The spatiotemporal evolution of cities from the ancient state period to the kingdom period in the Central Plains region, China

Lijie Yan
Institute of GEography, Henan Academy of Sciences

Ruixia Yang
Laboratory of Digital Earth Sciences: Institute of Remote Sensing and Digital Earth Chinese Academy of Sciences

Peng Lu (✉ bulate_0@163.com)
Institute of Geography, Henan Academy of Science https://orcid.org/0000-0002-9336-2697

Fei Teng
Institute of Geography, Henan Academy of Sciences

Xia Wang
Institute of Geography, Henan Academy of Sciences

Li Zhang
Institute of Geography, Henan Academy of Sciences

Panpan Chen
Institute of Geography, Henan Academy Of Sciences

Xiang Li
University of Queensland

Lanbo Guo
Institute of Geography, Henan Academy of Sciences

Dong Zhao
Institute of Geography, Henan Academy of Sciences

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Abstract

The Central Plains region in China has been an important area for human settlement since ancient times. As the only continuous civilization over thousands of years in the world, the Central Plains Civilization is the origin of the Chinese nation. The number, size, and distribution of cities have changed greatly from the ancient state period (i.e. the Yangshao and Longshan periods) to the kingdom period (i.e. the Xia and Shang Dynasties), which reflects the evolution of settlement and social organization. In this study, GIS technology was used to establish the city spatial database for the periods that witnessed the transition from ancient states to the kingdom, including the Yangshao period, the Longshan period, and the Xia and Shang Dynasties. Moreover, the nearest neighbor distance analysis and the gravity center analysis were implemented to explore the possible factors that were considered in the city site selection, including altitude and distances to nearest rivers. Furthermore, efforts were made to investigate the spatiotemporal evolution of the shape, size, agglomeration, and varying gravity center of cities as well as the spatiotemporal evolution of moats. The results show that: (1) Most city sites were distributed in areas with altitudes of < 500 m above sea level and distances of less than 3 km away from rivers during all three periods. (2) From the Yangshao period to the Xia and Shang Dynasties, the shape of the city gradually changed from circular to square, and the type of moats changed from trenches in the Yangshao period to city walls in the Longshan period and no walls in Xia and Shang Dynasties. (3) The size and grade of the 18 cities in the Yangshao period shared high similarity, with an average area of 20 hectares. In comparison, the sizes of 24 cities in the Longshan period increased significantly, with an average of 39 hectares. During the Xia and Shang Dynasties, there were 22 cities with an average size of 340 hectares, and the grade of sizes became obvious, marking the entrance into the centralized kingdom period. (4) Cities were scattered in the decentralized pattern during the ancient state periods (i.e. Yangshao and Longshan periods), whereas they became agglomerative in the kingdom period (i.e. Xia and Shang Dynasties). This reflects the evolution of the spatial scopes and social organizational forms. (5) From ancient states to the kingdom, the city center moved around Songshan Mountain from the northwest to the southeast and again to the northeast.

1. Introduction

The Central Plains region of China witnessed the emergence of probably the earliest cities in China. It is the core area that records the occurrence, development, and prosperity of ancient Chinese civilization, and it also plays an important role in the history of world civilization. Early states first became into shape in this region [1], which were gradually united by the centralized Kingdom. As is defined by Su [2], the term "ancient state" refers to the stable and independent political entity with its hierarchy higher than the tribe, which occurs during the transition from primitive society to civilization. In this context, the term generally corresponds to the period before the Xia Dynasty, namely the Yangshao period and the Longshan period. After the Longshan period, the centralized monarchic kingdom known as the Xia Dynasty entered the historic stage, with its culture known as the Erlitou culture [3]. The occurrence of cities in the Central Plains region marks the formation of Chinese civilization. Therefore, it is of crucial significance to
analyze the spatiotemporal evolution of cities from ancient states to the kingdom in the Central Plains region, which can help people better understand the origin and development of Chinese civilization.

Recently, more and more attention has been paid to the city site research, partly because of the implemented national great site protection plan. Moreover, GIS and RS technologies have been widely applied to aid research on archaeology. In this study, GIS technology was used to establish the spatial database of cities during the period from ancient states to the kingdom in Central Plains. This was integrated with the nearest neighbor analysis and the gravity center analysis to explore the spatial distribution, agglomeration form, and gravity center of cities over time. Moreover, the shape and type of moats were also investigated. Results of this study are expected to help reveal the spatiotemporal evolution of cities from ancient states to the kingdom in the Central Plains region and thus provide an important basis for studying the origin and site selection of early cities in ancient China.

2. Data And Methods

2.1 Study area

The Central Plains region 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 [4], the latter of which is adopted in this study (figure 1). Settlements in the Central Plains region can be dated back to the Paleolithic age, and the 5000 years of culture has been continuously developed since then. It has been regarded as the key area for research on environmental archaeology [5-9].

2.2 Data source

There are mainly two types of data, namely geographical background data and thematic city-data. The former type includes administrative region data and DEM data of Henan Province, which are primarily from the geospatial data cloud (http://www.gscloud.cn/). The latter type includes a series of literature, such as The archaeology of enclosure settlements in the pre-Qin period [10], A comprehensive study of early cities in the Central Plains [11], The cultural relics atlas of China (Henan Fascicule) [12], Cultural relics of Henan province [13], and Zhengzhou cultural relic atlas [14]. Moreover, the data of The third national census of cultural relics were also adopted. Information of a total of 64 cities was complied, including 18 in the Yangshao period, 24 in the Longshan period, and 22 in Xia and Shang Dynasties.

2.3 Methodology

2.3.1 Analysis of city sizes and shapes

City sizes and shapes were statistically compiled when there is available literature. Otherwise, remote sensing technology was used to identify the contours of cities and thus obtain data concerning city sizes.
and shapes.

### 2.3.2 Analysis of city agglomeration

As one of the most commonly used point pattern analysis methods [15], the nearest neighbor distance method was first proposed by Clark and Evans in 1954[16] and then introduced into geography by Dacey in 1960[17]. 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 [18].

In this study, the average nearest neighbor distance tool in ArcGIS 10.5 software was used to calculate the average distance between each element 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.

### 2.3.3 Analysis of the city gravity center

The concept of "center of gravity" 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 [19]. The gravity center of a city refers to the average center in the spatial distribution of cities in different regions. The calculation formula of the center of gravity of cities in Henan Province in a certain period is as follows:

\[
M_{xi} = \frac{\sum_{i=1}^{n} x_i}{n}, \quad M_{yi} = \frac{\sum_{i=1}^{n} y_i}{n}
\]  

(1)

where \(M_{xi}\) and \(M_{yi}\) represent the coordinates of the centers of gravity of cities or settlements in Henan Province, respectively, and \(x_i\) and \(y_i\) represent the coordinates of all cities or settlements in a certain period.

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

\[
D_{t-j} = \sqrt{(M_{yi} - M'_{yi})^2 + (M_{xi} - M'_{xi})^2}
\]

(2)

where \(D_{i,j}\) represents the displacement of the city center of gravity.

### 3. Results
3.1 Relationship between city distribution and environment

Settlement site selection is demonstrated to be affected by many factors, including altitude, slope or aspect, water source, and soil [20]. As the most important form of settlement sites, city site selection is also restricted by these geographical factors. Based on the analysis of 64 cities in the Central Plains region, the relationship between cities and these geographical factors is obtained, which provides an important basis for analyzing city site evolution.

(1) Altitude

Human beings can only survive in conditions with appropriate temperature and pressure. Since the pressure and temperature gradually decline with the rise of altitude, human beings have to live in certain areas with an upper limit of altitude. The tool of extracting multiple values to points in ArcGIS 10.5 is used to extract the altitude data of each city site (Table 1).

Table 1. Altitudes of cities in the Central Plains region

| Altitudes (m) | Yangshao Period | Longshan Period | 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                      |

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 [7]. Most of the settlement sites are below 500 m, but there are also a large number of settlements above 500 m. This is related to the flat terrain that is often required for the construction of the city site. Moreover, the altitude range of 100-200 m is seen with the largest number of city sites, which might indicate this range to be the most suitable for human habitation. In the Yangshao period, the average altitude of the city site is 199 m, the lowest is 51 m in the Dahecun site in Zhengzhou [21], and the highest is 478 m in the Zhouli site in Luoyang [122]. There are only two cities below 100 m and three cities above 300 m. In the Longshan period, the average altitude of the city site is 123 m, the lowest is 47 m, which is the Pingliangtai site in Huaiyang [23], and the highest is 260 m, which is the Wangchenggang site in Dengfeng [24]. Compared with cities during the Yangshao period, those in the Longshan period have much lower altitudes, and there are eight city sites below 100 m whereas there are no city sites 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 [25], and the highest is 467 m, which is the Nanwa site in
Dengfeng [26]. Compared with cities in the Longshan period, those in the Xia and Shang Dynasties have slightly higher altitudes.

(2) Water

The settlement 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 [27]. The horizontal distance from each city site to the river in three cultural periods is obtained in the DEM data of a 30 m resolution using the proximity near tool in ArcGIS 10.5 (Table 2).

Table 2. Horizontal distances between city sites and rivers in the Central Plains region

| Periods       | Yangshao Period | Longshan Period | Xia and Shang Dynasties |
|---------------|-----------------|-----------------|-------------------------|
| Horizontal distance from rivers (m) | Number | Percent | Number | Percent | Number | Percent |
| 0-500         | 1               | 5.56%           | 5                   | 23.81%           | 6       | 27.27% |
| 500-1000      | 5               | 27.78%          | 4                   | 19.05%           | 1       | 4.55%  |
| 1000-2000     | 5               | 27.78%          | 4                   | 19.05%           | 3       | 13.64% |
| 2000-3000     | 2               | 11.11%          | 4                   | 19.05%           | 2       | 9.09%  |
| 3000-5000     | 3               | 16.67%          | 2                   | 9.52%            | 5       | 22.73% |
| >5000         | 2               | 11.11%          | 2                   | 9.52%            | 5       | 22.73% |

Most of the cities are distributed within a distance of 3 km from rivers, accounting for 72.2% in the Yangshao period, 81% in the Longshan period, and 54.6% in Xia and Shang dynasties (Table 2). In the Yangshao period, this distance ranges between 257 m and 6780 m, with an average of 2253 m. During the Longshan period, this distance ranges between 192 m and 6459 m, with an average of 1946 m. During the Xia and Shang Dynasties, this distance ranges between 114 m and 9245 m, with an average of 3189 m.

3.2 Evolution of types and shapes of moats

3.2.1 Evolution of moat types

There were 18 cities in the Yangshao period, and among them, two cities were moated with walls, which were the Xishan City site [28] and the Longshangang site in Xichuan [29], respectively. The Xishan City site is the earliest walled settlement found in the Central Plains region, which is located 23 km away from the northern suburb of Zhengzhou City [30]. In the construction of city walls, ramming, plate building, and
trenching were adopted [31]. In the Longshan period, the city wall began to appear in large numbers. There were 13 trench sites, including the Wangchenggang site[24] and the Guchengzhai site[32]. In the Xia and Shang Dynasties, there were 11 cities moated with trenches and 8 cities with city walls. There were also 3 cities without trenches and city walls, which were the Erlitou site in Yanshi [33], the Yinxu site in Anyang [34], and the Xiaoshuangqiao ruins [35].

Table 3. Types of moats in cities from ancient states to the kingdom in the Central Plains region

| Periods                      | Trench | City wall | No trench nor city wall |
|------------------------------|--------|-----------|-------------------------|
| Yangshao period              | 16     | 2         | 0                       |
| Longshan period              | 11     | 13        | 0                       |
| Xia and Shang Dynasties      | 11     | 8         | 3                       |

3.2.2 Evolution of moat shapes

Moat shapes are reconstructed either according to the excavation report of the city, such as the Wangchenggang site in Dengfeng[24], or the remote sensing data, such as the Guchengzhai site[32].

Table 4. Shapes of moats in cities from ancient states to the kingdom

| Periods                  | Rectangle, square, or trapezoidal shape | Irregular shape | Ringlike or circular shape | Uncertain shape |
|--------------------------|----------------------------------------|-----------------|---------------------------|-----------------|
| Yangshao Period          | 0                                      | 0               | 7                         | 11              |
| Longshan Period          | 13                                     | 0               | 2                         | 9               |
| Xia and Shang Dynasties  | 10                                     | 2               | 3                         | 7               |

During the Yangshao period, there were 18 cities in total, of which 7 were circular in shape (Table 4). During the Longshan period, there were 24 cities, of which 13 were rectangular, square, or trapezoidal, while 2 were circular. In the Xia and Shang Dynasties, there were 22 cities, of which 10 were rectangular, square, or trapezoidal, 3 were circular, and 2 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 region.

3.2 Evolution of city sizes

Table 5. Sizes of cities from ancient states to the kingdom in the Central Plains region
## Characteristics of city agglomeration

It can be seen from Table 6 that the NNI statistics of the cities during the Yangshao period and Xia-Shang dynasties are all less than 1, the Z score values are all less than 0, and the results all pass the test of the significance level of 0.01. Therefore, cities during these two periods are in a state of agglomeration. In the same study area, a larger NNI value corresponds to a lower degree of agglomeration of sample points. The agglomeration of cities during the Yangshao period is more obvious than that in Xia and Shang Dynasties. The NNI value of the cities in the Longshan period is greater than 1, and the Z score value is greater than 0. Therefore, cities in this period are distributed in a decentralized way. Thus, the degree of agglomeration of cities from high to low is: Yangshao period > Xia and Shang dynasties > Longshan period.

Table 6. Average nearest neighbor distances of cities from ancient states to the kingdom in the Central Plains region

| Size          | Yangshao Period | Longshan Period | 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                       |

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.

During the Longshan period, the average city size reached 39 hectares. There were 5 cities with areas of more than 50 hectares, including the Shaochai site (200 hectares) in Yiluo River Basin [36], the Wadian site (130 hectares) in Yinghe River Basin [37], the Xinzhai site (100 hectares) in Shuanghe River Basin [38], the Mengzhuang site (100 hectares) in Northern Henan [39], and the Pinggaotai site (91 hectares) in Southwest Henan [40]. There were obvious differences in the sizes among the cities, which can be classified into four grades. Moreover, there are generally fewer larger cities and more smaller cities.

During the Xia and Shang Dynasties, the average city size increased significantly to 340 hectares. 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 [41] in the east of Songshan Mountain with an area of 2500 hectares, and the Erlitou site [33] of Yanshi in Luoyang, with an area of 350 hectares.
### Periods

| Period              | Number of samples | Average nearest neighbor distance (m) | Expected average nearest distance (m) | NNI statistics | Z value |
|---------------------|-------------------|--------------------------------------|--------------------------------------|----------------|---------|
| Yangshao Period     | 18                | 24640                                | 34608                                | 0.712          | -2.338  |
| Longshan Period     | 24                | 43477                                | 35229                                | 1.234          | 2.19    |
| Xia and Shang Dynasties | 22          | 22711                                | 25664                                | 0.885          | -1.03   |

#### 3.4 Evolution of gravity centers of cities

As is shown in Figure 6 and Table 7, the center of gravity of the city moved from the northwest during the Yangshao period to the southeast during the Longshan period, and further moved to the north during the Xia and Shang dynasties, reaching the proximity of the Songshan Mountain. This further confirms that the core cultural area of the Henan Province should lie in the area around the Songshan Mountain, which occupies a core position in the cultural development from the Neolithic to Xia and Shang Dynasties.

#### Table 7. Centers of gravity of cities from ancient states to the kingdom 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, near due north         |

#### 4. Discussion

The Yangshao period was featured by a vast territory with a sparse population, and moats are prevalent in cities, except for the Xishan City site and Longshangang city site [29] in the late Yangshao period. Therefore, this period was known as the “moated era” [10]. The warm and humid climate during this period promoted the great development of the Yangshao culture [38]. 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 [43]. 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. As a response, the average horizontal distance between the city site and the river was the largest in the Yangshao period. On the contrary, Yangshao cultural sites are densely distributed on the Loess Plateau of the western Henan Province and the Yiluo River area, where both the total amount and area of the cities increased rapidly [44]. This also explains
the high concentration of cities during the Yangshao period, when the center of gravity was in the northwest.

During the Longshan period, the space for human activities expanded, due to the dry climate and the shrunk water network [30]. Human beings began to enter the vast alluvial plain on a large scale [45], where the altitude was the lowest. Moreover, the horizontal distance from the river was also smaller than that in the Yangshao period. Meanwhile, the number of 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 city center of gravity was shifted to the southeast during this period. Moreover, the population density reached its peak in almost all areas [44]. Furthermore, cities were more scattered in this period, because of competition for the surrounding resources.

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 [46]. In this condition, the low-lying central and eastern plain areas were more suitable for human habitation, where two urban settlements 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 [47]. The city center of gravity was shifted to the northeast.

5. Conclusions

The prehistoric culture in the Central Plains is relatively developed, which is one of the important central regions of the origin of Chinese civilization. By using the methods of GIS and remote sensing, this paper analyzes the temporal and spatial evolution of the moat type, scale and shape, and the center of gravity of the cities from ancient countries to kingdoms in the Central Plains region. The research can provide important clues for further revealing the process, stage and mode of Chinese civilization.

It is found that the evolution from ancient states to kingdoms in the Central Plains has experienced three stages. Namely the Yangshao period, Longshan period, and Xia and Shang Dynasties. (1) During these periods, city sites were preferentially selected in areas with altitudes of < 500 m and distances of < 3 km away from rivers. (2) Cities gradually changed from being circular to being square, and moats changed from trenches in the Yangshao period to the city walls in the Longshan period, and then to no walls in Xia and Shang Dynasties. (3) The sizes of cities became larger and larger, with more and more complex grades of sizes. There were fewer high-grade cities and more low-grade cities. (4) In the Yangshao period, humans 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. (5) The study found the focus of the cultural development in the
Henan Province was in the area around Songshan Mountain. Moreover, due to the influence of climate and other environmental factors, the city center of gravity changed anticlockwise in the area around Songshan Mountain.

**Declarations**

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**Author information**

**Institute of Geography, Henan Academy of Sciences, Zhengzhou 450052, China**

Lijie Yan, Peng Lu, Fei Teng, Li Zhang, Xia Wang, Panpan Chen, Lanbo Guo, Dong Zhao

**Zhengzhou Base, International Center on Space Technologies for Natural and Cultural Heritage under the Auspices of UNESCO, Zhengzhou 450052, China**

Lijie Yan, Peng Lu, Fei Teng, Li Zhang, Xia Wang, Panpan Chen, Lanbo Guo, Dong Zhao

**Aerospace Information Research Institute, Chinese Academy of Sciences, 100094 Beijing, China**

Ruixia Yang

**School of Earth and Environmental Sciences, University of Queensland, QLD 4072 Brisbane, Australia;**

Xiang Li
Contributions

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

Corresponding author

Correspondence to Peng Lu.

Ethics declarations

Competing interests

All authors declare that they have no competing interest.

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Figures

Figure 1

The geographic location of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

(a) Yangshao Period  (b) Longshan Period  (c) Xia and Shang Dynasties
Figure 2

Distribution of different types of moats in cities from ancient states to the kingdom in the Central Plains region. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

Typical city shapes. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 4
The shape and distribution of cities from ancient states to the kingdom in the Central Plains region. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

![Maps showing evolution of city sizes](image)

**Figure 5**

Evolution of city sizes from ancient states to the kingdom in the Central Plains region. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 6

Displacement of centers of gravity of cities from ancient states to the kingdom in the Central Plains region. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.