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The spatiotemporal evolution of ancient cities from the late Yangshao to Xia and Shang Dynasties in the Central Plains, China

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Abstract

The Central Plains has a long history, rich culture, unique geographical advantages, and profound cultural heritage. The occurrence of ancient cities in the Central Plains marks the formation of Chinese state-level societies. The number, size, and distribution of ancient cities have changed greatly from the late Yangshao to the Xia and Shang Dynasties, which reflects the evolution of settlement and social organization. In this study, Geographic Information System (GIS) spatial database technology was used to establish a spatiotemporal database of ancient cities in the late Yangshao, Longshan, as well as Xia and Shang Dynasties in the Central Plains. This paper uses GIS spatial analysis technology to analyze the relationship between the ancient city distribution and the geographical environment, as well as the evolution of ancient city's shapes and sizes. Furthermore, by using the method of the nearest neighbor distance and gravity center analysis, this paper discusses the agglomeration characteristics and gravity center evolution of ancient cities. The results show that: (1) Most of the ancient cities were distributed in areas below 500 m and within 3 km from the river during the time interval from the late Yangshao to Xia and Shang Dynasties; (2) The shape of the ancient cities gradually changed from circles to squares in the Central Plains, which became a unified model for the later ancient city design; (3) The sizes of the 18 ancient cities in the Yangshao period shared high similarity, with an average area of 20 hectares. The sizes of 24 ancient cities in the Longshan period increased significantly, with an average of 39 hectares. During the Xia and Shang Dynasties, there were 22 ancient cities with an average size of 340 hectares, and the grade of sizes became obvious, marking the entrance into Chinese state-level societies; (4) Cities were scattered in the decentralized pattern during the late Yangshao and Longshan periods, whereas they became agglomerative in Xia and Shang Dynasties. This reflects the evolution of the spatial scopes and social organizational forms; and (5) From the late Yangshao to Xia and Shang Dynasties, the gravity center of ancient cities moved around the Songshan Mountain from the northwest to the southeast and again to the northeast.

Keywords: Ancient cities, Spatiotemporal evolution, GIS analysis, From the late Yangshao to Xia and Shang Dynasties, The Central Plains

Introduction

The Central Plains has a long history, rich culture, unique geographical advantages, and profound cultural heritage. It witnesses the inherited evolution of the ancient Chinese civilization [1]. The occurrence of ancient cities in the Central Plains marks the formation of Chinese state-level societies. The city is the symbol of the formation of Chinese civilization, and it is a kind of high-level

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settlement form that is different from the countryside when human society develops to a certain stage. The “city” in this paper refers to the ancient settlement with built partitions or defensive facilities. Defensive facilities are generally walls, moats, fences, and so on [2]. Cities in the Central Plains were built in the late Yangshao period. Cities from the late Yangshao to Xia and Shang Dynasties were early-stage products in the Chinese city development history, which has certain originality and uniqueness [3]. It is of crucial significance to analyze the spatiotemporal evolution of ancient cities from the late Yangshao to Xia and Shang Dynasties in the Central Plains region, which can help us better understand the origin and development of Chinese state-level societies.

Recently, more and more attention has been paid to ancient cities, and qualitative research methods have been commonly used to describe the nature of ancient cities in Central Plains [4, 5]. With the development of spatial information technology, Geographic Information System (GIS) and Remote Sensing (RS) technologies have been widely applied to aid research on archaeology [6–10]. The application of spatial information technology is becoming the development trend of modern archaeological technology.

In this study, GIS spatial database technology was used to establish the spatiotemporal database of ancient cities during the late Yangshao, Longshan, as well as Xia and Shang Dynasties in the Central Plains. This paper uses GIS spatial analysis technology to analyze the relationship between the ancient city distribution and the geographical environment, as well as the evolution of ancient city shapes and sizes. Furthermore, by using the method of the nearest neighbor distance and gravity center analysis, this paper discusses the agglomeration characteristics and gravity center evolution of ancient cities. Results of this study are expected to help reveal the spatiotemporal evolution of cities from the late Yangshao to Xia and Shang Dynasties in the Central Plains and thus provide an important basis for studying the origin of early cities in ancient China.

Data and methods

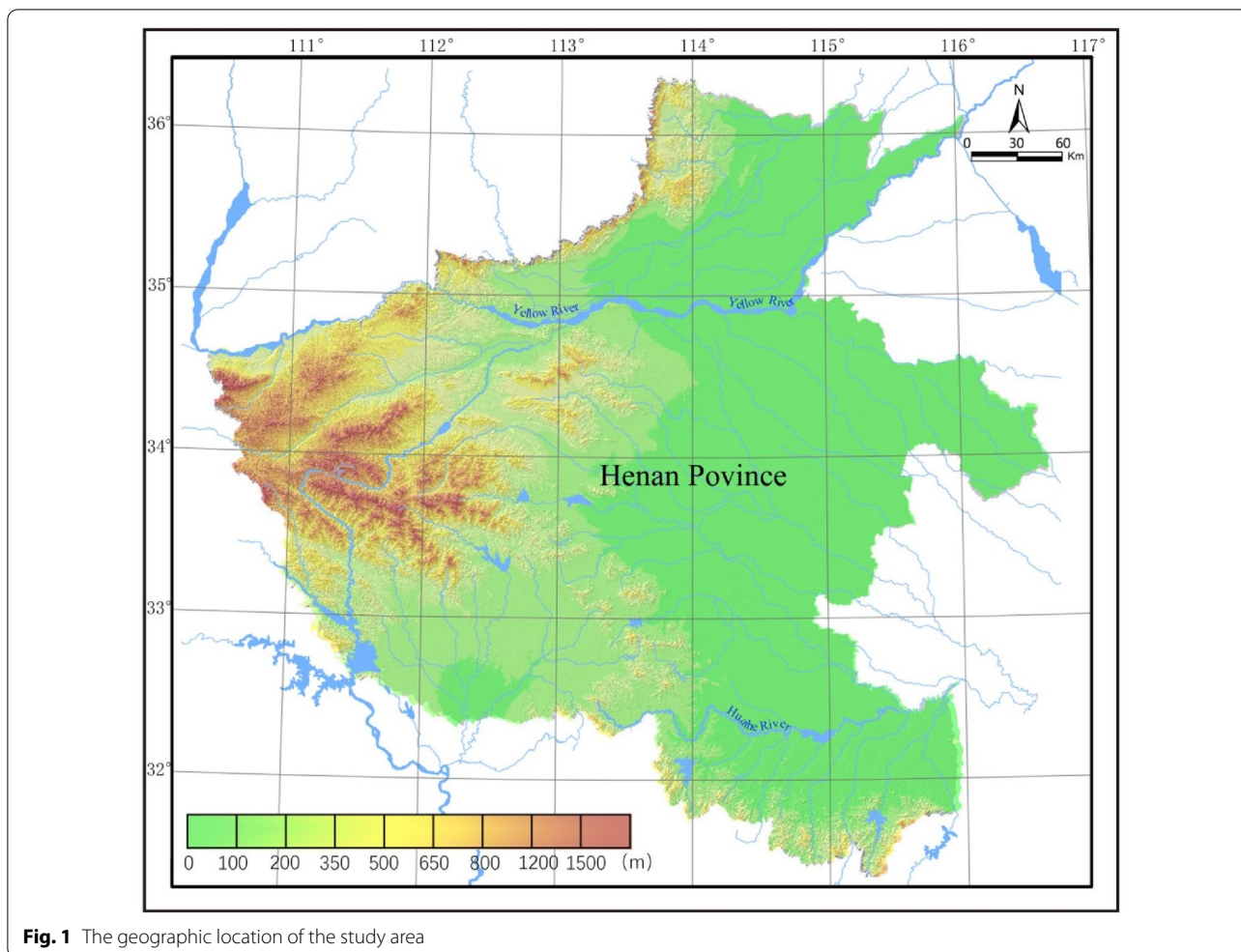
Study area

The Central Plains refers to the middle and lower reaches of the Yellow River in a broad sense and the current administrative division of Henan Province in a narrow sense [11], the latter of which is adopted in this study (Fig. 1). The Central Plains is situated in the conjunction between the middle and lower reaches of the Yellow River, and it is roughly located in 31°23′–36°22′ N, 110°21′–116°39′ E. It is about 580 km long from east to west and 550 km wide from north to

south, with a total area of 165,600 square kilometers. This area is located in the transition zone from the second ladder to the third ladder of China’s terrain, with significant topographic fluctuations. There are broad and flat plains in the east and mountains in the west. The complex terrain with many rivers, fertile soil, and rich resources results in a mild climate, which was suitable for the survival and development of primitive ancestors. Ancient people lived here very early and established settlements. Settlements in the Central Plains region can be dated back to the Paleolithic age (about 10,000 years ago), and typical sites include the Lingjing site [12] (125,000 years ago), the Laonainaimiao site [13] (about 40,000 years ago), and many others. The 5000 years of culture have been continuously developed since then. The Central Plains was manifested to have been in the central stage of the Chinese civilization at least during the Neolithic and Bronze Ages [1]. The Central Plains was the birthplace of the Chinese civilization, and the density and importance of settlement sites were very high. According to incomplete statistics, there were 65 ancient cities and 4095 settlements during the interval from the Neolithic Age to the Xia and Shang Dynasties [14]. So it had been regarded as one of the key areas for research on environmental archaeology in China [15–18].

Data source

The ancient cities data used in this paper are from the fascicles of the Chinese Cultural Relics Atlas for Henan Provinces [19] and the Cultural relics of Henan Province [20]. Besides, some data are also taken from relevant research papers or books such as the archaeology of enclosure settlements in the pre-Qin period [21], and a comprehensive study of early cities in the Central Plains [22]. Those data from the cultural relics atlas of China (Henan Fascicule) and Zhengzhou cultural relic atlas are compiled based on the administrative unit of the county in a unified format and map projection. For non-digital data from relevant research papers or books, we digitize the data using the ArcGIS 10.5 software [23] and position the locations (i.e., longitudes and latitudes) of the digitized sites. Their shapes and areas are derived from archaeological survey data. All ancient cities are plotted on the relief map obtained from the Shuttle Radar Topography Mission (SRTM4.1) digital elevation model (<http://www.gscloud.cn/>) with a spatial resolution of 30 m × 30 m. River data are extracted by the ArcGIS hydrological analysis module taking DEM as the base map. The geomorphic zoning map data are from the Atlas of Agricultural Resources and Agricultural



Regionalization of Henan Province with a scale of 1: 2,500,000 [24].

Information of a total of 64 ancient cities is compiled, including 18 ancient cities in the late Yangshao period (3500–2800 BC), 24 ancient cities in the Longshan period (2800–1700 BC), and 22 ancient cities in Xia and Shang Dynasties (1700–1000 BC).

Methodology

Analysis of relationship between the ancient city distribution and the natural environment

Using the GIS spatial analysis method, the elevation of each city site is extracted. Then, the relationship between the distribution of ancient cities and topography is analyzed. Taking DEM as the base map, rivers are extracted by using the hydrological analysis function of ArcGIS 10.5 [23]. In the river network extraction, the setting of the watershed threshold is very important, because a greater threshold results in a smaller river network density for the same flow

accumulation grid. Given the great dependence of ancient humans on water resources, some small tributaries are often ignored because they could not stably provide water for people. In addition, small tributaries were easier to change their routes with the change of landform. In this paper, the watershed threshold is set to 800 according to the relevant research results [25]. Only the tributaries with watersheds greater than 800 were extracted to analyze the relationship between distributions of ancient cities and rivers. Then the cost distances between the ancient cities and the river are calculated in ArcGIS 10.5.

Analysis of ancient city’s shapes and sizes

The data of the ancient city’s shapes and sizes are all from archaeological investigation or archaeological excavation by the archaeological department. The shapes and sizes of the ancient cities are classified and the number is counted by the statistical analysis

method, and the classification results are displayed in ArcGIS 10.5.

Analysis of ancient city agglomeration

As one of the most commonly used point pattern analysis methods [26], the nearest neighbor distance method was first proposed by Clark and Evans in 1954 [27] and then introduced into geography by Dacey in 1960 [28]. Its principle is to test the area occupied by each point by comparing the average distance of the nearest neighbor pair in the dataset with its counterpart in the random distribution model. Furthermore, the nearest neighbor index (NNI) can be used to judge whether the point pattern is agglomerative or diffusive [29].

In this study, the average nearest neighbor distance tool in ArcGIS 10.5 software [23] is used to calculate the average distance between each ancient city and its nearest neighbor, which was then compared with its counterpart in the random distribution model, returning the standard deviation (Z score) after the statistical analysis. A negative and small Z score indicates agglomeration, while the opposite suggests diffusion.

Analysis of the gravity center of ancient cities

Analysis of the gravity center of ancient cities is completed in ArcGIS 10.5 software [23]. The concept of “gravity center” comes from physics, and it generally refers to the action point of the resultant force produced by the gravity of all parts of an object [30]. The gravity center of ancient cities in a specific period refers to the average center in the spatial distribution of ancient cities in different regions. It is also the area with the highest density of ancient cities. The calculation formulas of the center of gravity of cities in a certain period are as follows:

$$M_{xi} = \sum_{i=1}^n x_i/n, M_{yi} = \sum_{i=1}^n y_i/n \tag{1}$$

where M_{xi} and M_{yi} represent the coordinates of the gravity center of ancient cities, respectively, and x_i and y_i represent the coordinates of all ancient cities in a certain period, respectively.

The distance between the gravity center of ancient cities in one period and that in the next period is the displacement of the gravity center of ancient cities. The formula is as follows:

$$D_{i-j} = \sqrt{(M_{yi} - M_{yj})^2 + (M_{xi} - M_{xj})^2} \tag{2}$$

where D_{i-j} represents the displacement of the gravity center of ancient cities.

The evolution of the gravity center of ancient cities reflects the change of the distribution pattern of the ancient cities, which is subject to the influence of the natural environment and social factors.

Results

Relationship between the ancient city distribution and the natural environment

Settlement site selection is affected by many factors, including altitude, slope, aspect, water source, soil, and climate, as have been reported in previous research [31]. Davis et al. [32] discussed the importance of water, soil, and elevation for settlements in the Bosutswe region of Botswana; Yaworsky et al. [33] studied the importance of precipitation, vegetation, and water; Zhao et al. [34] investigated the influence of topography, slope, aspect, and river on the distribution of middle Holocene settlements in northern Liaoning. As the most important form of settlement sites, the ancient city distribution is also restricted by these geographical factors. The 64 ancient cities are overlapped with DEM and river (Fig. 2) to analyze the relationship between the ancient city distribution and topography and rivers.

(1) Altitude

Among many natural factors, altitude has a very important influence on the distribution of ancient cities. With the increase of altitude, the temperature and pressure decline, and the landform is broken, which is not suitable for the development of agriculture. The tool of extracting multiple values to points in ArcGIS 10.5 [23] is used to extract the altitudes data of each ancient city (Table 1).

As shown in Table 1, the altitudes of cities in the three periods are all below 500 m, which is quite different from the altitude of the settlement distribution in this area published in previous studies. Previous studies have shown that most of the settlement sites are below 500 m, but there are also a large number of settlements above 500 m [18]. This may be ascribed to the fact that the construction of the ancient city needed a more flat terrain. Moreover, the altitude range of 100–200 m is seen with the largest number of ancient cities, which might indicate this range to be the most suitable for human habitation. In the Yangshao period, the average altitude of the ancient cities is 199 m, the lowest is 51 m in the Dahecun site in Zhengzhou [35], and the highest is 478 m in the Zhouli site in Luoyang [36]. There are only two cities below 100 m and

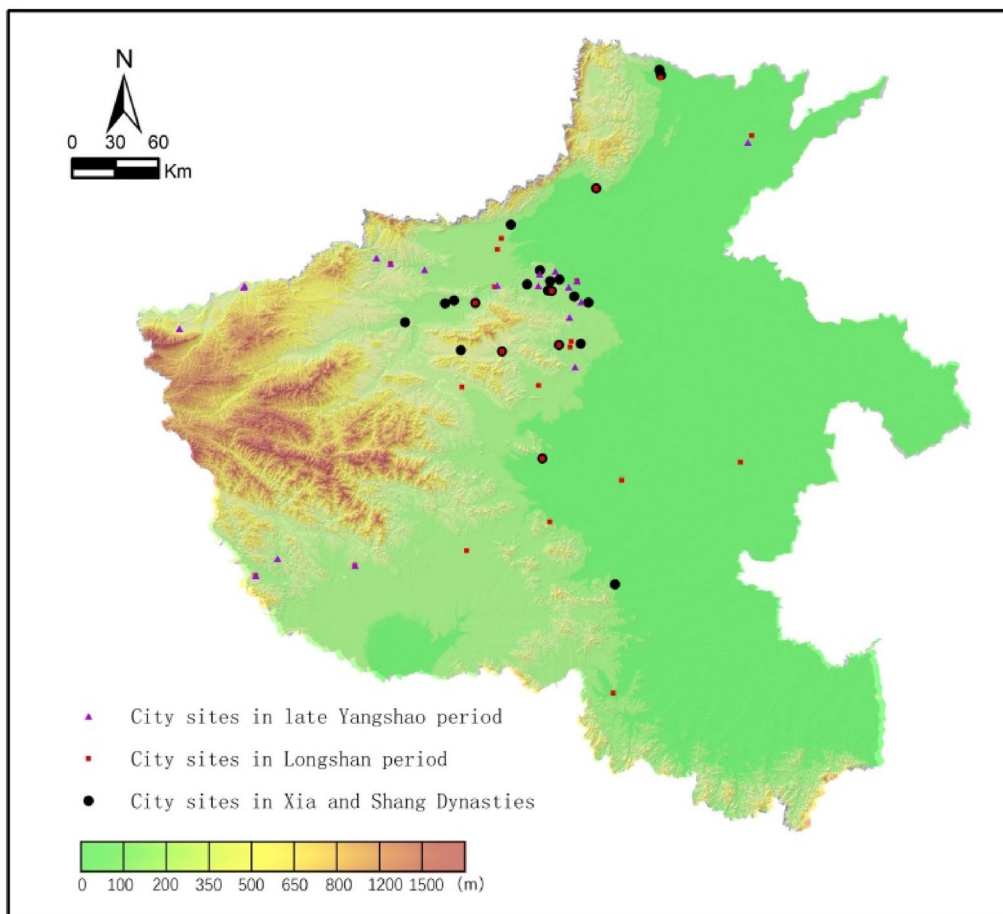


Fig. 2 The distribution of ancient cities from the late Yangshao to Xia and Shang Dynasties and DEM in the Central Plains region

three cities above 300 m. In the Longshan period, the average altitude of the ancient cities is 123 m, the lowest is 47 m, which is the Pingliangtai site in Huaiyang [37], and the highest is 260 m, which is the Wangchenggang site in Dengfeng [38]. Compared with cities during the Yangshao period, those in the Longshan period have much lower altitudes, and there are eight ancient cities below 100 m whereas there are no ancient cities above 300 m. During the Xia and Shang Dynasties, the average altitude of the city site is 136 m, the lowest is 74 m, which is the Huanbei Shangcheng site [39], and the highest is 467 m, which is the Nanwa site in Dengfeng [40]. Compared with cities in the Longshan period, those in the Xia and Shang Dynasties have slightly higher altitudes.

(2) River

Water resource is an important factor affecting the distribution of ancient cities. The distance from the water source is directly related to the

convenience of life and agricultural production. So the ancient cities should not be too far away from the river for the convenience of taking water, while it should also not be too close to the river for the sake of flood control [41]. In this paper, firstly, the Euclidean distance from each ancient city to the river in different peri-

Table 1 Altitudes of cities in the Central Plains region

Altitudes (m)	The number of ancient cities in the late Yangshao Period	The number of ancient cities in the Longshan Period	The number of ancient cities in the Xia and Shang Dynasties
0–100	2	8	6
100–200	11	11	14
200–300	1	2	1
300–400	2	0	0
400–500	1	0	1
>500	0	0	0

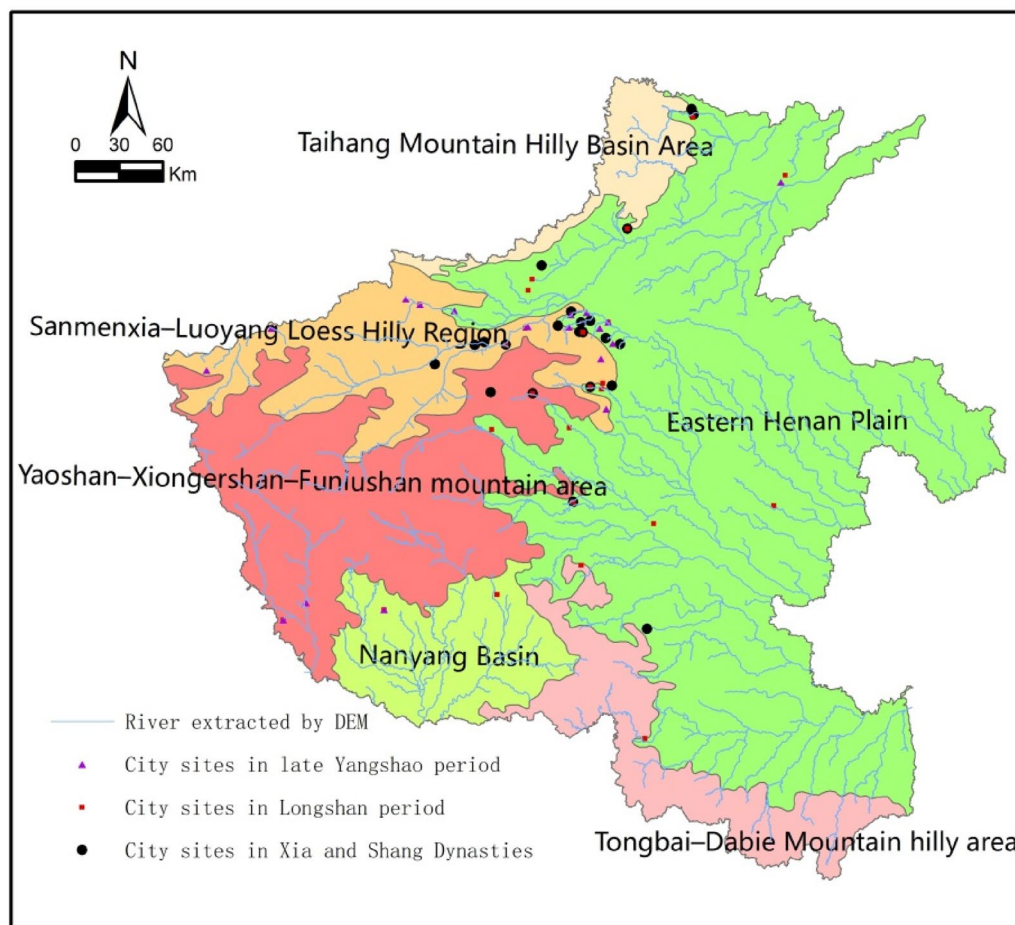


Fig. 3 The distribution of ancient cities from the late Yangshao to Xia and Shang Dynasties and River in the Central Plains region

ods is obtained by using the proximity near tool in Arc GIS 10.5 software [23]. Then, using the geomorphic zoning data of Henan Province, the distance is corrected by using the correction coefficient to obtain the cost distance from each ancient city to the river. There are six types of geomorphic zoning data in Henan Province (Fig. 3). They are Eastern Henan Plain, Nanyang Basin, Sanmenxia-Luoyang, Loess Hilly Region, Taihang Mountain Hilly Basin Area, Tongbai-Dabie Mountain hilly area, Yaoshan-Xiongershan-Funiushan mountain area. In the eastern Henan plain and Nanyang Basin, the terrain is flat, and the cost distance between the city site and the river system can be replaced by Euclidean distance. In Sanmenxia-Luoyang Loess Hilly Region, loess is distributed to form hills, and 1.2 times of Euclidean distance is used as the cost

distance. In the Taihang Mountain Hill basin area, there are low mountains, hills, and basins, which have a great impact on human travel, and 1.5 times of the Euclidean distance is used as the

Table 2 The types of geomorphic regionalization in Henan Province and its influence coefficients on the distance between ancient cities and river

The types of geomorphic regionalization in Henan province	The influence coefficient
Eastern Henan Plain	1
Nanyang Basin	1
Sanmenxia-Luoyang Loess hilly region	1.2
Taihang Mountain Hilly Basin area	1.5
Tongbai-Dabie mountain hilly area	2
Yaoshan-Xiongershan-Funiushan mountain area	2

cost distance. Tongbai-Dabie Mountain Hill area and Yaoshan-Xionershan-Funiushan mountain area belong to mountainous areas, and twice the Euclidean distance is used as the cost distance. The types of geomorphic regionalization in Henan Province and its influence coefficients on the distance between ancient cities and river are as follows (Table 2).

Most of the cities are distributed within a distance of 3 km from rivers, accounting for 72.2% in the Yangshao period, 70.83% in the Longshan period, and 59.09% in Xia and Shang dynasties (Table 3). In the Yangshao period, the cost distance ranges between 278 and 15626 m, with an average of 3416 m. During the Longshan period, the cost distance ranges between 304 and 12427 m, with an average of 3060 m. During the Xia and Shang Dynasties, the cost distance ranges between 135 and 26974 m, with an average of 3672 m.

Evolution of ancient city shapes

As can be seen from Table 4, during the Yangshao period, there were 18 cities in total, of which seven were circular in shape. During the Longshan period, there were 24 cities, of which 13 were rectangular, square, or trapezoidal, while two were circular. In the Xia and Shang Dynasties, there were 22 cities, of which 10 were rectangular, square, or trapezoidal, three were circular, and two were of irregular shapes. Therefore, it could be indicated that there was a tendency of transitioning circular cities to square cities in the Central Plains (Figs. 4, 5 and 6).

Evolution of ancient city sizes

With the help of the classification results of settlement scale [42], the scale of the ancient cities is

divided into five levels in this paper, which are 0–25 hectares, 25–50 hectares, 50–100 hectares, 100–200 hectares, and > 200 hectares, respectively.

During the Yangshao period, all the 18 cities were relatively small, with slight differences in sizes among different cities and an average area of 20 hectares. There was only one city that was larger than 50 hectares, namely the Shuanghuaishu site. The cities with larger sizes were mainly distributed in the Yellow River and Yiluo River areas, while the cities in other areas were relatively small (fig.7).

During the Longshan period, the average city size reached 39 hectares. There were five cities with areas of more than 50 hectares, including the Shaochai site (200 hectares) in Yiluo River Basin [43], the Wadian site (130 hectares) in Yinghe River Basin [44], the Xinzhai site (100 hectares) in Shuangjihe River Basin [45], the Mengzhuang site (100 hectares) in Northern Henan [46], and the Pinggaotai site (91 hectares) in Southwest Henan [47]. There were obvious differences in the sizes among the cities, and the ancient cities were distributed in the four grades of 0–200 hectares. Moreover, there are generally fewer larger cities and more smaller cities (fig.8).

During the Xia and Shang Dynasties, the average city size increased significantly to 340 hectares (fig.9). There were three cities with areas of more than 200 hectares, namely the Anyang Yin Ruins in the north of the Henan Province with an area of 3600 hectares, the Zhengzhou Shangcheng ruins [48] in the east of Songshan Mountain with an area of 2500 hectares, and the Erlitou site [49] of Yanshi in Luoyang, with an area of 350 hectares (Tables 5).

Characteristics of the ancient cities agglomeration

The average distance between each ancient city and its nearest neighbor is calculated in ArcGIS 10.5 as shown in Table 6. It can be seen that the NNI statistics

Table 3 Cost distances between ancient cities and rivers from the late Yangshao to Xia and Shang Dynasties in the Central Plains region

Cost distance from rivers (m)	Ancient cities in the late Yangshao period		Ancient cities in the Longshan period		Ancient cities in Xia and Shang Dynasties	
	Number	Percent	Number	Percent	Number	Percent
0–500	4	22.22	3	12.50	4	18.18
500–1000	1	5.56	3	12.50	4	18.18
1000–2000	6	33.33	7	29.17	4	18.18
2000–3000	2	11.11	4	16.67	1	4.55
3000–5000	2	11.11	3	12.50	4	18.18
> 5000	3	16.67	4	16.67	5	22.73

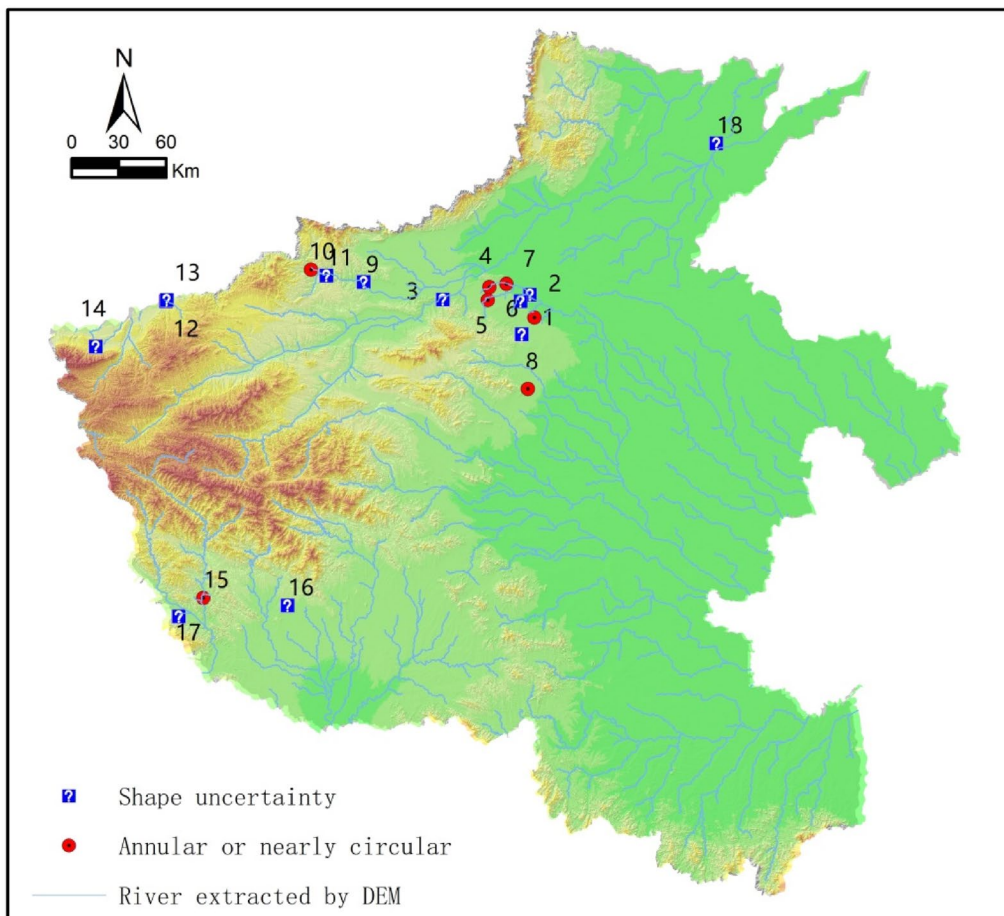


Fig. 4 The shape and distribution of ancient cities in the late Yangshao period in the Central Plains. 1 Shanggangyang, 2 Dahecun, 3 Shuanghuaishu, 4 Qingtai, 5 Wanggou, 6 Jianyeyihaochengbang, 7 Xishan, 8 Guchengcun, 9 Guzhangcheng, 10 Huangpo, 11 Zhouli, 12 Miaodigou, 13 Sanliqiao, 14 Xipo, 15 Gouwan, 16 Zhongwa, 17 Longshangang, 18 Xishuipo

of the ancient cities in the Yangshao period and Xia-Shang dynasties were all less than one, and the Z score values were all less than zero. Therefore, the ancient cities in the two periods were in a state of agglomeration. According to that in the same study area, a larger NNI value corresponded to a lower degree of agglomeration of sample points [22]. The agglomeration of cities during the Yangshao period was more obvious than that in Xia and Shang Dynasties. The NNI value of the ancient cities in the Longshan period was greater than one, and the Z score was greater than zero. Therefore, cities in this period were distributed in a decentralized way. Therefore, the degree of agglomeration of ancient cities from high to low was: the Yangshao period, the Xia and Shang dynasties, and the Longshan period.

Combined with Fig. 2, we can see more clearly that during the late Yangshao period, the ancient cities were concentrated in the piedmont area around the

Songshan mountain. During the Longshan period, the ancient cities were distributed in both plain and mountain areas. In Xia and Shang Dynasties, two capitals appeared, namely the Erlitou site and the Zhengzhou Shangcheng site. The ancient cities were mainly distributed around the two capitals.

Evolution of the gravity centers of ancient cities

As was shown in Fig. 10 and Table 7, the center of gravity of the cities moved from the northwest in the Yangshao period to the southeast in the Longshan period, and further moved to the northeast during the Xia and Shang dynasties. The gravity center in Xia and Shang dynasties reached the proximity of the Songshan Mountain. This further confirmed that the core cultural area of the Henan Province should lie in the area around the Songshan Mountain, which

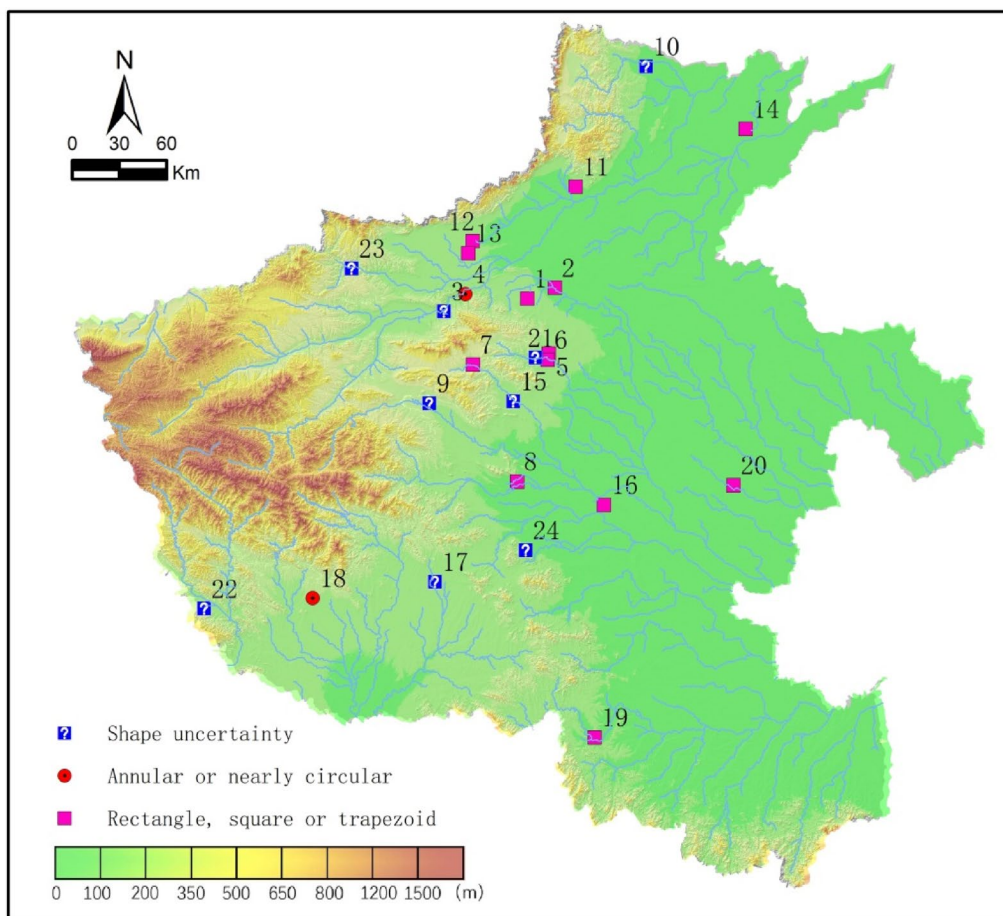


Fig. 5 The shape and distribution of ancient cities in the Longshan period in the Central Plains. 1 Dongzhao, 2 Daheacun, 3 Shaocai, 4 Huadizui, 5 Guchengzhai, 6 Renhezhai, 7 Wangchenggang, 8 Puchengdian, 9 Meishan, 10 Hougang, 11 Mengzhuang, 12 Xijincheng, 13 Xubao, 14 Qicheng, 15 Wadian, 16 Haojiatai, 17 Pinggaotai, 18 Zhongwa, 19 Sunzhai, 20 Pingliangtai, 21 Xinzhai, 22 Longshangang, 23 Zhouli, 24 Daduzhuang

occupied a core position in the cultural development from the Neolithic to Xia and Shang Dynasties (10,000–1000BC).

Discussion

In the late Yangshao period, ancient cities began to appear in the Central Plains. The shape of the ancient cities was circular. The warm and humid climate during this period promoted the great development of the Yangshao culture [50]. Meanwhile, with the increase of precipitation and the expansion of water area, the Yangshao culture was mainly located in relatively high and cool areas, with a few cities scattering in the central and eastern areas where the topography was low [51]. In this context, low-lying areas were not suitable for city construction anymore, and the areas close to the rivers were vulnerable to flood disasters. It may make that the average cost distance between the ancient cities and the river was the largest in the

Yangshao period. On the contrary, Yangshao cultural sites were densely distributed on the Loess Plateau of the western Henan Province and the Yiluo River area, where both the number and area of the ancient cities increased rapidly [52]. This also explained the ancient cities were highly concentrated and the gravity center of ancient cities was in the northwest during the Yangshao period.

During the Longshan period, the space for people activities expanded, due to the dry climate and the shrunk river network [53]. People began to enter the vast alluvial plain on a large scale [52], where the altitude was the lowest. Moreover, the cost distance from the river was also smaller than that in the Yangshao period. Meanwhile, the number of ancient cities increased greatly in the low-lying areas in the central and eastern parts, and a large number of city walls began to appear. The shape of the ancient cities gradually changed from circular to square, which became a

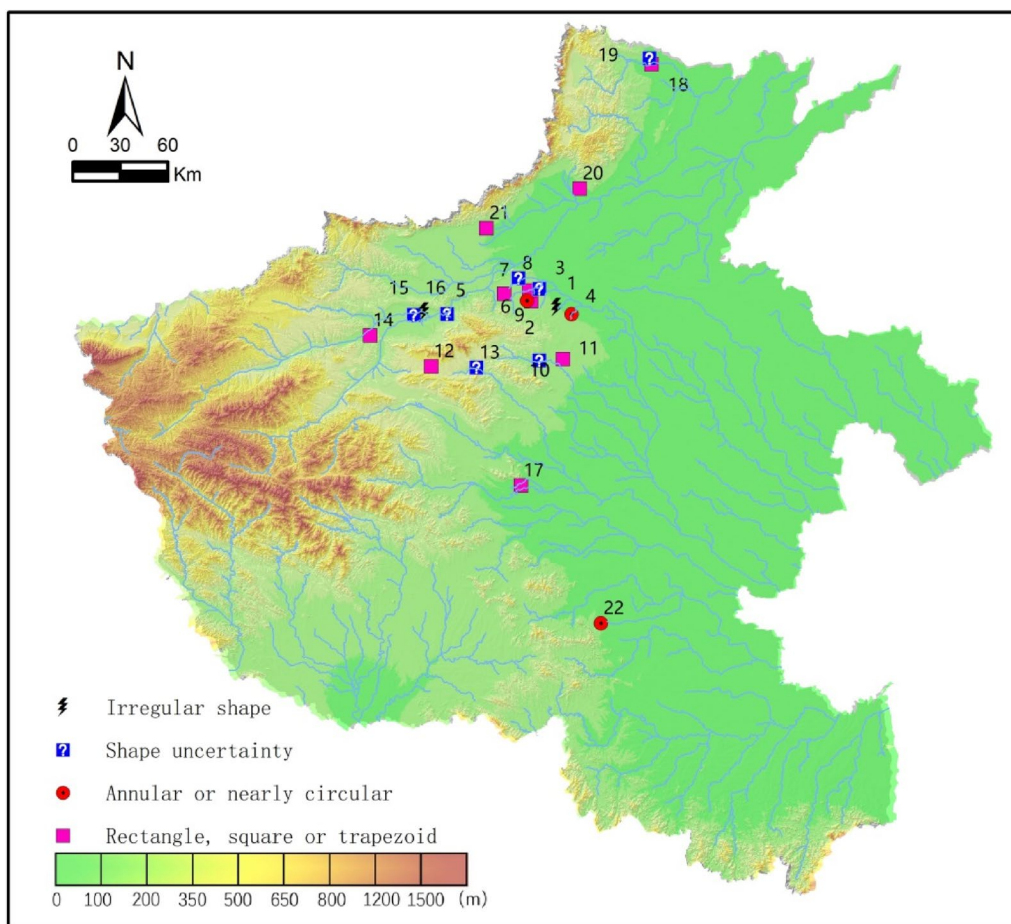


Fig. 6 The shape and distribution of ancient cities in the Xia and Shang Dynasties in the Central Plains. 1 Zhengzhoushangcheng, 2 Dongzhao, 3 Xiaoshuangqiao, 4 Lianghu, 5 Shaochai, 6 Dashigu, 7 Xishicun, 8 Tangtong, 9 Guandimiao, 10 Xinzhai, 11 Wangjinglou, 12 Nanwa, 13 Wangchenggang, 14 Houcheng, 15 Erlitou, 16 Yanshishangcheng, 17 Puchengdian, 18 Huanbeishangcheng, 19 Yinxu, 20 Mengzhuang, 21 Fucheng, 22 Yangzhuang

unified model of later ancient cities design. This may be because the distribution of the ancient cities transferred from the hilly area in the west to the flat area in the east, and may also be related to the technical development of people’s construction of the ancient city [54]. The gravity center of ancient cities was shifted to the southeast during this period. Moreover, the population density reached its peak in almost all areas [51]. Furthermore, cities were more scattered in this period. This may be due to the recovery of precipitation and temperature in the late Longshan period, and the appropriate climatic conditions and technological progress were likely to promote the scattered distribution of ancient cities and settlement sites in the late Longshan period [55].

During the Xia and Shang Dynasties, the arising Erlitou culture was characterized by a centralized system that witnessed the transition from pluralistic

ancient states to a unified dynasty. Moreover, this period was at the end of the Holocene Megathermal period, when the climate continuously became cold and dry [56]. In this condition, the low-lying central and eastern plain areas were more suitable for human habitation, where two capitals appeared, namely the Erlitou site and the Zhengzhou Shangcheng site. Moreover, this period was characterized by the centralized high-level settlements and the scattered low-level settlements surrounding them in the Yiluo Plain and the Suoxu River Plain [57]. The gravity center of ancient cities was shifted to the northeast.

Conclusions

The prehistoric culture in the Central Plains is well developed, which is one of the important regions for the research on the Chinese civilization. By using the GIS methods, this paper analyzes the relationship

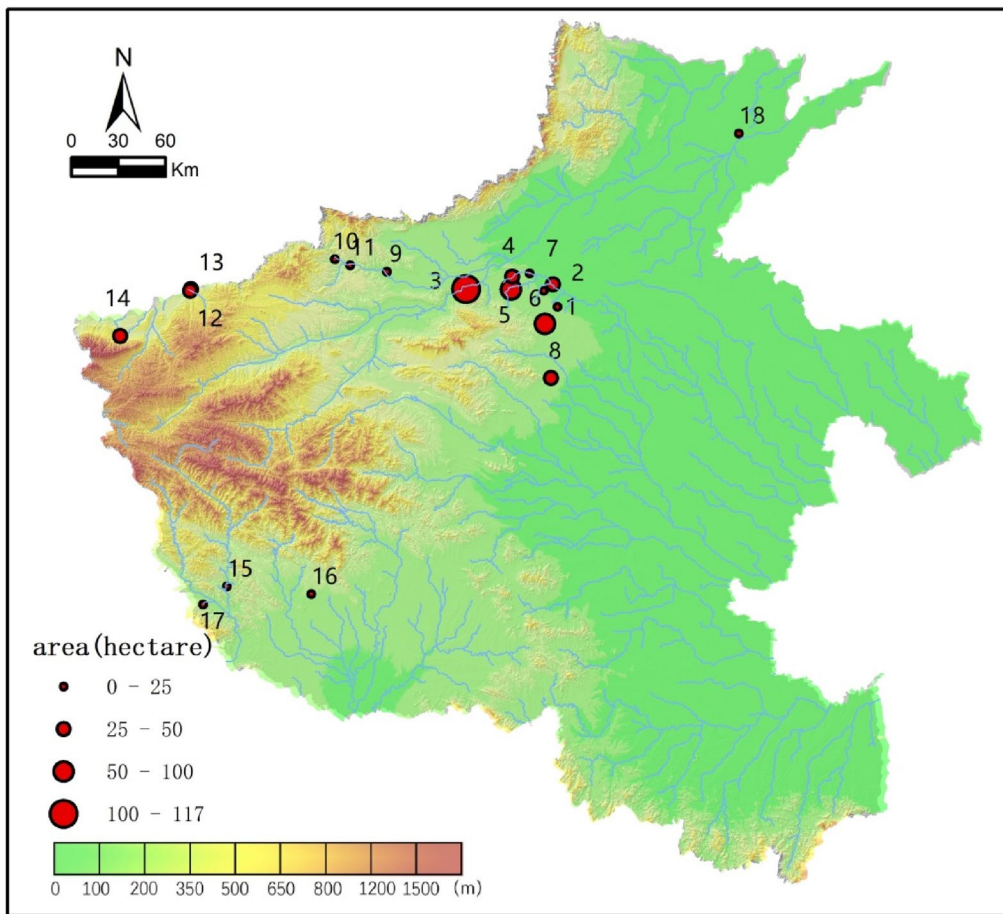


Fig. 7 The distribution of ancient cities sizes in the late Yangshao period in the Central Plains (The names of the ancient cities represented by the number mark are the same as those in Fig. 4)

Table 4 Statistical table of ancient cities shapes from the late Yangshao to Xia and Shang Dynasties

Periods	The number of rectangle, square, or trapezoidal ancient cities	The number of irregular ancient cities	The number of ringlike or circular ancient cities	Uncertain shape
Yangshao period	0	0	7	11
Longshan period	13	0	2	9
Xia and Shang Dynasties	10	2	3	7

Table 5 Statistical table of the ancient cities sizes from the late Yangshao to Xia and Shang Dynasties in the Central Plains region

Ancient cities area	The number of ancient cities in the late Yangshao period	The number of ancient cities in the Longshan Period	The number of ancient cities in the Xia and Shang Dynasties
0–25 hectares	12	14	9
25–50 hectares	5	5	5
50–100 hectares	0	3	3
100–200 hectares	1	2	3
> 200 hectares	0	0	2

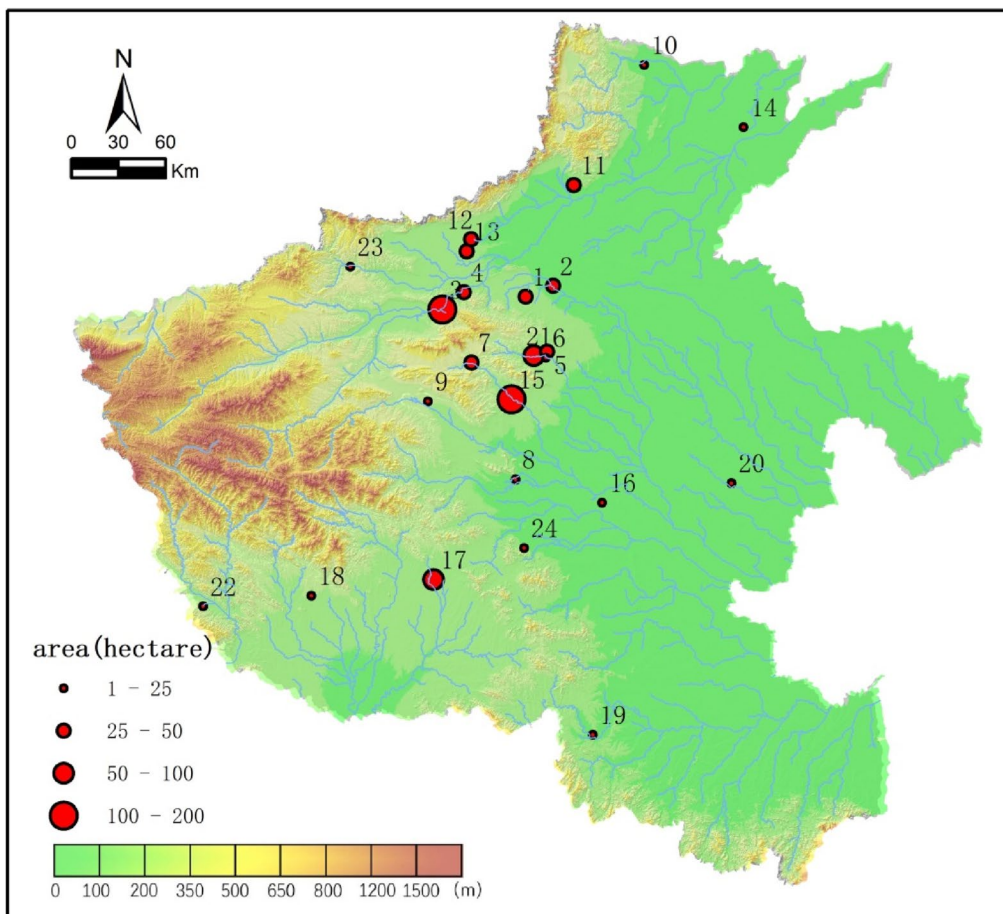


Fig. 8 The distribution of ancient cities sizes in the Longshan period in the Central Plains (The names of the ancient cities represented by the number mark are the same as those in Fig. 5)

between the ancient city distribution and the geographical environment, the spatiotemporal evolution of ancient city shapes and sizes, and the gravity center of the ancient cities from the late Yangshao to Xia and Shang Dynasties in the Central Plains region. The research can provide important clues for further revealing the process, stage, and mode of Chinese civilization.

The evolution of ancient cities from the late Yangshao to Xia and Shang Dynasties in the Central Plains area is as follows: (1) Most of the ancient cities were distributed in areas with an elevation below 500 m and a distance within 3 km from the river; (2) In the late Yangshao period, most of the ancient cities were circular in shape. In the Longshan period, among the 15 ancient cities with definite shapes, 13 ancient cities

Table 6 Average nearest neighbor distances of the ancient cities from the late Yangshao to Xia and Shang Dynasties in the Central Plains region

Periods	Number of ancient cities	Average nearest neighbor distance (m)	Expected average nearest distance (m)	NNI statistics	Z score
Yangshao Period	18	24,640	34,608	0.712	- 2.338
Longshan Period	24	43,477	35,229	1.234	2.19
Xia and Shang Dynasties	22	22,711	25,664	0.885	- 1.03

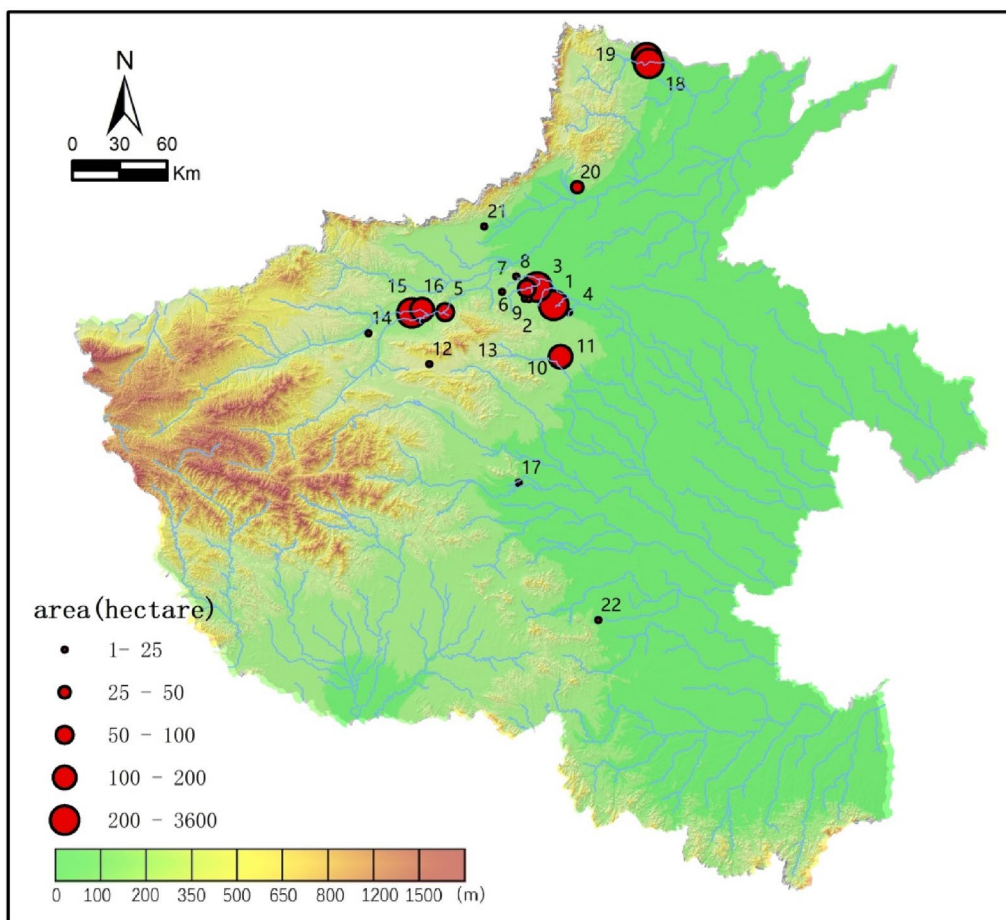


Fig. 9 The distribution of ancient cities sizes in Xia and Shang Dynasties in the Central Plains (The ancient cities represented by the label is the same as those in Fig. 6)

were square and two ancient cities were circular. In Xia and Shang Dynasties, among the 15 ancient cities with definite shapes, 10 ancient cities were square, three ancient cities were circular, and two ancient cities were irregular. The shape of the ancient cities gradually changed from circles to squares in the Central Plains; (3) The sizes of the ancient cities became larger and larger from the late Yangshao to Xia and Shang Dynasties, with more and more complex grades of sizes. There were a few high-grade cities and more low-grade cities; (4) In the Yangshao period, people were concentrated in the piedmont area, and the cities were distributed in a concentrated manner. In the Longshan period, due to the climate and other reasons, the scope of human activities spread to the east

and southeast of the Henan Province, resulting in the scattered distribution of cities. During the Xia and Shang Dynasties, cities were clustered surrounding the capital city of Zhengzhou Shangcheng and Erlitou of Yanshi; and (5) The focus of the cultural development in the Henan Province is found to be in the area around the Songshan Mountain. Moreover, due to the influence of climate and other environmental factors, the gravity centers of ancient cities changed counter-clockwise in the area around the Songshan Mountain.

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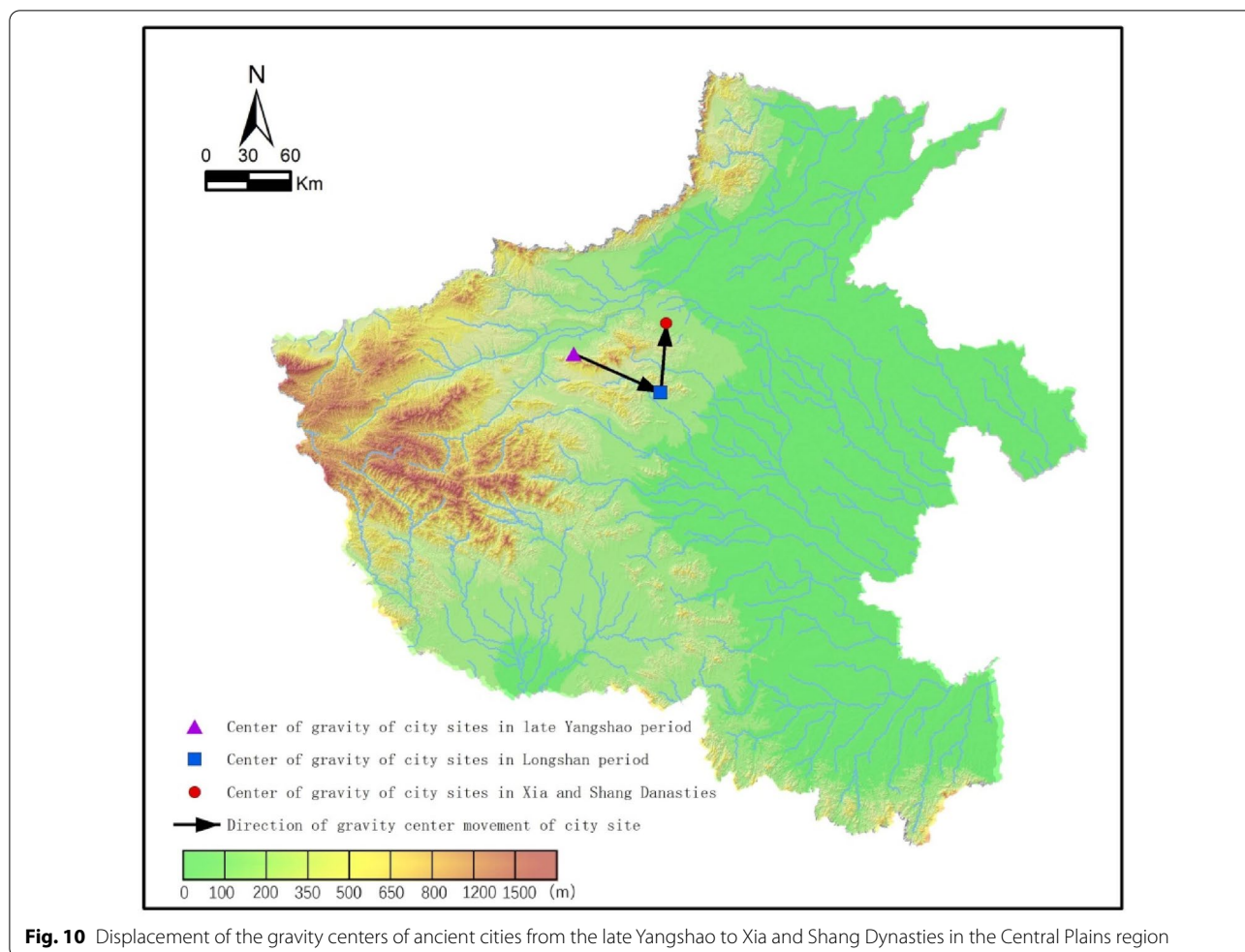


Table 7 The gravity centers of ancient cities from the late Yangshao to Xia and Shang Dynasties in the Central Plains region

Period	Displacement of the city center of gravity (km)	City moving direction
Yangshao to Longshan period	67	Northwest–southeast
Longshan period to Xia and Shang Dynasties	49	Southwest–northeast

Authors’ contributions

LY and RY proposed The framework of the paper, FT, XW and PC analyzed the data; PL and LZ performed the formal analysis; DZ, LX, and LG help edit the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

DEM data are primarily from the geospatial data cloud (<http://www.gscloud.cn/>). The ancient city data during the current study are available from Yan Lijie upon reasonable request, and her email address is lijiey1213@sina.com.

Declarations

Competing interests

All authors declare that they have no competing interests.

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