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Determination of the temporal–spatial distribution patterns of ancient heritage sites in China and their influencing factors via GIS

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Abstract

In this paper, we analysed the temporal and spatial distributions of ancient archaeological sites in China as well as their influencing factors. Our aim was to reveal the developmental trajectory of Chinese civilisation and to explore the natural and cultural factors affecting human distribution, with the goal of providing insights for the conservation and development of ancient relics. We employed spatial analysis methods using ArcGIS 10.8 software, such as kernel density analysis and trend surface analysis, to analyse 1194 historical ancient sites listed in the National Cultural Relics Protection Units of China. The research findings are as follows: (1) the distribution of ancient sites demonstrates an agglomerative spatial pattern. The nearest neighbour index ($R < 1$) for sites from various historical periods indicates an agglomerative spatial distribution of ancient sites across historical periods, with the clustering degree being relatively poor for sites from the Wei-Jin, Northern and Southern Dynasties and in the Ming and Qing periods. The regions with a concentration of ancient sites are the middle and lower reaches of the Yangtze River and Yellow River Basins. Furthermore, there is a higher abundance of ancient sites in the southeastern region than in the northwestern region. (2) The distribution of ancient sites in different historical periods also exhibits an imbalance, with an overall decreasing trend in the number of ancient sites in China. Notably, more ancient sites were found for the prehistoric and pre-Qin periods. The temporal trend of ancient sites during historical periods follows a trajectory from northeast to northwest, northeast to southwest, etc. (3) The temporal and spatial distributions of ancient sites are influenced by multiple factors, including social development, the natural environment, geographical elements, and socioeconomic and political factors. Finally, based on an understanding of the spatiotemporal distribution pattern of ancient sites and the factors that influence this pattern, recommendations for conservation and development can be proposed and supported by modern technological methods, with the aim of offering insights for the protection and sustainable development of heritage sites.

Keywords Ancient Chinese heritage sites, Geographic information systems (GIS), Temporal–spatial distribution, Influencing factors

Introduction

Ancient sites refer to traces of activities left by ancient humans, including architectural complexes and locations where humans interacted with the natural environment. According to the "Protection Law of the People's Republic of China," these sites can be designated as national, provincial, municipal, or county-level key cultural heritage protection units based on their historical, artistic, and scientific value as immovable cultural relics. The list

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of these cultural heritage protection units includes five types: ancient sites, ancient tombs, ancient buildings, grotto temples and stone carvings, and modern historical sites and representative buildings. The ancient sites mainly include human activity remnants, such as ancient city sites, ancient residential sites,ancient military sites and ancient production sites, ranging from large to small, such as the Erlitou site, Helongdadong site, Military defense sites in the Turpan Basinand Nanyao site. As treasures of human history, ancient sites possess rich historical and cultural importance and contain valuable socioeconomic information. Such research is crucial for understanding human history, addressing contemporary environmental challenges, and providing practical importance for land planning and spatial layout optimisation [1–5]. In-depth research on ancient sites can unveil the origins, development, and evolution of human civilisation, showcasing the continuity of human culture. National-level cultural heritage protection units hold the highest authority and possess the deepest historical and cultural value. Therefore, we focused on ancient sites listed in the national cultural heritage protection unit directory.

The study of ancient sites began in the 1930s when scholars began exploring the factors influencing their evolution from different disciplinary perspectives. Early research focused on qualitative analysis, with scholars analysing the sizes and remains of sites based on literary materials from different dynasties. There has been a trend in archaeological site research shifting from qualitative to quantitative analysis. This trend has emerged based on advanced technical capabilities, abundant archaeological site resources, and favourable political conditions. First, there has been widespread application of archaeological technologies such as remote sensing and geographic information systems (GIS) [6, 7]. In particular, the extensive use of GIS technology, with its powerful spatial analysis capabilities, enables in-depth analysis of site concentration, distribution patterns, and potential influencing factors, partially addressing shortcomings in studying site spatial distributions [4, 8–10]. Furthermore, China possesses many archaeological sites. This provides a solid foundation for research on ancient sites. In the context in which the nation greatly emphasises cultural development and has focused on building a culturally strong country, studies of the spatial distribution patterns of ancient sites can support the development goal of enhancing cultural awareness. Moreover, research on ancient sites is facilitated by advantageous technical conditions, available resources, and a conducive political environment. Moreover, researchers have focused mainly on specific historical periods, such as the prehistoric or Xia-Shang-Zhou periods; spatially, researchers have concentrated on regions with dense site distributions. Comprehensive studies covering the historical period and national scale are scarce, both in China and internationally. While some scholars have referenced the distribution of ancient sites within spatial studies of cultural heritage units, a detailed account of the specific temporal and spatial distributions of ancient sites has yet to be provided [11, 12]. Therefore, there is considerable room for exploration of the distribution patterns of ancient sites. In this context, our purpose of this research was to explore the spatial and temporal distribution characteristics and evolutionary patterns of ancient sites throughout the ancient period using research methods such as kernel density analysis and trend surface analysis in GIS. Additionally, the factors that influence site distribution have been explored from different perspectives [13]. This analysis aimed to provide a more intuitive understanding of the factors influencing ancient site distributions during historical periods. Finally, based on the analysis results and developments, targeted recommendations are proposed to contribute to the protection, development, and inheritance of ancient sites.

Research methods and data sources

Research methods

Kernel density analysis

Kernel density analysis can be used to estimate the density of point features and assess their clustering trend in space [3, 14]. In this study, ancient sites within cultural heritage units were considered point features, and their spatial density characteristics were investigated using the following formula:

$$f_{(x)} = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \tag{1}$$

In the formula, the kernel density was estimated as the probability that the density function f is valid at point x, where $k\left(\frac{x-x_i}{h}\right)$ is the kernel function, h is the search radius, which must be greater than 0, and the distance (km) between the estimated point x and the point of interest x_i is considered.

Nearest neighbour index

The nearest neighbour index is used to determine the distance between the centroid of each object point within a spatial unit and the centroid position of its nearest neighbour object point. This index is crucial for studying the spatial distribution type (e.g., uniform, random, or clustered) of point features in geography. The index is calculated using the following formula:

$$E = \frac{\overline{r}_1}{r_E} = \sqrt[2]{D} \quad (2)$$

In this equation, E represents the nearest neighbour index, r_1 signifies the average nearest neighbour distance between features, r_E is the theoretical average nearest neighbour distance between features, and D denotes the point density. When $E = 1$, it indicates a random spatial distribution of point features. When $E > 1$, the point features tend towards a uniform distribution. Conversely, when $E < 1$, point features exhibit a clustered distribution pattern [21].

Centroid model

Geographical phenomena exhibit three types of spatial distribution characteristics: regular, random, and clustered [15]. Changes in centroids are effective indicators for studying the evolutionary trends of massive sets of spatiotemporal data [16].

$$\overline{x} = \sum_{i=1}^{n} w_i x_i \Bigg/ \sum_{i=1}^{n} w_i,\ \overline{Y} = \sum_{i=1}^{n} w_i Y_i \Bigg/ \sum_{i=1}^{n} w_i. \quad (3)$$

In the equation, $\overline{x}$ represents the longitude of the centroid of ancient sites in different periods; $\overline{Y}$ represents the latitude of the centroid of ancient sites in different periods; n denotes the number of grids within the study area; i is the grid index; x_i and y_i are the longitude and latitude of the geometric centre of the ith grid, respectively; and w_i is the density value of ancient sites in the ith grid.

Trend surface analysis

Trend surface analysis is a method used to fit mathematical functions to spatial sample point values using global polynomial functions. Notably, two-dimensional spatial sample point data are transformed into a three-dimensional visualization of a smooth curve, reflecting the spatial changes in geographic features. In this study, trend surface analysis was utilised to express the trends at ancient sites in different historical periods. zi (x_i, y_i) represents the true observed value of the ith geographic feature, and Ti (x_i, y_i) denotes the trend surface fitting value. The corresponding formula is as follows:

$$z_i\left(x_i, y_i\right) = T_i(x_i, Y_i) + \varepsilon_i \quad (4)$$

In the equation, (x_i, y_i) represents the geographic coordinates, and ε_i is the deviation between the true value and the fitted value.

Data sources

The selection of research data for ancient sites was derived from the official website of the National Cultural Heritage Administration (http://www.nach.gov.cn), which publishes a total of 1194 nationally important cultural heritage sites (excluding those in Hong Kong, Macau, and Taiwan) in batches of one to eight. We utilised mapLocation to obtain the latitudinal and longitudinal coordinates of the ancient sites, and the base map was generated from mapshaper (https://mapshaper.org/). The national DEM elevation data and national river data were obtained from the Geographic Spatial Data Cloud (http://www.gscloud.cn/sources/) and the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/).

Spatial and temporal characteristics of ancient site distributions

Distribution of ancient sites in different periods in China

Integration of the temporal information of ancient sites listed in the national catalogue of important cultural heritage sites enables the sites to be categorised into seven historical periods: the prehistoric period, pre-Qin period, Qin and Han period, Wei, Jin, Southern and Northern Dynasties period, Sui, Tang, Five Dynasties, Ten Kingdoms period, Song and Yuan period, and Ming and Qing period.

Spatiotemporal evolution of ancient sites in China

Figure 1 shows the distribution of ancient site quantities in different historical periods. The spatiotemporal data curve of ancient sites exhibits large fluctuations than a linear trend, indicating distinct variations in the quantity of ancient sites across stages. Within the studied ancient sites, the prehistoric and pre-Qin periods constituted 38.8% of the total, whereas the quantities of ancient sites from the Qin-Han, Sui-Tang, Five Dynasties and Ten Kingdoms, as well as the Song-Yuan periods, were relatively limited. Notably, there was a sudden cliff-like decline in the number of ancient sites during the Wei, Jin, Ming, and Qing periods, which may be attributed to political changes, frequent wars, and human production developments at that time.

Temporal and spatial distribution of ancient sites

In addition to changes in the quantities of ancient sites across historical periods, changes in their spatial distribution over time were explored. The evolution of the spatial distribution pattern of ancient sites in different historical periods (Fig. 2) reflected the changes in the spatial scope of human activities during those times:

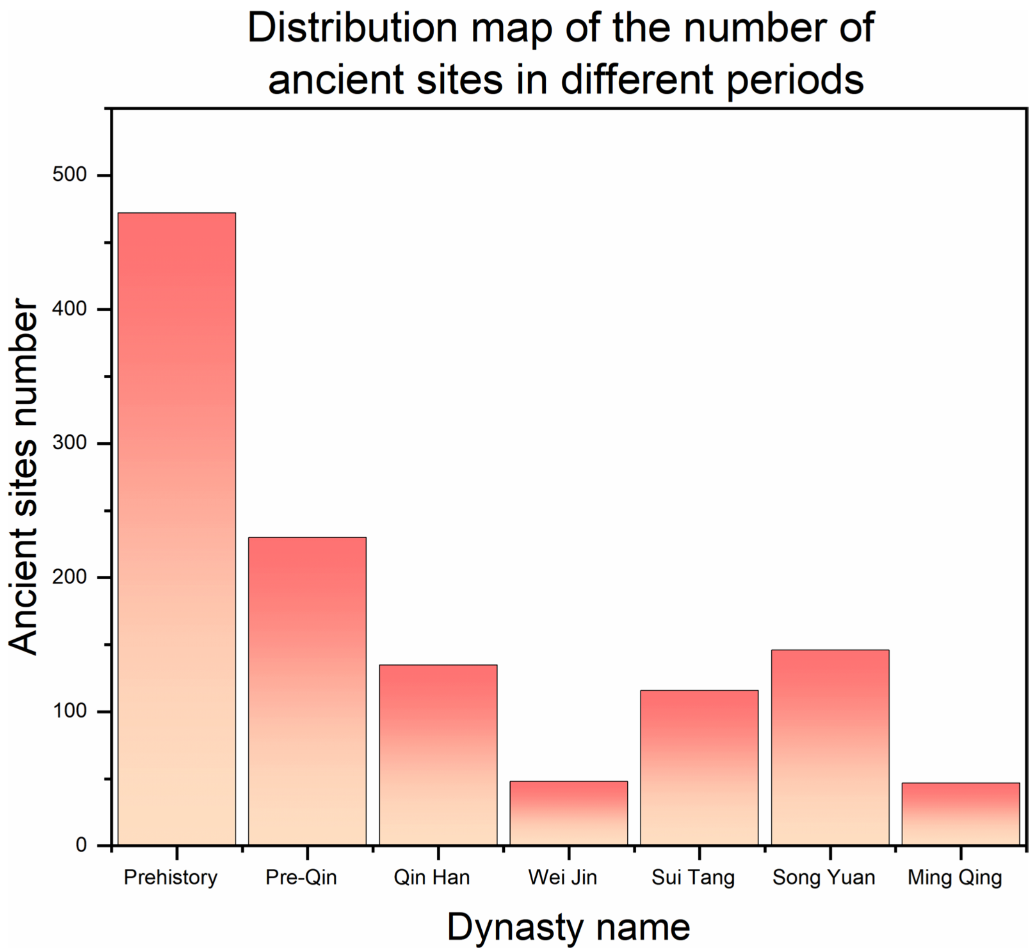

Fig. 1 Distribution map of the number of ancient sites in different periods

(1) Prehistoric and Pre-Qin Periods

During the prehistoric period (shown in Fig. 2a), ancient sites were mainly concentrated in core areas, namely, Henan Province, Shandong, Jiangsu and Zhejiang, the border area between Hunan and Hubei, the central and southern parts of Shaanxi Province, and the southwestern part of Shanxi Province. These sites formed a distribution pattern centred on a core area, radiating outwards. The distribution characteristics of these prehistoric sites demonstrated the diverse and integrated nature of the Chinese ethnic group. During the Pre-Qin period, the spatial distribution characteristics of ancient sites largely inherited the distribution patterns of prehistoric civilisations. The central and northern parts of Henan Province remained the core areas of distribution. However, after thousands of years of development and evolution, the range of human activities also expanded. In the Pre-Qin period (shown in Fig. 2b), the more densely populated areas shifted to regions in the central and western parts of Shanxi Province, the central and southern parts of Hebei Province, the central and southern parts of Shanxi Province and other areas. Moreover, the distinctive pattern of site distribution, known as the “moon surrounded by stars” phenomenon, became more pronounced. Since prehistoric times, the Huaxia people have primarily inhabited the Yellow River basin. From prehistoric times to the Pre-Qin period, other ethnic groups lived in different regions. The Huaxia people maintained close relations with ethnic groups. Some Huaxia people, who travelled to various regions, enriched the cultural system via collaboration with local populations, leaving behind numerous historical relics.

(2) Qin and Han Dynasties

In comparison to previous historical periods (shown in Fig. 2c), the Qin and Han Dynasties experienced large differences in the spatial distributions of ancient sites. The core areas were mostly in central Shaanxi, southern Shanxi, central-northern Henan, and surrounding

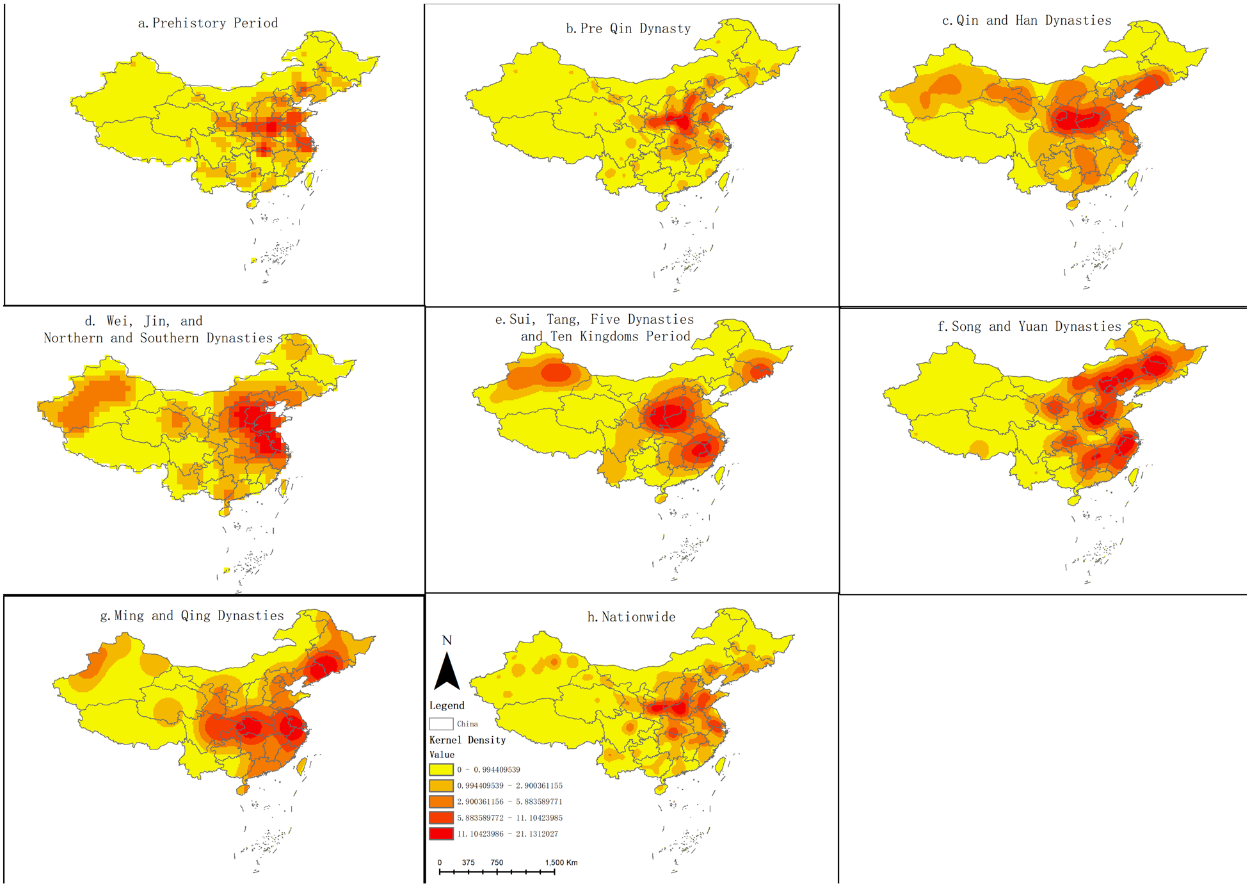

Fig. 2 Kernel density map of spatiotemporal distribution of ancient site heritage

regions. The densely populated areas during the Qin and Han Dynasties were mainly in the northeastern part of Liaoning Province. Xinjiang, Gansu, Inner Mongolia, Hunan, and other regions were moderately populated. During the Qin and Han Dynasties, the agrarian world began interacting with the nomadic world. Emperors such as Qin Shihuang and Emperor Wu of the Han expanded their borders through military means, which was also a form of communication. On the other hand, during the reign of Emperor Wu of Han, Zhang Qian's mission to the Western Regions represented a peaceful form of interaction. The result of the exchange between these two worlds was the expansion of the Central Plains dynasty's control and the widespread distribution of Central Plains cultural sites. During this period, ancient sites were highly concentrated in the Luoyang and Chang'an areas.

(3) Wei, Jin, and Northern and Southern Dynasties

As the second major period of division in history, the spatial distribution characteristics of ancient sites during the Wei, Jin, and Northern and Southern Dynasties differed from those of the strong unified dynasties (shown in Fig. 2d). The core region of the ancient site distribution was scattered and was mostly in southern Hebei Province, Shanxi Province, Shandong Province, eastern Henan Province, Jiangsu Province and Anhui Province. In addition to the core region, lower-density aggregation areas were found in Xinjiang, Qinghai, Liaoning, and other regions. The Wei and Jin periods were turbulent in Chinese history, as they experienced the division of the Three Kingdoms and the political chaos of the Northern and Southern Dynasties. The turbulent political situation caused social instability, population mobility, cultural transformations, social changes, and frequent changes in settlement locations, which affected the formation and preservation of ancient sites.

(4) Sui, Tang, Five Dynasties and Ten Kingdoms Period

During the Sui Tang, Five Dynasties and Ten Kingdoms periods, the distribution of ancient sites included two core areas and two moderately populated areas (shown in Fig. 2e). The first core area included the Guanzhong region and southern Shanxi Province, and the second core area included the northeastern part of Jiangxi, Zhengjiang, the southern of Anhui and the northern of Fujian Province. The two moderately populated areas were central Xinjiang and northeastern China. The political centres during the Sui, Tang, and Five Dynasties were mainly concentrated in the Central Plains region (present-day Henan, Shaanxi, etc.). The construction and prosperity of these political centres attracted a large population and resources, forming prosperous economic centres and hubs of cultural exchange. Therefore, many sites were formed around these political centres. During the Sui, Tang, and Five Dynasties, transportation conditions greatly improved due to the opening of the Grand Canal and the development of land transportation, which improved connections between regions. Convenient water and land transportation undoubtedly accelerated the flow of population and goods and the exchange of culture and economy among regions. As a result, many sites were established in transportation hubs, coastal areas, and river basins.

(5) Song and Yuan Dynasties

During the Song and Yuan dynasties (shown in Fig. 2f), the spatial distribution of ancient sites was mostly concentrated in three core areas: the central-western part of Jilin, the northern part of Hebei Province, and the border area between Jiangsu and Zhejiang. In addition, three moderately populated areas with ancient site distributions were found in the southeastern part of Inner Mongolia, the northern part of Hebei Province, and the border area between Hunan and Jiangxi. Compared to other dynasties, the Song and Yuan dynasties had a greater number of core areas, as observed in the distribution of ancient sites, reflecting the extensive human activities and the complexity of cultural exchange at that time. With the shift of the political centre to the south, many people migrated southwards, leading to critical development in agriculture, handicrafts, and commerce in that region. This progress further facilitated the development of the southern region, leading to economic prosperity and other social phenomena that influenced the distribution of ancient sites.

(6) Ming and Qing Dynasties

During the Ming and Qing dynasties (shown in Fig. 2g), the spatial distributions of ancient sites were somewhat similar to those of the Song and Yuan periods and continued to develop, revealing a distribution pattern of three core areas. The first core area included the southern and central parts of Northeast China; the second core area included the border areas of Zhejiang, Jiangsu, and Jiangxi; the third core area included the central and eastern parts of Sichuan Province and Hubei Province. In the late Qing period, due to frequent wars and other factors, many sites suffered varying degrees of damage, resulting in a smaller number of ancient sites during the Ming and Qing periods.

(7) Overall distribution of ancient sites

From a nationwide perspective (shown in Fig. 2h), ancient sites in China are mostly distributed in the Henan, Shaanxi, Shandong, and Jiangsu-Zhejiang regions, presenting a belt-like distribution pattern. On the other hand, ancient sites in Xinjiang exhibit a patchy distribution, while in places such as Jilin, the distribution is scattered. These areas are mostly in the flat terrain and fertile soil of the Yangtze River and Yellow River basins, which have well-developed water systems and abundant resources conducive to human production, life, and reproduction. Therefore, these areas have more ancient sites that are more densely distributed.

Spatial distribution characteristics of ancient heritage sites in China

Spatial agglomeration characteristics

As shown in Table 1, the average observation distance of each period generally shows an upwards trend. The shortest distance was found in the prehistoric period, and the longest distance occurred in the Ming and Qing Dynasties. When the nearest neighbour ratio R was less than 1 and the Z score was less than 0, the sites in the country and in each historical period were in an agglomerated state. However, the degree of site agglomeration varied during different historical periods. From the prehistoric period to the Wei, Jin, Northern and Southern Dynasties, the nearest neighbour ratio R of ancient sites increased from 0.44 to 0.64, indicating a decrease in the degree of agglomeration during the latter period. The prehistoric period had the highest level of spatial distribution agglomeration among several periods. From the Wei, Jin, Northern and Southern Dynasties to the Song and Yuan Dynasties, agglomeration trends in the spatial distribution of ancient sites reappeared. However, from the Song and Yuan Dynasties to the Ming and Qing Dynasties, the distribution of ancient sites became relatively scattered.

Spatial direction characteristics

Since the Stone Age, factors such as social structure, political policies, economic conditions, and cultural customs have caused the number and spatial locations of ancient sites to vary, resulting in differences in the centre of gravity and distribution of ancient sites in different historical periods. An analysis of the transfer trajectory of the centre of gravity at ancient sites via the gravity model indicated that the direction of the centre of gravity at ancient sites during historical periods exhibited a pattern

Table 1 Spatial agglomeration characteristics of ancient sites in China based on the nearest neighbour index

Region and period	Average observation distance (km)	Expected average distance (km)	Nearest neighbour ratio (R)	Z score	P	Distribution pattern
Nationwide	30,770	64,428	0.47	−32.27	0	Cluster
Prehistoric	44,994	93,009	0.44	−22.97	0	Cluster
Pre-Qin	65,030	120,253	0.54	−12.7	0	Cluster
Qin Han	86,263	158,056	0.54	−10.42	0	Cluster
Wei, Jin	156,656	241,488	0.64	−4.75	0	Cluster
Sui Tang	106,602	197,165	0.54	−9.2	0	Cluster
Song Yuan	78,281	157,692	0.49	−12	0	Cluster
Ming Qing	190,725	256,500	0.74	−3.53	0	Cluster

of northeast–northwest–northeast–southwest–northeast–southwest.

In the prehistoric period, the centre of gravity of the ancient sites was in the middle of Henan Province (113°52", 34°16′22"); during the Pre-Qin period, it shifted to the northern part of Henan Province (113°50′57", 34°54′10"), moving approximately 70.11 km to the northeast. During the Qin and Han dynasties, the centre of gravity was in the central region of Shaanxi Province (108°39′39", 39°49′29"), moving approximately 480.71 km to the northwest. In the Wei, Jin, Northern and Southern Dynasties, the centre of gravity was in the southwestern part of Shanxi Province (108°57′56", 36°1′8"), moving approximately 34.99 km to the northeast. During the Sui and Tang dynasties, it was in the eastern part of Gansu Province (108°26′36", 35°19′21"), moving approximately 90.91 km to the southwest. In the Song and Yuan dynasties, the centre of gravity was in the northeastern part of Hebei Province (115°58', 36°16′8"), moving approximately 686.15 km to the northeast. During the Ming and Qing dynasties, it was at the junction of Hebei Province and the central-western part of Henan Province (112°49′32", 35°12′52"), moving approximately 306.52 km to the southwest.

Spatial distribution trends

The surface fitting results of the spatial distribution trend of ancient sites in different historical periods are shown in Fig. 3. The layout patterns of the prehistoric, Pre-Qin, Ming and Qing periods (shown in Fig. 3a, b, g) showed a trend of "higher in the north, lower in the south, higher in the east, and lower in the west." Exhibiting distinct spatial directional characteristics, the high-density areas of ancient sites distribution for these three historical periods were located in the northern and eastern parts of China. In contrast, the spatial distribution trend of ancient sites in other historical periods (shown in Fig. 3c, d, e, f) was "higher in the south, lower in the north, higher in the east, and lower in the west." The ancient sites from these historical periods were primarily distributed in the southeastern region of China. This finding indicated that the southern region became more developed after the Qin and Han Dynasties. Furthermore, the trend surface in the east–west direction was steeper than that in the other directions, while the transition in the north–south direction was relatively gentle, indicating more prominent spatial analysis characteristics in the east–west direction.

Factors influencing the spatiotemporal distribution characteristics of ancient sites

Numerous domestic and international studies have shown that the distribution of ancient sites is closely related to the natural climate, water systems, topographical features, politics, economy, and other factors [17–20]. Considering the historical period, the development and evolution of the number and morphology of ancient sites must have resulted from the interplay of multiple factors. While no single factor can be decisive, at specific stages, certain factors may become dominant. In this study, ArcGIS tools were used to visually analyse the relationships between site quantity and the aforementioned factors.

Topography

The Chinese DEM elevation map was divided into six layers: below 500 m, 500–1000 m, 1001–2000 m, 2001–3000 m, 3001–4000 m, and above 4001 m. Below 500 m was the first level, and above 4001 m was the sixth level. The ancient sites were overlaid with the national DEM elevation map to obtain the data shown in Fig. 4. The quantity of ancient sites in each historical period was statistically analysed according to elevation and is plotted in Fig. 5. The distribution range of ancient sites was mostly in the middle and low altitudes. The first-level sites accounted for 66% of the total, the second-level sites accounted for 13%, and the third-level sites accounted for 14%, while the proportion of sites at the fourth level and above was relatively small. Overall, the ancient sites exhibited a plain–plain distribution pattern during the historical period. As the elevation increased, the terrain became

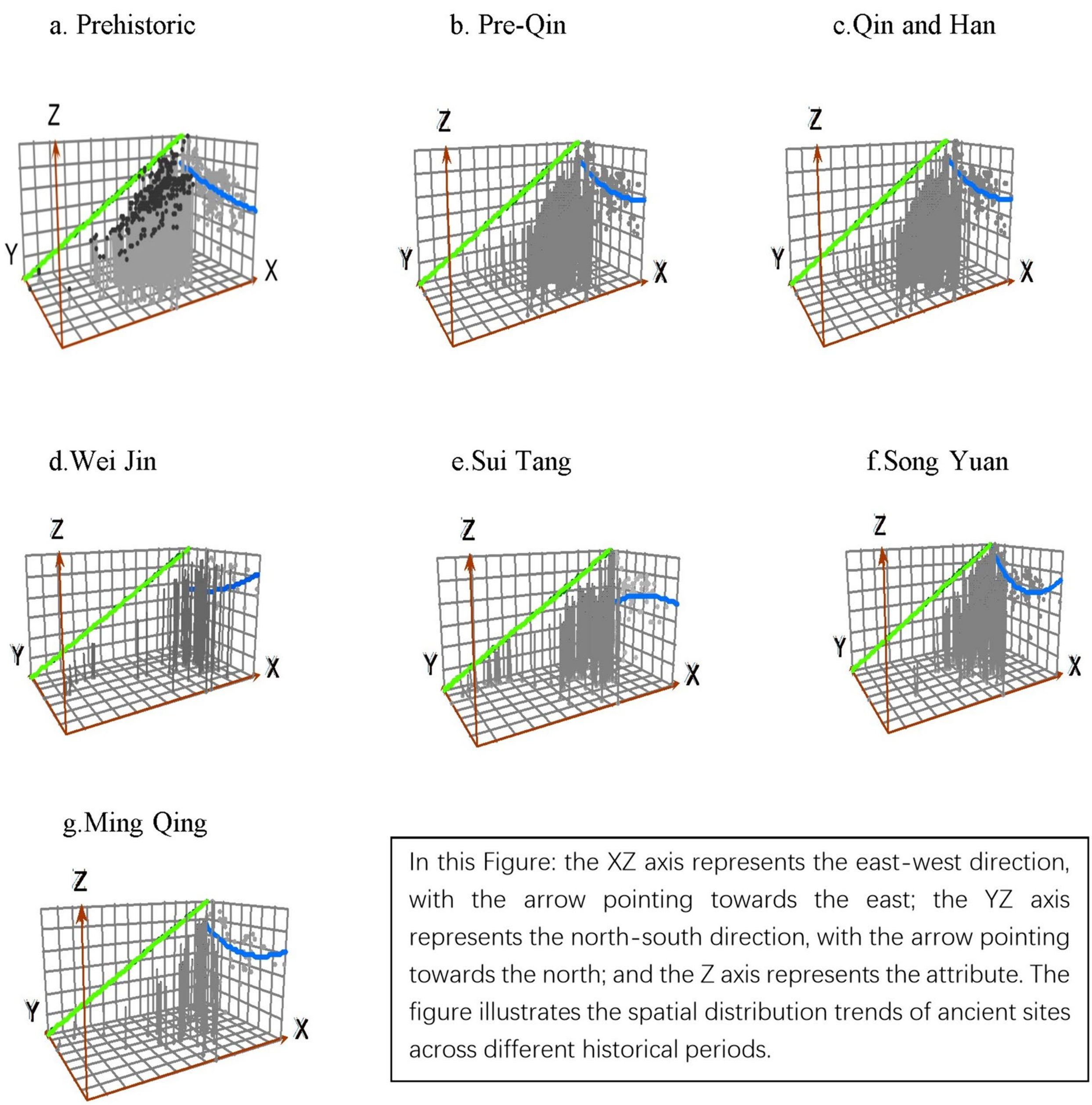

Fig. 3 Trend surface analysis of historical period ancient sites. **a** is the spatial trend surface fitting condition during the Prehistoric period. **b** is the spatial trend surface fitting condition during the pre-Qin period. **c** is the spatial trend surface fitting condition during the Qin and Han periods. **d** is the spatial trend surface fitting condition during the Wei Jin periods. **e** is the spatial trend surface fitting condition during the Sui Tang periods. **f** is the spatial trend surface fitting condition during the Song Yuan periods. **g** is the spatial trend surface fitting condition during the Ming Qing period

more complex and variable, which was not conducive to human habitation, resulting in a gradual decrease in the number of ancient sites. Although the first-level elevation sites had an absolute advantage in terms of the total number of ancient sites, a comparison of the number of sites at the first level with that at other elevation levels revealed that, except for the clear contrasts between the prehistoric and Pre-Qin periods, differences in site numbers at varying elevations in other historical periods were less prominent. This finding indicated that with the development of productivity and advances in production technology, people's ability to transform the natural environment has been enhanced, partially increasing their adaption to different altitude areas.

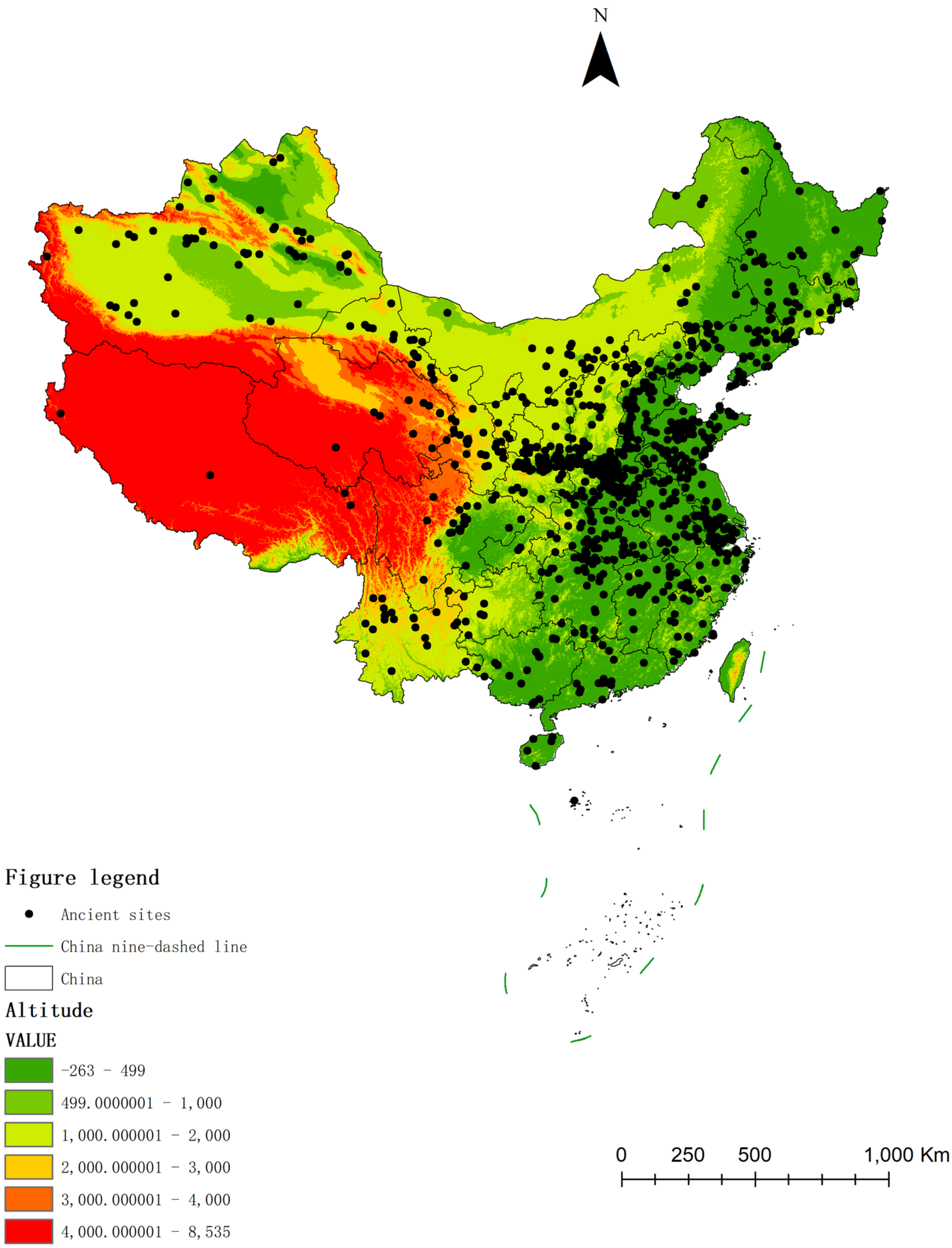

Fig. 4 Distribution of ancient sites at different elevations

Rivers

Water sources are important in human production and livelihoods. Sites near rivers are beneficial for water supply, irrigation, livestock, and transportation. Furthermore, these sites can utilise the defensive effects of rivers and surrounding mountainous areas. Overall, historical sites are mostly distributed in the Yangtze River and Yellow River Basins. To further explore the relationship between rivers and the distribution of ancient sites, an overlapping analysis of the relationship between fourth-level and above domestic rivers and the spatial distribution of ancient sites was conducted. The buffer zones were set at 10 km, 30 km, and 60 km (Fig. 6). Within a 10 km buffer zone, there were 460 sites; within a 30 km

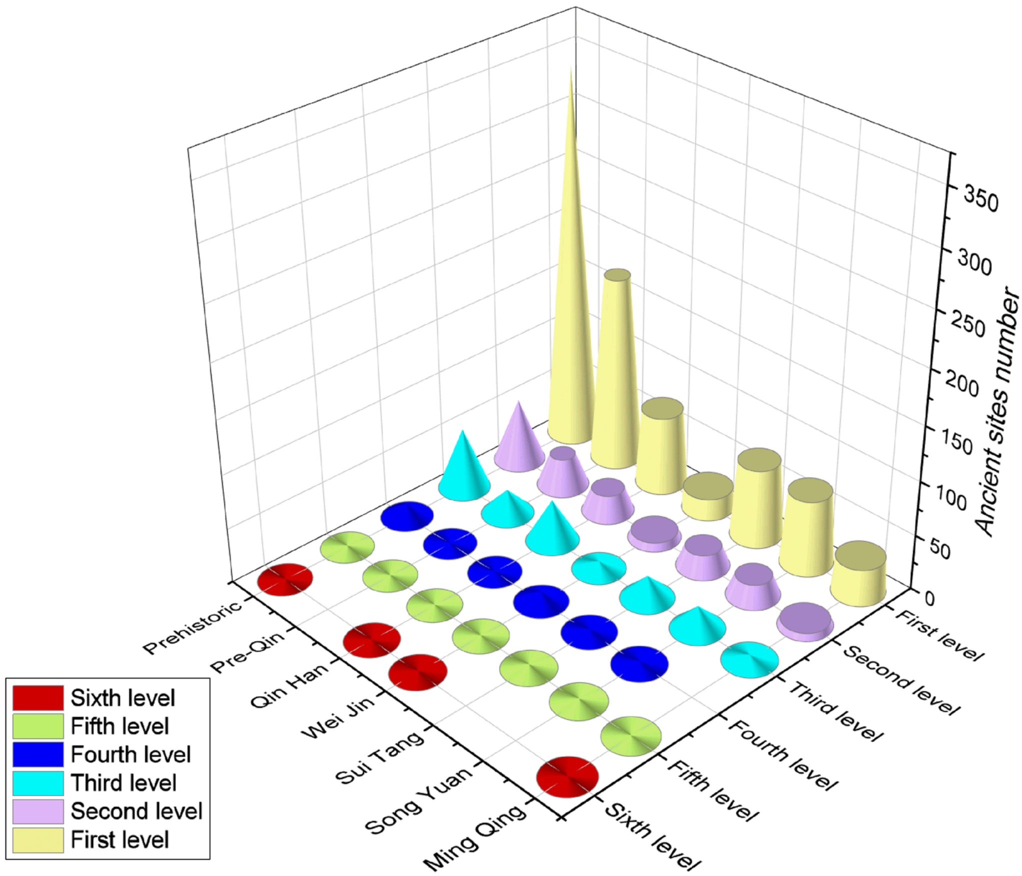

Fig. 5 Variation in the number of ancient sites of different altitudes in different historical periods

buffer zone, there were 837 sites; and within a 60 km buffer zone, there were 1033 sites. These data indicated that the quantity of ancient site distribution was related to the distance from rivers, with a greater number of sites being closer to rivers. In the 10 km buffer zone, the prehistoric period had the greatest number of ancient sites throughout history. In the 30 km buffer zone, the Pre-Qin period had the greatest number of ancient sites. In the 60 km buffer zone, the Qin and Han periods had the greatest number of ancient sites. This finding indicated that in ancient times, there was a stronger reliance on water than in later periods.

Climate

Climate is one of the limiting factors for human development and crucially impacts human society. Climate change profoundly affects socioeconomics, population distribution, political development, etc. Moreover, this impact is irreversible, long-term, and far-reaching [22]. Since the Qin and Han Dynasties, the climate during China's historical periods has undergone multiple changes, alternating between warm and cold periods and revealing an overall cooling trend [23]. Humans have made adaptations in terms of production and livelihood, which are reflected in changes in the distribution patterns of both population and agricultural and pastoral cultures. Warm periods in Chinese history, such as the Qin and Han, Sui and Tang dynasties, were favourable for crop growth, leading to a large expansion of agricultural regions and a relative contraction of pastoral regions. The Wei, Jin, Southern and Northern Dynasties; the middle period of the Tang Dynasty to the Five Dynasties; and the Ming and Qing Dynasties were cold periods, with a colder climate and severe crop damage. As a result, pastoral regions expanded rapidly. When agricultural regions experienced famines, people, especially ethnic minorities in the north, were forced to migrate southwards, leading to events such as the "Five Barbarians' Invasion" during the Northern and Southern Dynasties, the "An Lushan Rebellion" during the Tang Dynasty, and the "Jingkang Incident" during the Northern Song Dynasty. Historical ancient sites, as important

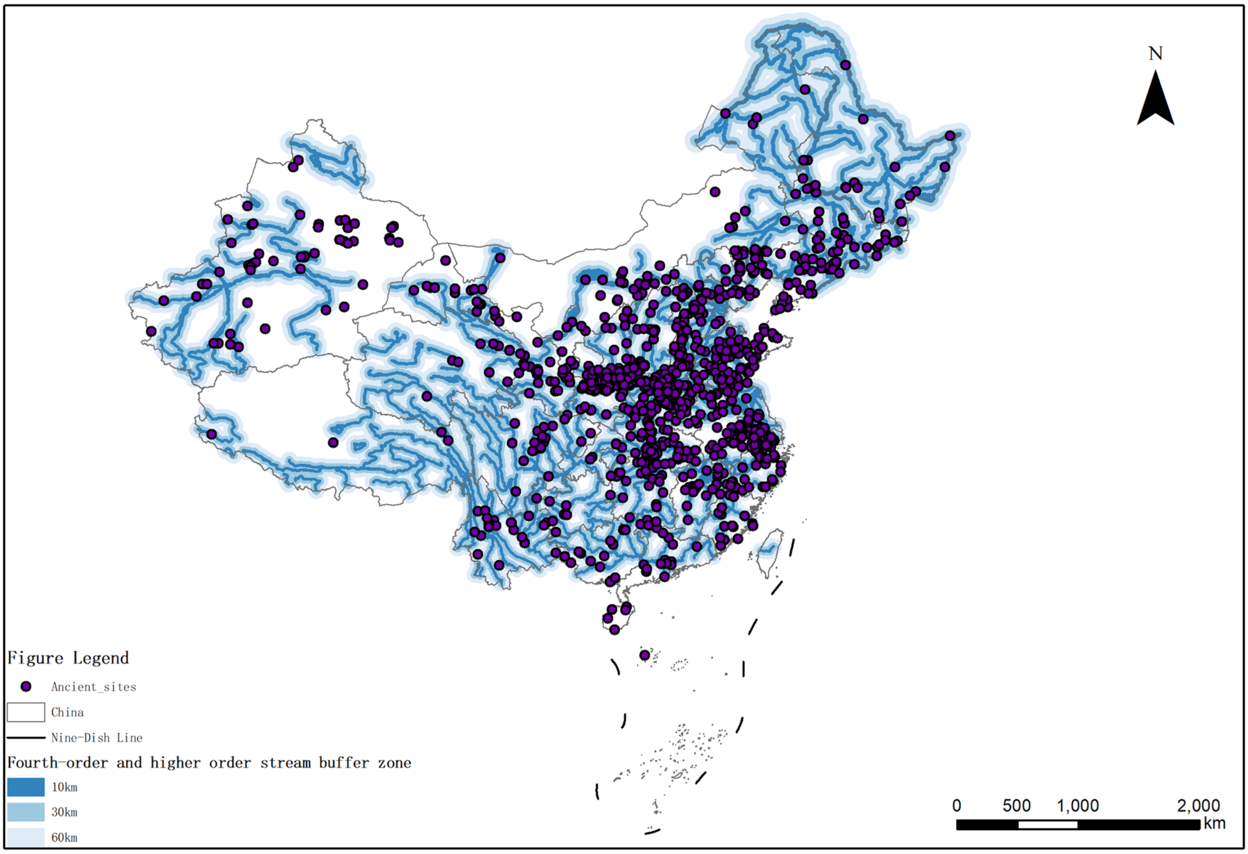

Fig. 6 Distribution of ancient sites in the buffer zones of fourth-order and higher-order river's

carriers of human activities and cultural exchange [24], reflect the characteristics of climate change through changes in their quantity and types.

Agriculture

China was one of the first countries to cultivate crops. The ancient agricultural economy was crucial in the development of ancient Chinese society as it served as the main source of fiscal revenue for ancient feudal dynasties. However, natural disasters and human activities could greatly damage agricultural economies since small-scale farms were highly vulnerable to these events. Therefore, the rulers of various dynasties, who relied on this economy to support their governance, attached great importance to and protected agricultural development. The rulers often managed small-scale farming economies through measures such as encouraging land reclamation, compiling agricultural literature, developing agricultural water conservancy, and implementing land taxation policies. In the "Book of Rivers and Canals", Sima Qian mentioned the experiences of the ruling class in water management from the Xia Dynasty to the Western Han Dynasty, as well as the situation of water conservancy construction throughout the country. Over time, ancient people progressed in terms of cultivation methods and agricultural tools, which enabled cultivation areas to expand to higher altitudes. From the Wei and Jin Dynasties onwards, the southern region underwent large-scale land development, resulting in an increase in cultivated land area. Consequently, the spatial distribution of ancient sites also changed accordingly.

Politics

The distribution of ancient sites is closely intertwined with the political environment. During periods of effective governance and stability, with the country enjoying peace and prosperity, the number of ancient sites tended to increase. Conversely, during times of political turmoil, frequent warfare, and societal distress, the number of ancient sites often decreased. For instance, during the Qin and Han Dynasties, when the political situation was relatively stable compared to that during the Wei-Jin and Northern and Southern Dynasties, there were more ancient sites. The impact of the political environment on the distribution of ancient sites is also evident in the hierarchical nature of ancient site resources.

For example, ancient capital city sites such as the Han Dynasty's Chang'an served primarily the ruling elite and represented the authority of the rulers. The ruling class often invested essential human, material, and financial resources in their construction, resulting in an unparalleled scale and richness of content compared to other sites. Moreover, national policies throughout history also greatly influenced the distribution of ancient sites. For instance, to safeguard borders, some rulers often constructed numerous military facilities in border regions. For example, during the Tang Dynasty, a military defence system was established in Xinjiang, known as the Chang Ji Prefecture Beacon Towers, which helped maintain stability in the Western Regions. Consequently, a larger number of military sites are preserved in border regions. Additionally, rulers sometimes implement policies such as "settling the frontier with migrants" to consolidate frontier areas, thereby contributing to the increase in the number of ancient sites in border regions.

Discussion and conclusion

Based on data from ancient sites within national cultural heritage areas and utilising spatial analysis methods in ArcGIS to study the temporal and spatial distribution patterns of these sites and their influencing factors, the following three conclusions were drawn:

(1) The distribution of ancient sites demonstrates an agglomerative spatial distribution pattern. The nearest neighbour index ($R < 1$) for sites from historical periods indicates an agglomerative spatial distribution for sites across historical periods, with the clustering degree being relatively poor for sites from the Wei-Jin, Northern and Southern Dynasties, as well as the Ming and Qing periods. The regions with a high concentration of ancient sites are the middle and lower reaches of the Yangtze River and Yellow River Basins. Furthermore, there is a higher abundance of ancient sites in the southeastern region than in the northwestern region.

(2) The distribution of ancient sites is uneven across historical periods. Overall, the number of ancient sites in China has shown a downwards trend. Prehistoric and pre-Qin period sites account for a large proportion of the sites, while Wei, Jin, Southern and Northern Dynasties, Five Dynasties and Ten Kingdoms, and Ming and Qing Dynasty sites account for a smaller proportion. The focus of site distribution during historical periods follows a trajectory of northeast–northwest–northeast–southwest–northeast–southwest.

(3) The spatial and temporal distributions of ancient sites are influenced by multiple factors, such as social development, the natural environment, geographical elements, and economic and political factors. In plain areas, there is an absolute advantage in the number of sites, forming a typical pattern of plain-to-plain distribution. As human adaptability to the environment strengthens, human activities gradually spread to higher altitudes. Additionally, the distribution of sites exhibits hydrophilic characteristics, meaning that more ancient sites are found closer to rivers. Generally, the number of ancient sites increases as the distance to the political centre decreases and the size of the economic environment increases.

In this paper, we discuss the spatial distribution patterns of ancient sites and the corresponding influential factors; to a certain extent, this research partially addresses the shortcomings of previous research and provides a valuable reference for the future protection and proper utilisation of ancient heritage sites. However, there are limitations in its content. We relied mainly on the data of ancient sites listed in national key cultural heritage protection units. However, the data do not include research on ancient buildings, tombs, or stone carvings, and site data from provincial-municipal, and county-level cultural heritage protection units are not included in the scope of the study. Therefore, data on ancient sites are limited. In terms of the factors influencing site distribution, the inability to accurately reconstruct historical factors such as topography and rivers, including multiple changes during the Yellow River, may have negatively impacted the data, as the river in the Yellow River Basin differs greatly from the historical river; the distribution and quantity of ancient sites in the Yellow River Basin throughout history were greatly influenced by these changes. Therefore, we relied only on existing site data and geographic information for research and interpretation, which is the second limitation in terms of content.

Ancient sites are valuable to human history, as they contain profound historical heritage and showcase unique artistic, academic, and social value. Observing the dynamic evolution of the geographical locations of ancient sites in different historical periods can reveal their spatial and temporal distribution patterns and influencing factors. This approach is essential for the application and implementation of scientific research projects related to ancient sites, as well as for the protection, development, and management of ancient sites [13]. However, over the course of thousands of years, natural disasters such as floods and earthquakes, as well as human factors such as preservation negligence, land cultivation, warfare-related destruction, and illegal trafficking [24], have caused varying degrees of damage and destruction to ancient sites. Many ancient sites have disappeared from history. Among the preserved sites, during the development process, deviations in development strategies have led to issues such as excessive commercialisation. Although the government has established key national cultural heritage protection units that include these sites in the protection list and has promulgated the "14th Five-Year Plan for Cultural Heritage Protection and Technological Innovation" to establish and improve the system for site protection, the tasks of protecting, managing, and inheriting ancient sites are pressing. Therefore, based on the differentiated characteristics of site distributions and the problems, we propose the following suggestions.

1. The government needs to improve the legal mechanisms for cultural heritage protection, increase funding for the protection and restoration of cultural relics, ensure balanced planning of land resources to accommodate both economic development and site preservation, cultivate many highly skilled professionals, actively apply for world-class cultural heritage projects, and enhance international influence to strengthen the protection of ancient sites.

2. Based on the analysis of ancient site density, trend surface analysis, and spatial clustering, ancient site resources can be divided into high-density areas, medium-density areas, and low-density areas. To overcome administrative barriers within each region, efforts should be made to achieve coordinated protection and development through regional cooperation. By mobilising the advantages of ancient sites in various provinces within each region and creating boutique tourism routes according to certain standards, the transformation and upgrading of industries within the region can be promoted to achieve mutual benefits.

3. The rational use of scientific technologies such as spatial archaeology (SA), metauniverse [25–27], PJM [28–30], VR, and AR can assist in archaeological site-related work. During the excavation process of archaeological sites, technologies such as SA and GIS can be used to locate sites, facilitating the excavation and protection of ancient sites. In terms of site management, site information can be integrated, and a digital archive of sites can be established, creating globally shared digital resources. Furthermore, in terms of heritage conservation and development, technologies such as 3D modelling, VR, and digital projection can be utilised to reconstruct sites beyond the limitations of the real world. Additionally, by integrating cultural elements, high-end site cultural industries can be developed. Through cross-disciplinary integration with cultural industries such as animation, performing arts, and catering, the cultural product system of ancient sites can be enriched, increasing visitors' expectations for heritage tourism. Furthermore, leveraging new media platforms such as Douyin and Kuaishou for public interaction can enhance the influence of cultural sites. Finally, improving site risk assessment and prevention is necessary. Strengthening the prediction and assessment of potential risks such as earthquakes, extreme rainfall, and rising sea levels can minimise threats to ancient sites.

Finally, we must recognise that the protection of sites is not solely the responsibility of certain groups or projects. As a shared cultural asset of society, protection should be normalised for the public than considered an elite endeavour and integrated into collective memory. This means promoting site protection within public communities and involving more people in the preservation and inheritance of ancient sites [31].

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Author contributions
Xiaojia Li completed the paper, including the collection and analysis of the data, the preparation of the figures, and the independent writing and review of the manuscript.

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Declarations

Competing interests
The authors declare that they have no competing interests.

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