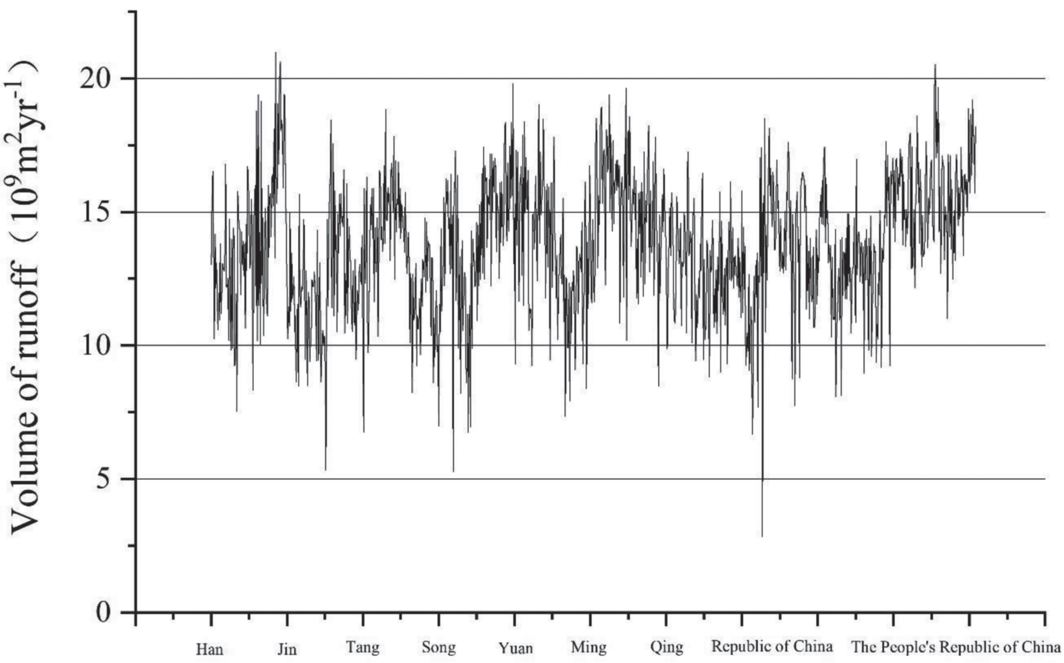


Fig. 11. Change in average annual runoff in the historical period.

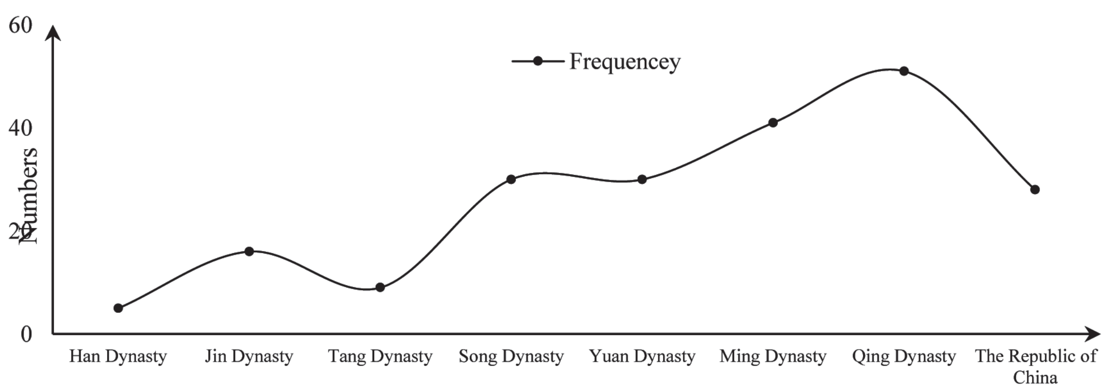


Fig. 12. The number of disasters and the years between them.

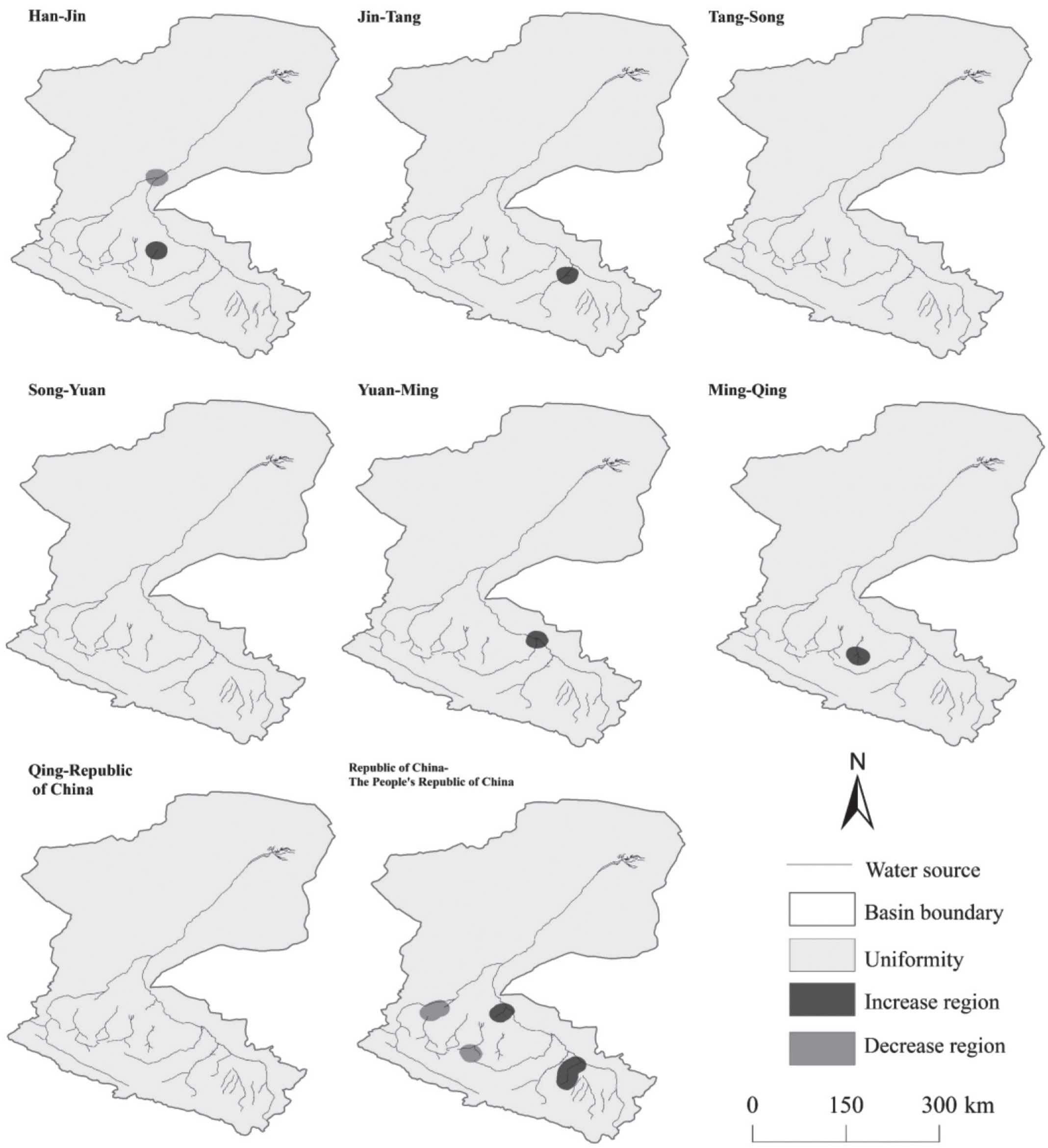


Fig. 13. Spatial variation characteristics of water source sites.

systems, further facilitating river flow. Additionally, artificial irrigation channels were constructed between rivers to improve waterway clearance. In terms of the study period, the watersheds remained relatively stable from the Han Dynasty to the Yuan Dynasty. However, an evident increase in watersheds occurred from the Ming Dynasty onward, reaching its peak during the era of the People's Republic of China. The article also presents the total length of watersheds during different periods, as illustrated in Figure 14. The research findings indicate that the length of watersheds fluctuated between 2300 km and 2350 km from the Han Dynasty to the Republic of China period. However, during the era of the People's Republic of China, there was a significant surge in length, with an increase from 2350 km to 2514 km. This represents a growth of 164 km, reflecting the substantial increase in demand for watersheds in the Heihe River Basin due to rapid agricultural development and population growth during modern times. It also highlights the expansion of agricultural land, which has resulted in a greater number of tributaries in the watershed.

Spatial and Temporal Characteristics of Water Conservancy Facilities Changes

The geometric center migration method was used to determine the center points of water conservancy facilities during different periods, as depicted in Figure 15 and Figure 16. The research revealed that the water conservancy facilities of the eight dynasties were concentrated in the upper reaches of the Heihe River Basin, displaying a 'loop-shaped' variation in their center points. The center points migrated approximately 99.46 km southeast from the Han and Jin Dynasties to the central positions during the Tang, Song, and Yuan Dynasties. Subsequently, they shifted northwest by 44.95 km to the center during the Ming

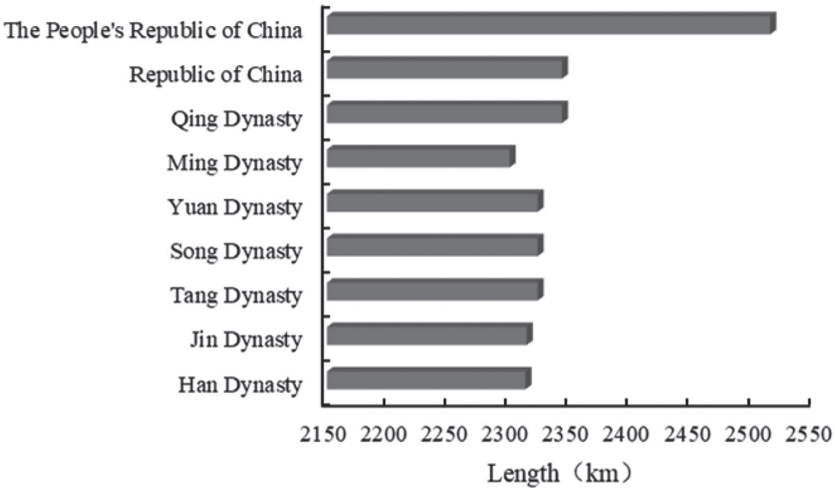
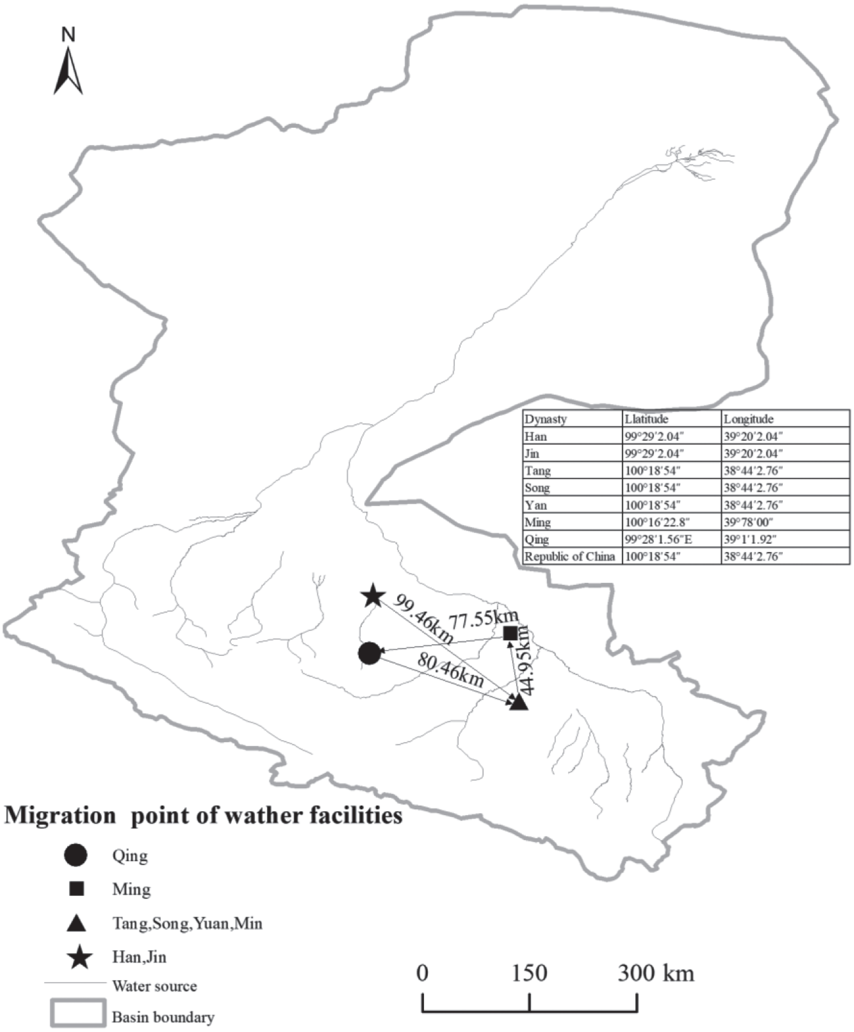


Fig. 14. Changes in water source sites by period.



Dynasty	Llatitude	Longitude
Han	99°29′2.04″	39°20′2.04″
Jin	99°29′2.04″	39°20′2.04″
Tang	100°18′54″	38°44′2.76″
Song	100°18′54″	38°44′2.76″
Yan	100°18′54″	38°44′2.76″
Ming	100°16′22.8″	39°78′00″
Qing	99°28′1.56″E	39°1′1.92″
Republic of China	100°18′54″	38°44′2.76″

Fig. 15. The number of water conservancy facilities varies from period to period.

Dynasty, then migrated southwest by 77.55 km to the center during the Qing Dynasty, and finally moved southeast to the center during the Republic of China period. In terms of the number of major water conservancy facilities, the highest number was observed during the Qing Dynasty, with a total of 12 locations, while the lowest number was during the Tang, Song, and Yuan Dynasties, with only three locations. The variation in the quantity of water conservancy facilities differs from the number of agricultural land and irrigation channels during each period. This difference

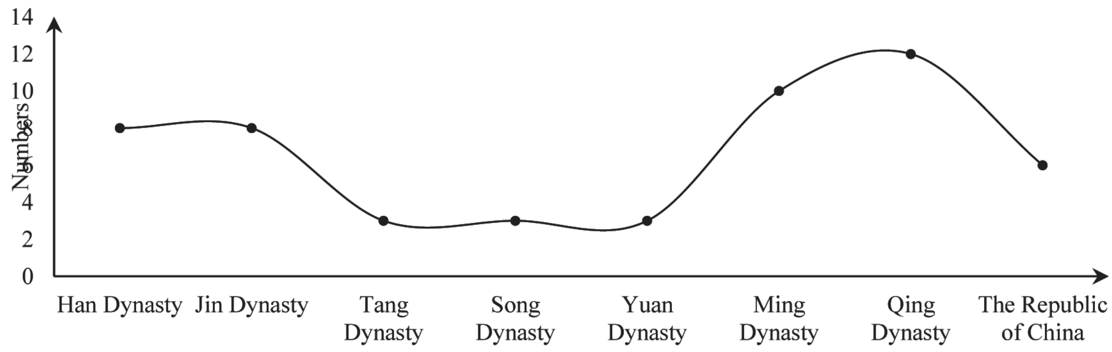


Fig. 16. Central point migration diagram of water conservancy facilities.

may be attributed to partial data missing, but it also reflects the interplay between agricultural development, socio-economic factors, and social infrastructure during that time.

Overall Characteristics of Agricultural Facility Changes in the Heihe River Basin

This paper integrates agricultural land, irrigation channels, watersheds, and water conservancy facilities and produces a spatial distribution map of agricultural facilities in the Heihe River Basin, as shown in Figure 17. It can be observed that agricultural facilities in the Heihe River Basin have been relatively comprehensive since the Han Dynasty, primarily developing and evolving in areas with flat terrain and abundant water resources. The main agricultural facilities form two agglomerated regions within the basin: one in the southern part, characterized by a strip-like distribution, and another in the northern part, exhibiting a point-like distribution. During the Jin Dynasty, the scale of agricultural facilities in the Heihe River Basin decreased, and the spatial distribution characteristics were similar to those of the Han Dynasty. By the Tang Dynasty, the distribution of agricultural facilities in the Heihe River Basin had evolved from strip-like agglomeration during the Han and Jin Dynasties to multiple scattered points of concentration. During the Song and Yuan Dynasties, the distribution of agricultural facilities in the Heihe River Basin resembled that of the Tang Dynasty, with a predominant concentration of point-like clusters. However, starting from the Ming Dynasty until the era of the People's Republic of China, the distribution of agricultural facilities gradually reverted to a strip-like agglomeration, and the number of various agricultural facilities increased rapidly. Nevertheless, in the northern region of the basin, the main agricultural facilities were abandoned and disappeared.

Throughout the entire study period, agricultural land had the largest scale among agricultural facilities in the Heihe River Basin, followed by irrigation channels, which showed an increasing trend in quantity. On the other hand, there were significant differences in the distribution of watersheds, with the fewest observed during the Ming Dynasty and reaching the highest total length during the era of the People's Republic of China. The distribution of water conservancy facilities exhibited noticeable fluctuations and a relatively small-scale distribution. The periods with the highest number of water conservancy facilities were the Qing Dynasty and the Ming Dynasty, followed by the Han Dynasty and the Jin Dynasty. The Tang Dynasty, Song Dynasty, and Yuan Dynasty had the fewest number of water conservancy facilities, and there were no significant changes in length during these periods.

The Influence of the Main Social Economic Factors on Agricultural Facilities

Land Taxation Policy

China is a large agricultural country with a farming civilization spanning more than 5,000 years, and the changes in the land system have largely influenced the development and changes of the Chinese economy. The government of each dynasty has formulated corresponding economic systems, including land, taxation, and corvée systems, among which the land and taxation systems directly affect agricultural production and play an important role in the development and evolution of agricultural society [13].

The Han dynasty, while practicing rest and recuperation, followed the name field system of the Qing dynasty, which was based on the military title system and granted fields according to household registration. At the same time, different titles and different amounts of land were assigned according to military merit, and the land granted by the state became private possession, and the state would not take it back. In addition to allowing people to open up land, land could be bought and sold freely, which increased the enthusiasm of farmers in farming [22]. From the Jin dynasty to the Northern and Southern dynasties, the state reduced field rents, abolished harsh taxes, issued equal-field decrees, and implemented the equal-field system, allocating land to peasants according to gender and age. The main part of these lands was only allowed to be used and not to be bought and sold, and the peasants who received the fields had to pay rent and taxes to the state and perform corvée and military service [13].

From the evolutionary development of land policies in various historical periods (Figure 18), the land system in

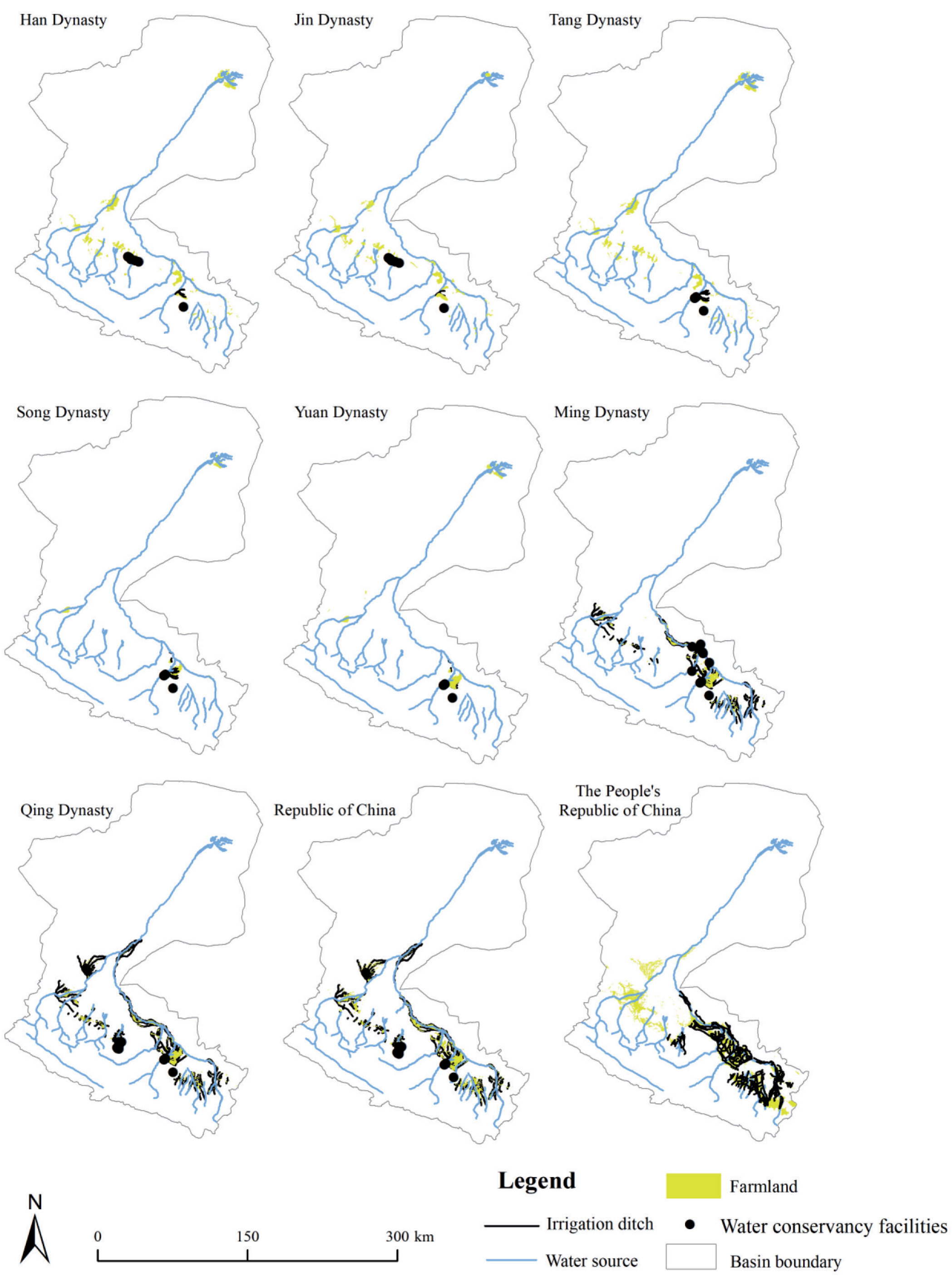


Fig. 17. Spatial distribution of agricultural facilities in the Heihe River Basin.

the region has been continuously modified and improved since the Han dynasty, with farmers receiving more land for cultivation and reduced taxes, while farmers' rights and interests in farming have been systematically guaranteed and their motivation to cultivate has increased, promoting local agricultural development.

Military Warfare

During the Han dynasty, the Heihe River Basin was located between the four major regions of Guanzhong; the Western Region, Inner Mongolia, and Huangshui River, with a collection of roads, dangerous terrain, and developed agriculture and animal husbandry. It also had a high strategic location value. There are 23 documented battles related to the area recorded in the literature [10]. Since the Han dynasty, the operation of the Heihe River Basin and the northwestern region by successive central governments was full of military colors, the fundamental purpose of which was to guarantee the security of the frontier through the border defense system, so the agricultural development of the area had special military defense attributes. Figure 19 shows the main military situation

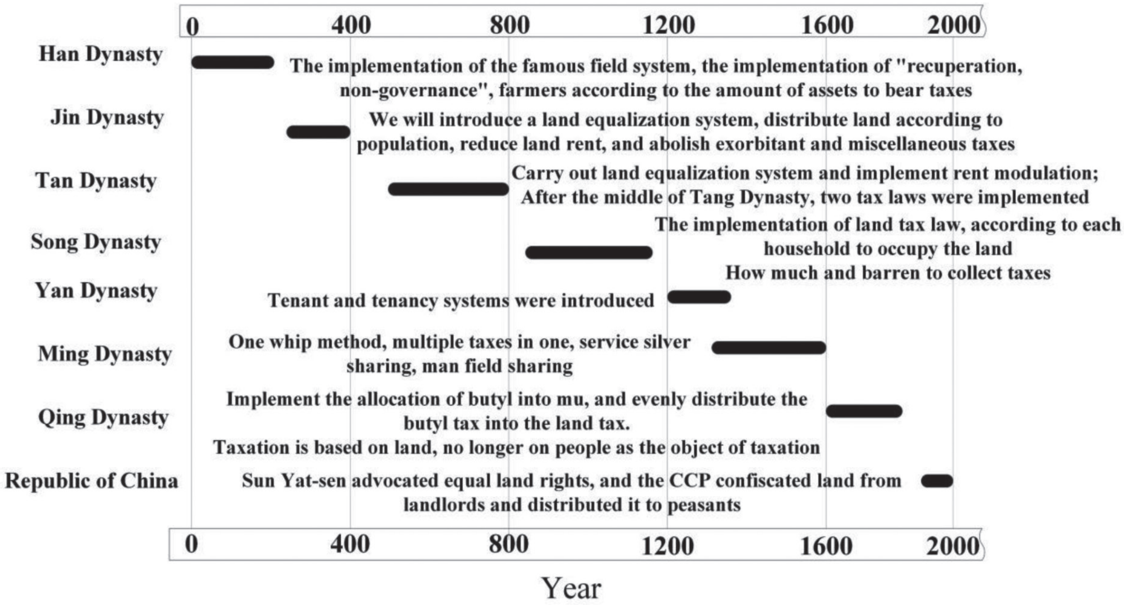


Fig. 18. Evolution of the land/tax system in major dynasties.

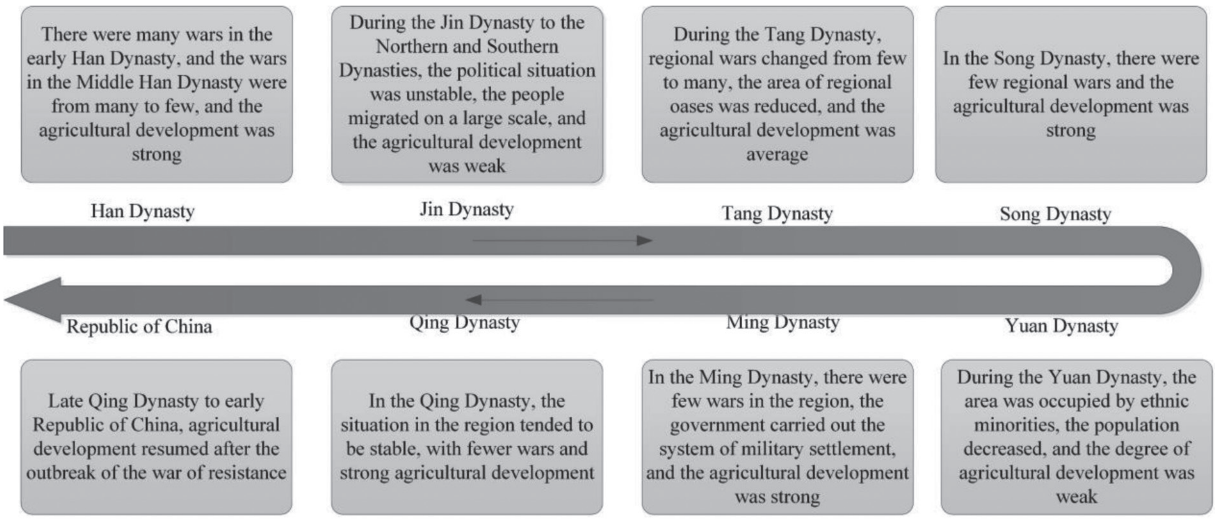


Fig. 19. War and agricultural development in the Heihe River Basin in the historical period.

in different periods. It can be seen that the stability of the regional situation has the most direct impact on agricultural production. Regional unrest and frequent warfare will directly lead to a sharp decline in population, land abandonment, and agricultural production interruptions. Only regional stability, population concentration, technological development, and agricultural development will be faster.

Population

Population is the main body of social production and life. In a social economic system dominated by agriculture, population fluctuations will have a huge impact on agricultural production and agricultural facilities. During the Han Dynasty, the Central Plains regime had a strong control over the frontier, social stability attracted a large number of foreigners and there was a steady growth in population. During the Jin Dynasty, due to frequent wars, social unrest, and uncertain population migration, the total population decreased significantly. Combined with the literature records [16, 23], according to the above-mentioned estimation results for each period, the population of the Heihe River Basin in the Tang and Yuan dynasties was also small. The population data of Heihe in the Ming Dynasty can be found in many local records, among which "Re-repairing the New Records of Suzhou·Hukou" and "Re-publishing the records of Gan Zhen·Sui Ji" are more systematic, "Ganzhou Fu Records", "Five Liang Kao Zhi and six De Records" have scattered

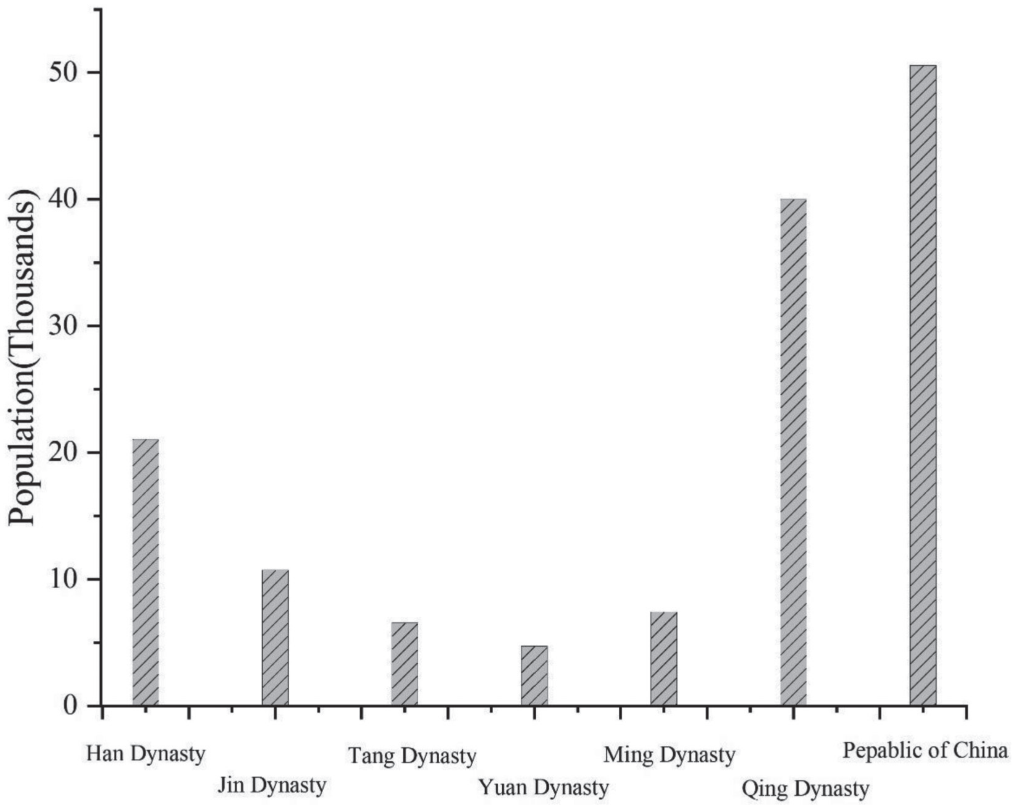


Fig. 20. Population scale of the Heihe River Basin in the historical period.

records. At the end of the Ming Dynasty and the beginning of the Qing Dynasty, after years of war and natural disasters, the whole of Hexi was barren and sparsely populated. After the late Kangxi period, the social order was relatively stable. In the fifty-first year of Kangxi, the edict of "breeding people and never adding Fu" was issued, and the system of "sharing Ding into mu" implemented in the Yongzheng period also promoted population growth in the valley [24]. During the Qianlong period of the Qing Dynasty, the population of Hexi once again flourished. After the "Kangqian" Prosperous Age, the population of the basin increased by leaps and bounds, reaching the highest population in feudal society. During the period of the Republic of China, due to the special geographical environment and good foundation of agriculture and animal husbandry, the Heihe River Basin was a relatively "solitary" place, which attracted a large number of foreigners and made the population grow rapidly [25].

According to the relevant literature, this study estimated the population of the river basin in each period and found that the population change from the Han Dynasty to the Republic of China showed a trend of decreasing first and then increasing (Figure 20). The large increase in population makes the need for agricultural land increase, so the best reclamation, the expansion of arable land to the mountain area, is also a kind of promotion of agricultural development. Therefore, the change in population is basically consistent with the development and change trend of agricultural facilities.

Limitation and Prospect

This study explores the spatiotemporal evolution of agricultural facilities since the Han Dynasty, which, although of certain scientific significance, also has its limitations. When collecting information from historical documents, even when comparing various sources to reduce errors, there is still an inherent uncertainty that cannot be eliminated. Although field surveys can determine specific locations, the influence of human factors is inevitable when defining their extent based on historical data, especially when indirectly analyzing the evolution of agricultural facilities through historical events. This is due to the constraints of time and manpower costs, making it impossible to thoroughly comb through all historical literature. Therefore, in the future, we plan to further deepen the research based on this study, aiming to establish more accurate data and analyze the intrinsic mechanisms of how natural and social changes affect agricultural facilities.

Although agricultural land and water sources have been continuously increasing since the Han Dynasty, given the frequent occurrences of modern droughts and extreme climate events, the Heihe region should pay more attention to the protection of downstream water resources. It is recommended to construct reservoirs and adopt flood irrigation methods for farmlands to conserve water resources and effectively respond to future extreme climate events.

Conclusion

Immigrants implemented large-scale agricultural development measures to fortify the borders, including the construction of water conservancy facilities and the development of a collective farming system, following the Han Dynasty's control of the Hexi Corridor. Advanced agricultural technology was used in this region, resulting in a rapid expansion of agricultural land. During the mid and late Han Dynasty, farmland and water conservancy facilities faced significant neglect. In the era of the Jin Dynasties, while the Central Plains experienced frequent wars and social unrest, the Hexi Corridor remained relatively stable, significantly enhancing agricultural development. After the middle of the Tang Dynasty, the basin was controlled by Tubo and Huihu, and agriculture development declined because of the unstable society and frequent wars. In the Song Dynasty, the basin was ruled by the Western Xia and continued to build water conservancy. Once the Yuan Dynasty established firm rule, it prioritized agricultural production, constructed water conservancy facilities, and emulated Western Xia's crop cultivation methods, thereby boosting production development.

Agriculture and various agricultural facilities were developed in various periods in ancient China, which made positive contributions to the development of agriculture for the whole mainland of China. It was found that agricultural facilities in the Heihe River Basin were influenced by various comprehensive factors, including natural and socio-economic aspects. Temperature, precipitation, and water resources were the basic natural elements that play a decisive role in agricultural development, and natural disasters play an inhibiting role in agricultural development, while policy, military war, and population migration were important factors that affected the changes in agricultural facilities.

Conflict of Interest

The authors declare no conflict of interest.

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