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Analysis of the relationship between the temporal and spatial evolution of henan grotto temples and their geographical and cultural environment based on GIS

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Abstract

Grotto temples in Henan Province, which began in the Northern Wei Dynasty and ended in the Republic of China, have been excavated and repaired to varying degrees in the Sui, Tang, Song, Yuan, Ming and Qing dynasties. In this study, 119 grotto temples sited in Henan Province were considered as the research object, and the spatial and temporal distribution of grotto temples in Henan Province is analyzed by using the method of quantitative geographic analysis and ArcGIS 10.5 software. The analysis results indicate that the grrotto temples (including cliff statues) in Henan Province tend to have a cohesive distribution, with uneven regional distribution, mainly concentrated in the western and northern regions of Henan. The distribution direction and center of the grotto temples (including cliff statues) did not change much during the Northern Dynasties, Sui and Tang dynasties, and Song and Yuan dynasties, mainly distributing in the northwest of Henan. However, the situation underwent significant changes and began to migrate to south of Henan, reflecting the changes the changes in the political and cultural center at that time. The spatiotemporal distribution of the cave temples (including cliff statues) was based on the related topography, river systems, stratigraphic lithology, road traffic, and was direct or indirect influenced by the authorities as well.

Keywords Grotto temple (including cliff statues), Spatial statistical analysis, Geographic information system, Space–time distribution and evolution, Henan province, Natural environment

Introduction

The sinicization of Buddhism holds an important position in the entire development and evolution of Buddhism, receiving numerous attention in this research since there are two branches of Buddhism that are directly related to sinicization in the existing three branches—Han Buddhism and Tibetan Buddhism [1]. Henan Province plays an extremely important role in the entire evolution process. Since its introduction to China, Buddhism has had the imprint of Henan Province. Baima Temple–the first Buddhist temple in China was located in Luoyang City Henan Province, where the earliest Han Buddhist monk received ordination [2]. The birthplace of Chan Buddhism, Shaolin Temple, is located in Dengfeng City Henan Province [3]. Therefore, the sinicization and dissemination of Buddhism are closely related to Henan. The main reasons should be that Henan Province has been the center of Chinese politics, economy, and culture since ancient times, especially from the Han Dynasty to the Song Dynasty; Henan Province is constantly influencing the dissemination and development of political culture on the land of China. In addition, Henan Province is located in the Central Plains region and has a rich geographical environment: the Taihang Mountains, the

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Dabie Mountains, the Yellow River, and the Huai River pass through the province, and the eastern plain has fertile fields for thousands of miles [4]. The impact of such a unique environment on the evolution and dissemination of Buddhism in China has also attracted increasing numbers of scholars to study [5, 6].

Amongst Buddhist research, it is usually based on Buddhist scriptures, texts, paintings, statues, and architecture. The grotto temple is a collection of architecture, sculpture, murals, and calligraphy. It is not only a relic left by ancient people built for religious activities but also a true record of the relationship between humans and nature in the historical development and environmental evolution, which has significant value both in academic research and cultural heritage. The construction of grotto temples (including cliff statues) in Henan Province began around the Northern Wei Dynasty moving to Luoyang [7, 8], and the related investigation and related research of the grotto temples in Henan Province began in the late nineteenth century [9]. For a long time, academic research on the grotto temples mainly focused on the archaeological research of the grotto temples such as the periodization of the statues, solving the problems of repairing and breaking the grottos, and how repainting and research on multi-layer murals [10–12]. Additionally, there was also some research on the study of the style characteristics of the grotto temples by the art iconography [13, 14].

With the development of technology, there are more methods and equipment being applied to that research. For example, three-dimensional (3D) scanning and 3D printing were employed to protect and repair the grotto temples [15]. Furthermore, some geographical perspectives and methods were also used to study the distribution characteristics of grottoes in specific time and space [16, 17]. With the continuous development of international GIS technology, it has developed rapidly in historical research with its more systematic and spatial analysis potential [18–22]. In recent decades, GIS, as the most important technological innovation in archaeology, has provided an analytical tool for archaeologists [23, 24]. Combined with remote sensing technology, it also is used for longer mapping and detection of climate change and human activities around archaeological sites, as well as the impact on the sites [25]. Combined with photogrammetry, the GIS has been used in underwater archaeology for many years [26, 27]. In addition, GIS is widely used to construct a spatiotemporal model of sites by combined with big data, to analyse and study the evolution of the sites, human activities, as well as the evolution and internal relationships of society, nature, and other factors at that time [28–30]. Increasing numbers of scholars begin to apply GIS to the protection and research of cultural heritage, Buddhist landscapes, etc [31, 32]. However, there is a lack of the comprehensive research on the distribution and evolution characteristics of Grotto temples (including cliff statues) in different time and space throughout Henan Province, which could provide a comprehensive vision to understating the evolution of grotto temples in whole Henan and easier to find the dynamic details during the entire evolution.

In 2021, the State released a medium and long-term plan for the archaeology of grotto temples in China, clarifying the direction of future archaeological research on grotto temples, exploring the inherent cultural value of grotto temples, and strengthening interdisciplinary cooperation. Therefore, the collection and research of geographic information on grotto temples (including cliff statues) can be further deepened and detailed. This plan aims to conduct systematic geographic information research on grotto temples (including cliff statues) throughout the province, and then propose more comprehensive plans for subsequent protection and development, which always requires extreme long time and energy.

Herein, a simple and effective method, ArcGIS (a geographic information system (GIS) software), was employed to systematically study the distribution characteristics of grotto temples (including cliff statues) in Henan Province. Combining its natural factors to explore the reasons that affect its spatiotemporal distribution, this article analyzes the differences in its spatiotemporal distribution, as well as its historical trajectory, spatial layout, and cultural characteristics, and confirms with the political and cultural factors of relevant eras. The study of spatiotemporal distribution characteristics is a necessary prerequisite and important basis for the spatial integration and protection of historical and cultural heritage. At current, the research on the spatiotemporal distribution characteristics of grotto temples (including cliff statues) in Henan region is still rare. The related research has extremely reference significance for the spatial integration protection, value inheritance, and sustainable utilization of Henan grottoes. This study focus on the research on the spatiotemporal distribution of grotto temples (including cliff statues) in Henan region from Northern Dynasties to Qing Dynasty, revealing the relationship between the distribution of grotto temples and natural and cultural factors. In addition, the study is also conducive to a deeper understanding of the transmission routes and development changes of Buddhism, and further exploration of the roles of various factors in the process of Sinicization of Buddhism, and provide data basis for the protection, development, and research of Buddhist grottoes (main phase of this work shown in Additional file 2: figure S1).

Research methods and source of data

Data source

In this study, a total of 119 grotto temples (including cliff statues) sited in Henan Province were collected to study, including Longmen Grottoes and Qingtian River Cliff Statues. The spatial and temporal data of the cultural relics are mainly derived from the Third National Cultural Relics Census (2007–2010) and the reports on the newly discovered immovable cultural relics (ending in September 2021). The source of the data covers the situation of grotto temples (including cliff statues) in entire Henan Province from the Northern Dynasties to Qing Dynasty with good continuity and comprehensive coverage and reflecting a good correlation with the natural environment as well. However, the data source also has limitations, such as some grotto temples have undergone relocation or burial leading to the data cannot reflect the original appearance like Xiwo Temple, Pugou Grottoes. Besides, the geospatial coordinate information of the grotto temples (including cliff statues) was obtained through Google Geographic Information System and Baidu Map combined with the Records of Cultural Relics of Henan Province and the relevant records of local chronicles.

Case study

Henan, known as "Yu" in ancient times [33], is located in the center of Nine Provinces, which terrain is high in the west and low in the east. The Yellow River enters from Tongguan County, Shaanxi Province, and crosses the north of Henan. Henan is bordered by Hebei and Shanxi in the north, Hubei in the south, Shandong and Anhui in the east, and Shaanxi in the west. The province covers an area of more than 167,000 square kilometers. By 2022, Henan Province govern 18 prefecture-level cities and 21 county-level cities (including one county-level city directly under the provincial government), 82 counties, and 54 municipal districts with a permanent population of 98.83 million. According to the Chronicles of Reading History, Henan Province is located in the middle of China extending in all directions [33] and it is the birthplace of Chinese culture, and also the earliest place where Buddhism flourished in China.

In terms of the distribution of existing grotto temples and stone carvings, the study area covers the whole province (Fig. 1). In order to better fit the distribution and development of grotto temples (including cliff statues), the research region in this study was divided into western Henan Province, including Luoyang City and Sanmenxia

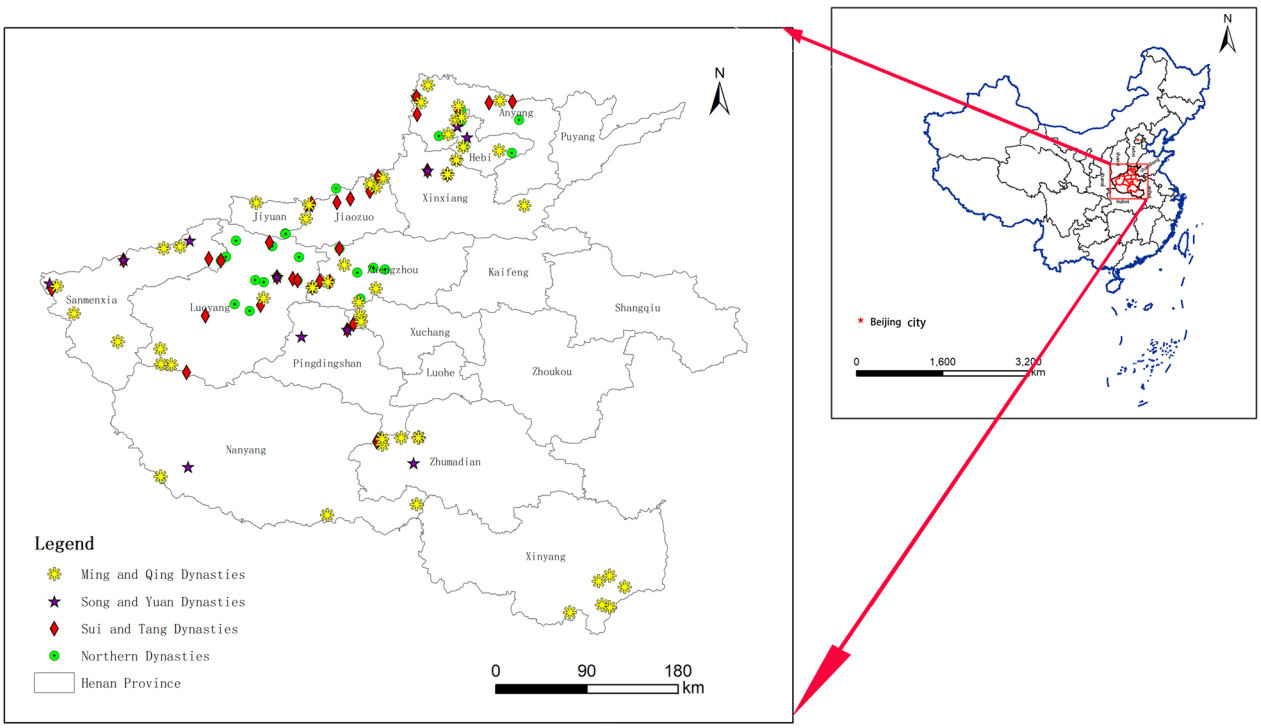

Fig. 1 Schematic of the grotto temples (including cliff statues) in Henan province

City; Central Henan includes Zhengzhou City, Pingdingshan City, Xuchang City and Luohe City; North Henan includes Xinxiang City, Jiaozuo City, Jiyuan City, Anyang City, Hebi City and Puyang City; South Henan includes Nanyang City, Zhumadian City and Xinyang City; The eastern part of Henan Province includes Shangqiu City, Zhoukou City and Kaifeng City.

GIS analysis

ArcGIS 10.5 was employed to establish the spatial distribution map of the Grottoes Temples (including cliff statues) in Henan Province to analyse the spatial and temporal distribution characteristics and evolution rules of grotto temple cultural sites. Thus, plenty of scientific computation methods in spatial statistics were utilized in this study.

Average nearest neighbor (ANN)

ANN is an index to describe the distribution of elements in a specific spatial range [34], which calculates the nearest neighbor index based on the average distance between each element and its nearest neighbor element as follows:

$$\overline{D_0} = \sum_{i=1}^{n} \frac{d_i}{n} \tag{1}$$

$$\overline{D_E} = \frac{0.5}{\sqrt{n/A}} \tag{2}$$

$$ANN = \frac{\overline{D_0}}{\overline{D_E}} \tag{3}$$

where $\overline{D_0}$ is the average value of the nearest distance of the actual measured points, $\overline{D_E}$ is the theoretical nearest distance when the elements are randomly distributed, n is the number of the elements and A is the area of the research region. ANN is the ratio of the average value of the actual measured nearest distance to the random distribution of the same number of elements in the range, reflecting the degree of the mutual proximity of geographical objects in space [35]. In this work, ANN is employed to define the spatial distribution type of Grottoes Temples (including cliff statues) in Henan. If ANN = 1, the spatial distribution of grotto temples is random. If ANN > 1, the grottoes temples should be discretely distributed in the Henan province. While if ANN < 1, the grottoes temples (including cliff statues) would be distributed agglomerative in Henan [36].

Kernel density estimation (KDE)

Kernel density is mainly used to describe the density of elements in their surrounding neighborhood [34]. Compared with the ANN describing the distribution characteristics of the elements in the whole research scope with a certain ratio, the kernel density can describe the distribution characteristics of the elements around each location in the space scope and can directly reflect the concentration and dispersion of Buddhist grottoes, cliffs and other relics in this study [37, 38]. KDE could be described as following [39]:

$$f(x) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \tag{4}$$

where *K(x)* is the non-negative kernel density function, n is the number of the elements and h is the bandwidth, (x-x_i) indicates the distance from the evaluation point x to the element x_i. In this work, the KDE is used to intuitively reflect the density of the distribution of grottoes temples (including cliff statues) in Henan Province.

Geographic concentration index (GCI)

GCI is mainly used to measure the concentration degree of the spatial distribution of geographical elements, which could be calculated as follows [40]:

$$G = 100\sqrt{\sum_{i=1}^{n} \left(\frac{X_i}{T}\right)^2} \tag{5}$$

where X_i is the number of grotto temples owned by the i^{th} prefecture-level city in Henan Province, T is the total number of grotto temples (including cliff statues) in Henan Province, and n is the total number of the prefecture-level cities in Henan Province. The larger the G value is, the higher the concentration degree is. Assuming the average distribution of grotto temples in the province, the value of the GCI is $G_0 = 100/\sqrt{n}$. When $G > G_0$, it means centralized distribution, otherwise, it means dispersion.

Inequality index

Inequality index is employed to qualify the degree of difference in the proportion of elements in the group, which would be significant to reflect the balanced distribution of grotto temples in various cities of Henan Province. The inequality index (S) could be calculated as following [41]:

$$S = \frac{\sum_{i=1}^{n} Y_i - 50(n+1)}{100n - 50(n+1)} \tag{6}$$

where n is the total number of the prefecture-level cities in Henan Province, Y_i refers to the cumulative percentage of the number of grotto temples in cities at all levels in the i^{th} place of the total number of grotto temples in the region, in which the percentage of each prefecture-level city is ranked from the largest to the smallest. The value of the inequality index S is between 0 and 1. If $S=0$, it indicates that the elements are evenly distributed in each city. If $S=1$, it means that all the elements are gathered in one city.

Spatial and temporal evolution and distribution characteristics

Spatial distribution characteristics

Distribution characteristics

The spatial distribution of grotto temples (including cliff statues) in Henan Province shows the trend of agglomeration: the *ANN* calculated by ArcGIS 10.5 is 0.62 and $ANN<1$, indicating that the grotto temples (including cliff statues) in Henan Province present a typically agglomerative distribution. The kernel density of grotto

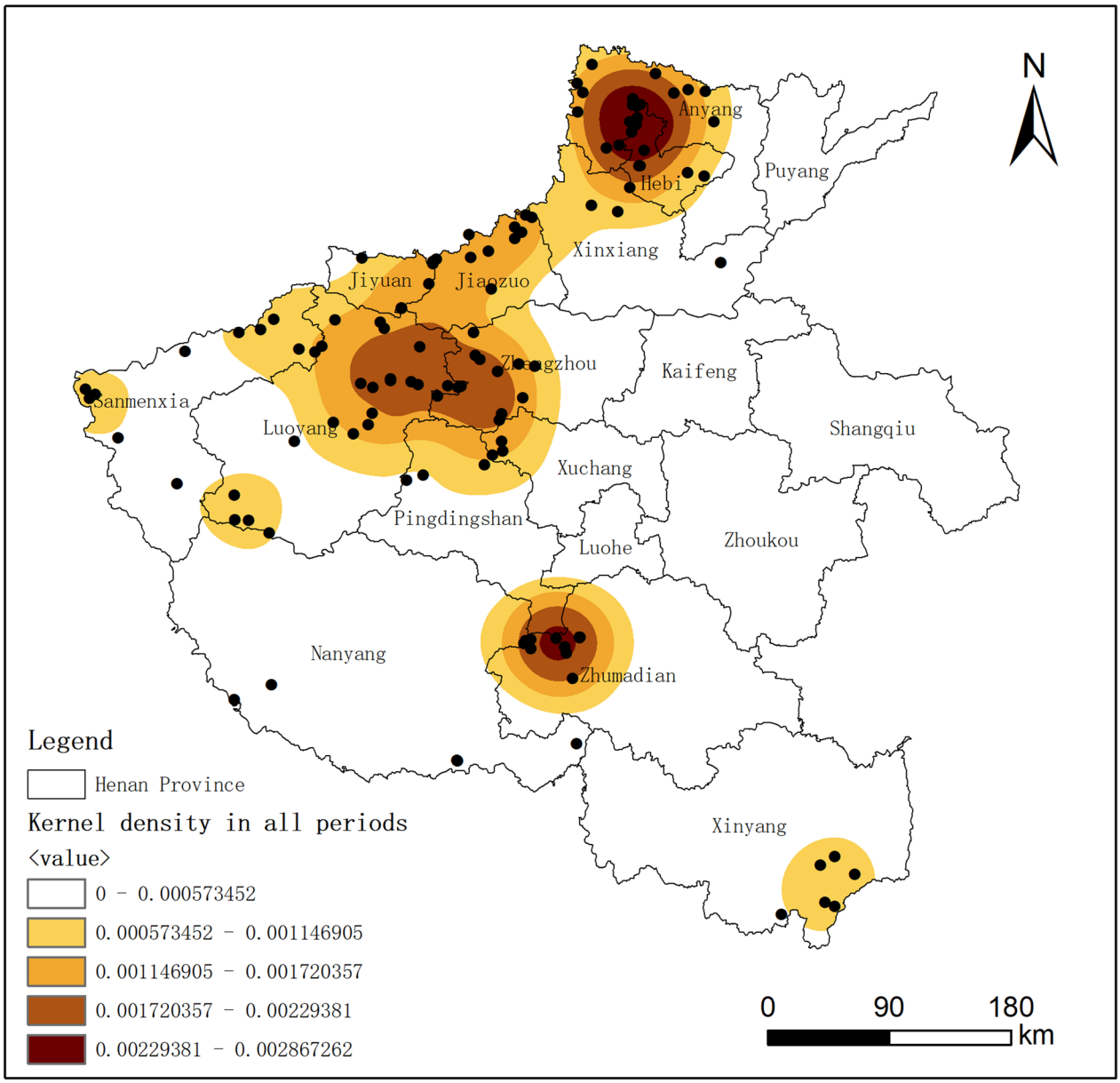

Fig. 2 Kernel density of the grotto temples (including cliff statues) in Henan province

temples (including cliff statues) in Henan Province was further analyzed and a kernel density map (shown as Fig. 2) was generated. As shown in Fig. 2, the spatial distribution density of grotto temples (including cliff statues) in Henan Province is significantly different, forming three high-density core areas respectively centered around Luoyang city, Anyang city and Zhumadian city, and four sub-density areas including Sanmenxia city, Hebi city, Jiyuan city, Zhengzhou city. Besides there are also several other scattered areas. To further confirm the agglomerative distribution, the geographical concentration index (G) was also employed to study the distribution of the grotto temples. There are 119 grotto temples (including cliff statues) distributed in 18 prefecture-level cities in Henan Province, and $G=32.05$ is calculated according to Eq. 5, while the theoretical geographical concentration of each city is $G_0=23.57$. $G>G_0$, it demonstrates the grotto temples (including cliff statues) at the municipal level are concentrated.

The formation of such zones in the grotto temples (including cliff statues) in Henan Province is inseparable from the natural environment. The terrain of Henan Province is high in the west and low in the east, surrounded by mountains in the north, west and south, and flat in the east. The water system and rivers in the province are relatively complex. The Yellow River and the Beijing-Hangzhou Grand Canal pass through the plain region of Henan Province, while the middle and small rivers originate from the mountainous areas and flow radially to whole province. Therefore, it provides three natural environments conducive to the construction of grotto temples in western, northern and southern Henan, and forms a distribution trend centered on these three places.

Analysis of spatial distribution balance

The inequality index reflects the balanced distribution of the number of grotto temples (including cliff statues) in the whole province. All the 18 cities in Henan Province are divided into five regions according to geographical division (show as Fig. 3). According to the figure, it is direct to find the distribution is now even as some cities have no grotto temples remaining. Especially, there is zero grotto temple (including cliff statues) remaining in all the east Henan. Statistical data show that grotto temples are the most distributed in northern and western Henan, accounting for 36.1% and 27.7% respectively. According to Eq. 6, the inequality index is calculated as $S=0.535$ which is for the distribution of grotto temples (including cliff statues) in the whole province, indicating that the distribution of grotto temples (including cliff statues) is uneven in the whole province. The distribution curve of grotto temples (including cliff statues) is generated according to the statistical data (Fig. 3). According

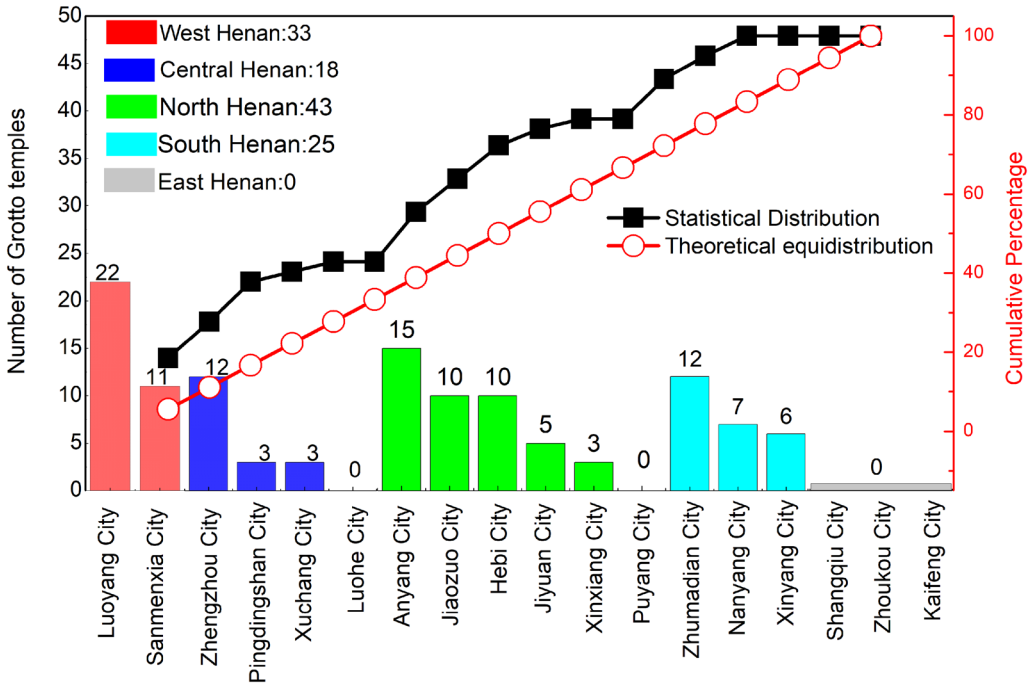

Fig. 3 The distribution number and cumulative percentage of grotto temples in cities

to the comparison between the actual distribution curve (black line with black square) and the theoretical equi-distributional curve (red line with red circle), the curve of statistical distribution rises in steps which indicates that the distribution of grotto temples (including cliff statues) in every cities is uneven. Especially in Luoyang City, Anyang City, Zhengzhou City, Zhumadian City and Sanmenxia City, each of them has more than 10 grotto temples (including cliff statues) and the total proportion of grotto temples (including cliff statues) is 60.5%, while in Kaifeng City, Puyang City, Luohe City, Shangqiu City and Zhoukou City, there are not existing grotto temples (including cliff statues) in those five prefecture-level cities.

Spatial distribution characteristics

Overall timing variation characteristics

Buddhist grotto temples began in India, first prevailed in the northwest after being spread to the east and did not appear in Henan until the Northern Dynasty. Buddhist grotto temples began in India, first prevailed in the northwest after being spread to the east and did not appear in Henan until the Northern Dynasty. In order to facilitate the study, the excavation period of grotto temples (including cliff statues) in Henan Province was divided into four stages: the Northern Dynasty, the Sui, Tang and Five Dynasties, the Song and Yuan Dynasties, and the Ming and Qing Dynasties. The number of grotto temples (including cliff statues) has changed significantly at each stage, and the growth of the number is uneven. In the four historical periods, expecting for five statues of unknown time, the largest number of statues in the Ming and Qing Dynasties was 51, accounting for 42.9%, while the smallest number was in the Song and Yuan Dynasties, with only 15, accounting for 12.6%. In addition, there were 26 places (23.6%) in the Northern Dynasty and 22 places (18.5%) in the Sui, Tang and Five Dynasties. The number of grotto temples (including cliff statues) in Henan Province during these four periods present a trend of high-low–high.

Comparing the distribution characteristics of grotto temples (including cliff statues) in different periods, it is found that the distribution characteristics of Buddhist remains in the Northern Dynasty, the Sui and Tang Dynasties are relatively consistent, and a considerable part of the grottoes were excavated from the Northern Wei Dynasty and preserved until the Sui and Tang Dynasties. Although the number of grotto temples (including cliff statues) in the Ming and Qing dynasties was large, most of the grotto niches chose natural caves, which were slightly trimmed, and the size of which was far less than that of the Northern Dynasties, the Sui and Tang dynasties. In addition, the number of grottoes and cliffs in the Song and Yuan Dynasties was the smallest and all of them were small-scale.

The number of grotto temples (including cliff statues) in different historical periods is closely related to the historical development of Henan Province. As well know, Henan Province has a long history, which is the birthplace of the Chinese culture and has thousands of years of historical civilization. Buddhism has prevailed in the Han Dynasty, and the grotto temples ware began to excavate near the capital after moving the capital to Luoyang in Northern Wei Dynasty. Therefore, there are a large number of large-scale grotto groups left in Henan Province from the Northern Dynasty. Although Henan was no longer the capital city in the Ming and Qing dynasties, the grotto temples (including cliff statues) in the province once again ushered in a peak period due to its special geographical location and convenient transportation. Tens of thousands of stone sculptures remained in these grottoes, fully confirming the important historical positioning of Henan as the development of Buddhism.

Distribution characteristics in different periods

Spatial distribution characteristics during the Northern Dynasty The opening of grotto temples in Henan province began in Northern Dynasty period. The niche of Lady Yuchi in the 19th year of Taihe in the Guyang Cave of the Longmen Grottoes is the earliest stone sculpture known to date in Henan Province [42]. Since then, large-scale cave opening activities have begun in Henan Province, leaving a large number of cultural relics. The nearest neighbor distance index of Grotto Temple (including cliff statues) in the Northern Dynasty is ANN = 0.56, 0.56 < 1, showing the characteristics of spatial agglomeration. According to the distribution of Kernel density during the Northern Dynasty (shown as Fig. 4a), the agglomeration characteristics is obvious, mainly distributed in the west and north of Henan Province, that is, in three points around today's Luoyang city, Zhengzhou city and Anyang city. It was centralized in these three areas, but none in other cities. Furthermore, the kernel density around Luoyang city is the highest. After the Northern Wei Dynasty moved its capital to Luoyang, the royal nobles dug the Longmen Grottoes near the capital [43]; while the Eastern Wei Dynasty moved the capital to Yecheng (near today's Anyang city), the royal family immediately started a new round of cave statues around the new capital [44]. It can be seen that the grotto temples (including cliff statues) of the Northern Dynasty were distributed around the capital city.

Spatial distribution characteristics of Sui, Tang and Five Dynasties During the Sui, Tang and Five Dynasties, the nearest neighbor distance index of grotto temples (including cliff statues) is $ANN = 0.69 < 1$, which was still char-

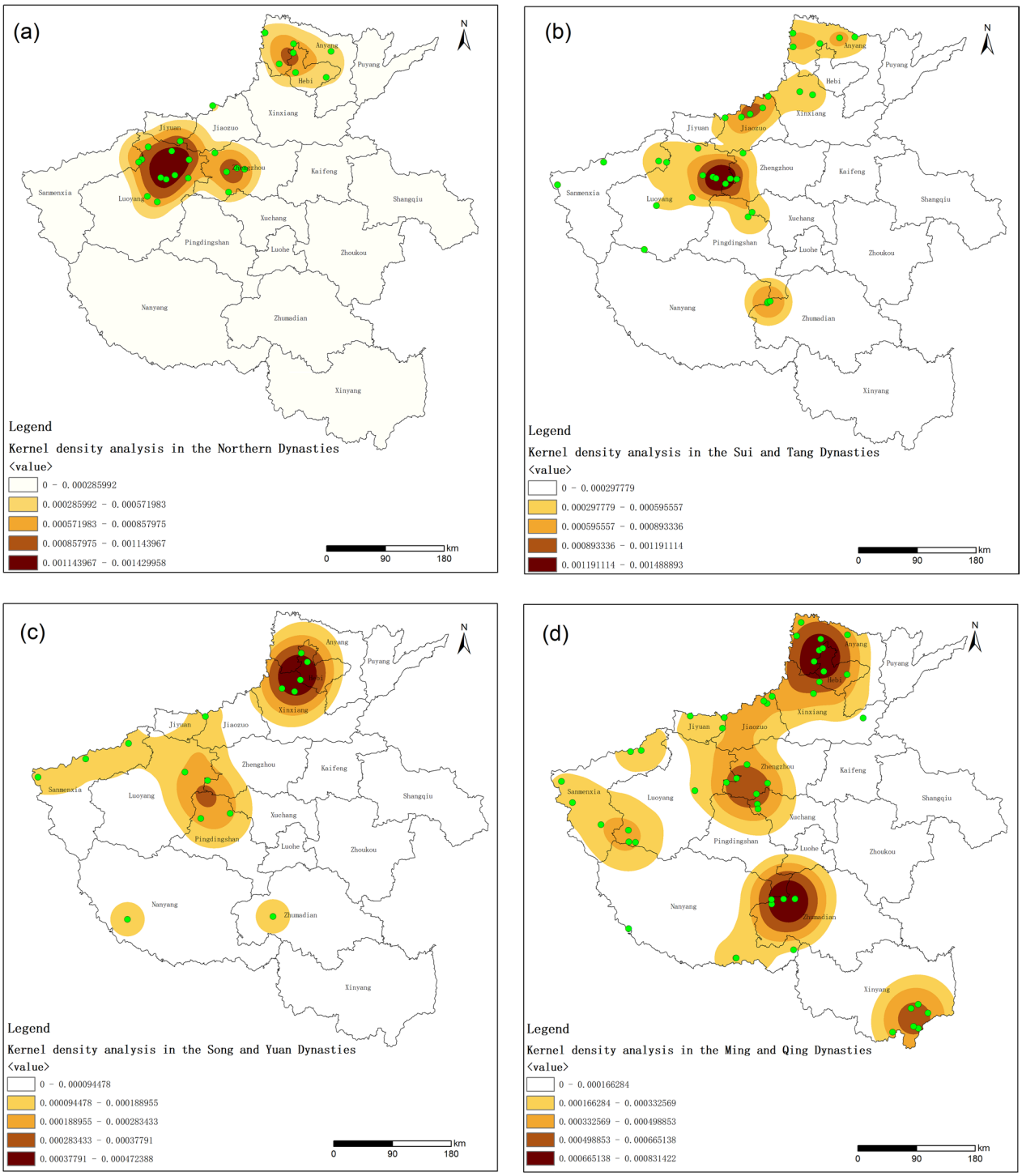

Fig. 4 Kernel density of grotto temples in Henan province of **a** northern dynasty, **b** Sui, Tang and five dynasties, **c** Song and Yuan dynasties, **d** Ming and Qing dynasties

acterized by spatial agglomeration, covering from western and northern Henan to southern Henan. According to the distribution of the kernel density in the Sui, Tang and Five Dynasties (shown in Fig. 4b), the grotto temples were multi-centre distribution. The center areas were the junction of Zhengzhou City and Luoyang City, the area around Jiaozuo City, and the area between Nanyang City and Zhumadian City. Compared with the distribution of Northern Dynasty, the distribution scope became larger in Sui, Tang and Five Dynasties. Expect for some new-excavate grotto temples and cliff statues, plenty of the grotto temples built in Northern Dynasty was continued to be rebuilt and extended in this period. During the Sui and Tang Dynasties, Luoyang was still the regional political and cultural center. With the opening of the Beijing-Hangzhou Grand Canal, the traffic and communication in Kaifeng, Zhengzhou, Jiaozuo, Xinxiang, Anyang and other places along the Yellow River have become more convenient. The Grand Canal had promoted the economic and trade development and urban prosperity along the line, but also stimulated the development of Buddhism. After Empress Wu moved her capital to Luoyang, Buddhist activities became more prosperous, such as the Longmen Grottoes, which had reached its peak in the Tang Dynasty [45]. At this period, the radiation scope of the grottoes gradually spread to the south, indicating that the grottoes became gradually more common and popular in Henan Province.

Spatial distribution characteristics of Song and Yuan Dynasties During the Song and Yuan Dynasties, the number of grotto temples (including cliff statues) do not increase much. The nearest neighbor distance index is ANN = 1.32 > 1, and the spatial distribution was discrete. Shown as in Fig. 4c, the grotto temples presented a discrete point distribution, mainly concentrated in the North of Henan Province with Anyang city as the center. In addition, the intersection of Zhengzhou city and Luoyang city is the sub-center, and several other places are scattered around Nanyang and Zhumandian. From the perspective of the distribution area, it is roughly the same as that of the Sui and Tang dynasties, and the density is lower than that of the Sui and Tang dynasties, which is related to the existing quantity of the grotto temples from this period. The Northern Song Dynasty was a period of political, economic and cultural prosperity in Chinese history, but the remains of the grotto temples were not many. The main reason is that the Northern Song Dynasty developed the Confucian school of idealist philosophy of the Song and Ming dynasties, Taoism Flourished and Buddhism developed slowly at this time. In addition, Kaifeng, the capital city, is located in the East Henan Plain, adjacent to the Yellow River, which has been plagued by floods of the Yellow River in history [46], and it is difficult to preserve the ground buildings.

Spatial distribution characteristics of Ming and Qing Dynasties In the Ming and Qing dynasties, the nearest neighbor distance index of grotto temples (including cliff statues) is ANN = 0.79 < 1, showing a certain degree of agglomeration in spatial distribution. According to the distribution of kernel density in the Ming and Qing Dynasties (Fig. 4d), the remains of the grotto temples in this period were distribute in multi-center. The most obvious three core area were the area covering Xinxiang, Jiyuan and Jiaozuo with Anyang as the core, the intersection area of Zhumadian and Nanyang, as well as the southern area of Xinyang City. Moreover, the surrounding area of Sanmenxia City and the urban area of Zhengzhou City also show relatively obvious dense distribution. Furthermore, Grotto temples (including cliff statues) in the Ming and Qing dynasties were more widely distributed than in the historical period. Except for Kaifeng city, Zhoukou city, Shangqiu city and Puyang city, grotto temples are almost all over the province. At this time, there are a large number of Buddhist cultural relics at all major traffic routes in the province.

Analysis of distribution direction characteristics in different periods

The standard deviation ellipse tool (installed in ArcGIS 10.5) was employed to summarize the center, distribution and direction of grotto temples (including cliff statues) [47]. In the calculation results of the standard ellipse, the long axis of the ellipse represents the direction of data distribution, and the short axis represents the main range of data distribution. The overall distribution direction and trend of the grotto temples (including cliff statues) in different historical periods in Henan Province are calculated through the standard ellipse difference (Fig. 5). From Fig. 5, there are obvious difference in the spatial distribution of grotto temples (including statues) in different historical periods in Henan Province. The central position of grotto temples (including cliff statues) in the Northern Dynasties, Sui and Tang Dynasties and Song and Yuan Dynasties has changed little, and the dominant direction is northwest, mainly concentrated in western and northern Henan with Luoyang and Anyang as the core. Although the distribution direction of grottoes (including cliff statues) in the Sui and Tang Dynasties is the same as that in the Northern Dynasty, the short axis of the ellipse is longer than that in the Northern Dynasty, indicating that the coverage has expanded. In the Song and Yuan Dynasties, the distribution direction of grotto temples (including cliff statues) also showed a trend of northwest in general, but the length of the major axis of

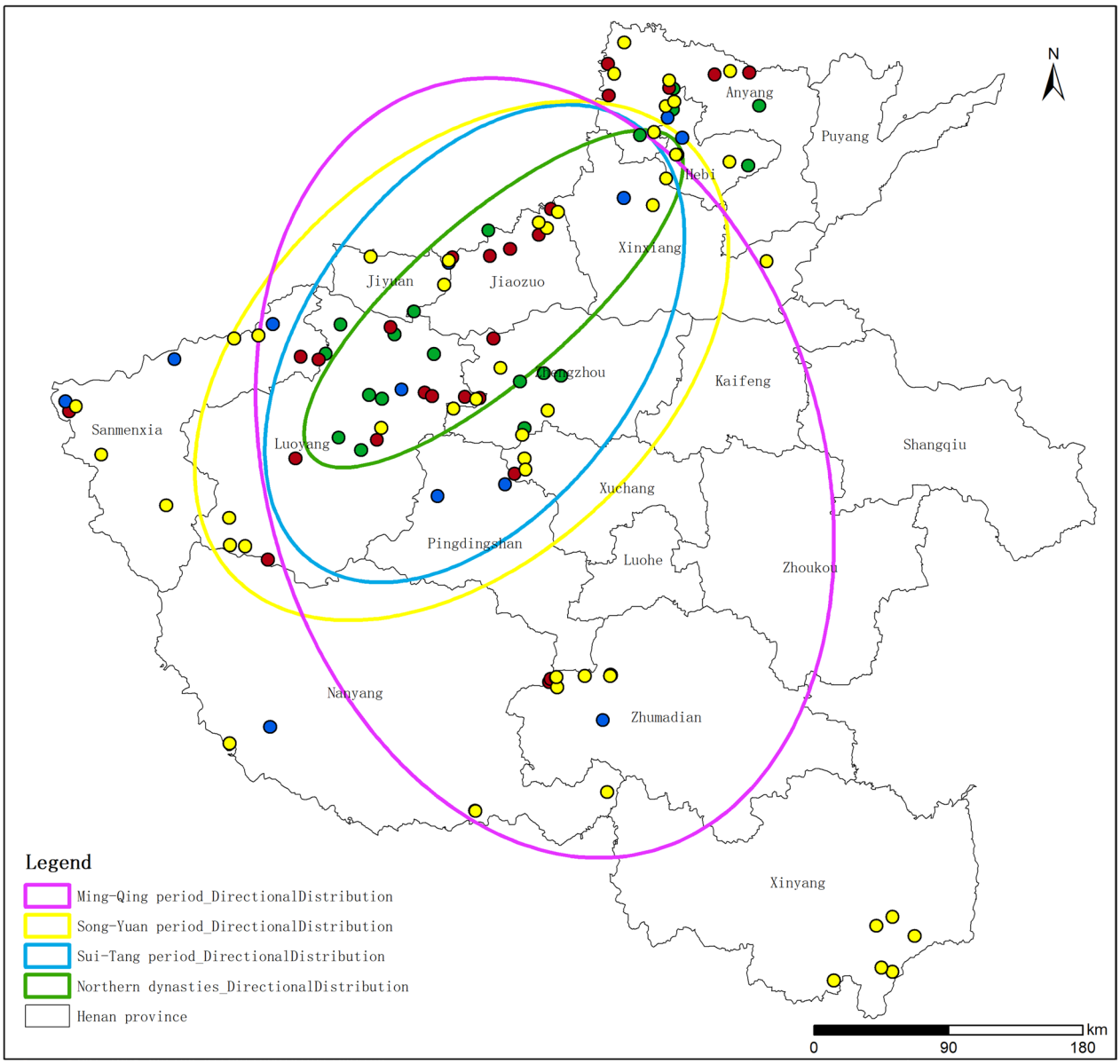

Fig. 5 Picture of standard deviation ellipse result of the grotto temples distribution changes in different periods

the ellipse increased significantly and the spatial scope was wider. During the Ming and Qing dynasties, the ellipse direction changed greatly, and the ellipse direction changed and spread south-west. The long axis was longer and fluctuated southward in Zhumadian and Xinyang areas. It demonstrated that the coverage of the distribution in Ming and Qing Dynasties was wider than in previous periods.

Analysis of center of gravity shift in different periods

The analysis of center migration can reflect the spatiotemporal evolution of the distribution of grotto temples (including cliff statues) in Henan Province [48], which also reflected the distribution centre of Buddhism in different historical periods. According to the calculation of the center migration (shown in Fig. 6), it can be found that the central locations of grotto temples (including the cliff statues) in the Northern Dynasty, Sui and Tang Dynasties, and Song and Yuan Dynasties changed very littles, mainly around Luoyang and Jiaozuo in the northwest of Henan province. Until Ming and Qing Dynasties, the center had undergone major changes and gradually shifted from the northwest to the south of Henan Province.

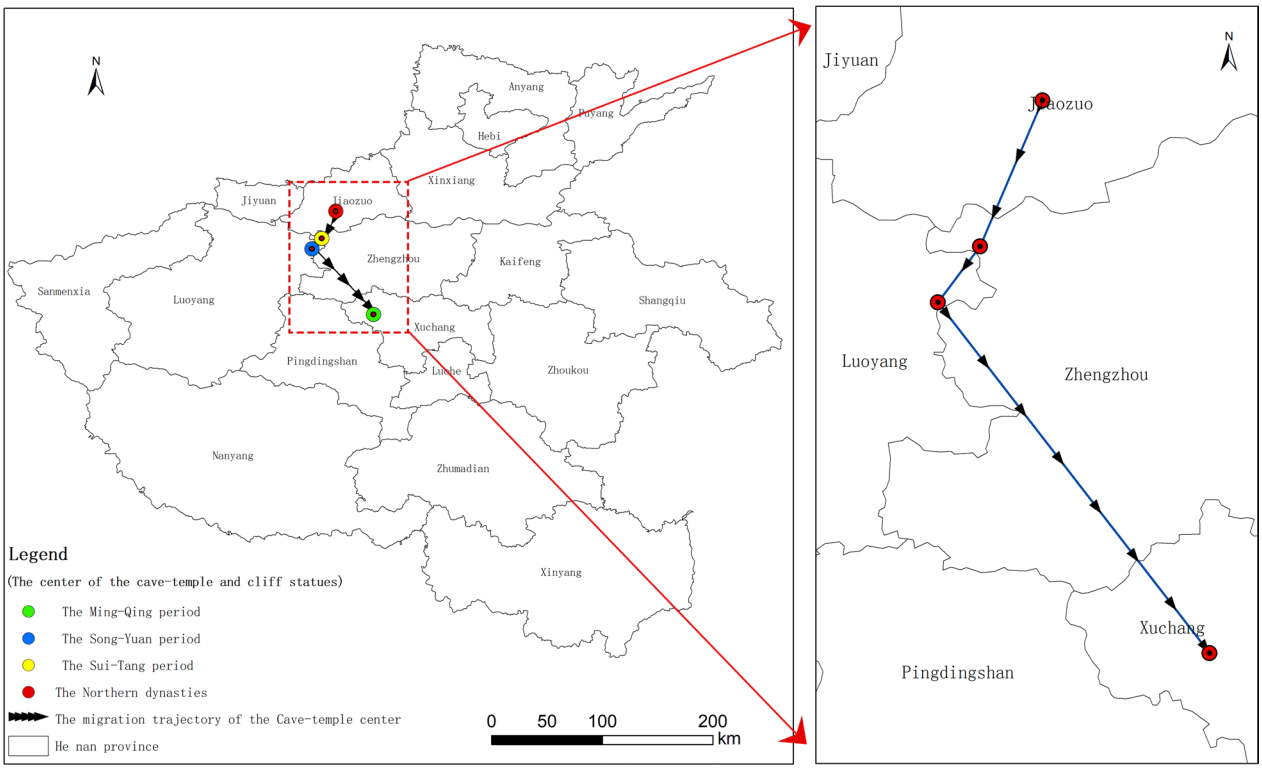

Fig. 6 Picture of the distribution center migration with the dynasties change

Influencing factors of the distribution

Geographical factors

Henan Province is located in the transition zone between Loess Plateau with edge formed by Taihang Mountains and North China Plain, with rich landforms, high in the west and low in the east, surrounded by mountains in the north, south and west, and plain in the east. This landform has a great impact on the spatial distribution of grotto temples (including cliff statues) in Henan Province [49]. The distribution map of grotto temples (including cliff statues) in Henan Province is calculated using the 90 m elevation data of Henan Province (Fig. 7a). As shown in Fig. 7a, 85 grotto temples (including cliff statues) in Henan Province are distributed between 179 and 732 m above sea level, accounting for 71.4% of the total (119 grotto temples and cliff statues). This altitude provides abundant stone resources for the cave opening statues [50], which is also conducive to manual excavation and is also convenient for Zen monks to live. With the elevation of more than 800 m, the number of grotto temples gradually decreases. According to statistics, there are 6 places with an altitude of more than 1000 m, accounting for only 5%. The highest elevation is the Cheyu Thousand Buddha Cave at Cheyu Village, Guxian Town, Lingbao City, with an altitude of 1705 m, followed by the Lingshan Cave Grottoes at Wangwu Mountain, with an altitude of 1615 m. However, the lower elevation areas of the eastern Henan Plain, such as Puyang, Shangqiu, Kaifeng, Zhoukou and other places, not only do not have the physical conditions to excavate grottoes and cliff statues, but also the ground temple buildings are difficult to preserve because they are located in the flood area of the Yellow River, so the remains of the grotto temples are almost blank.

The slope reflects the index reflecting the undulation of the terrain. The terrain of Henan Province is complex and diverse, and the overall terrain is high in the west and low in the east. Through the analysis of the slope data of grotto temples (including cliff statues) in elevation (Fig. 7b), it can be seen that, on the whole, grotto temples (including cliff statues) in Henan Province are concentrated in small slope areas. There are 59 places in the 8–10° range, which are concentrated in Zhengzhou City, Jiaozuo City, Hebi City, Anyang City, Pingdingshan City and Xinyang City, accounting for 49.6% of total grotto temples (including cliff statues) in Henan Province. There are 45 places in the 10–25° range, accounting for 37.8%, which are concentrated in Luoyang City, Sanmenxia City, Nanyang City and Jiyuan City. The number of grotto temples in the 1–5° range is 15 places and mainly located in Zhumadian City and Xuchang City. In addition, the flat terrain or too steep area are not distributed.

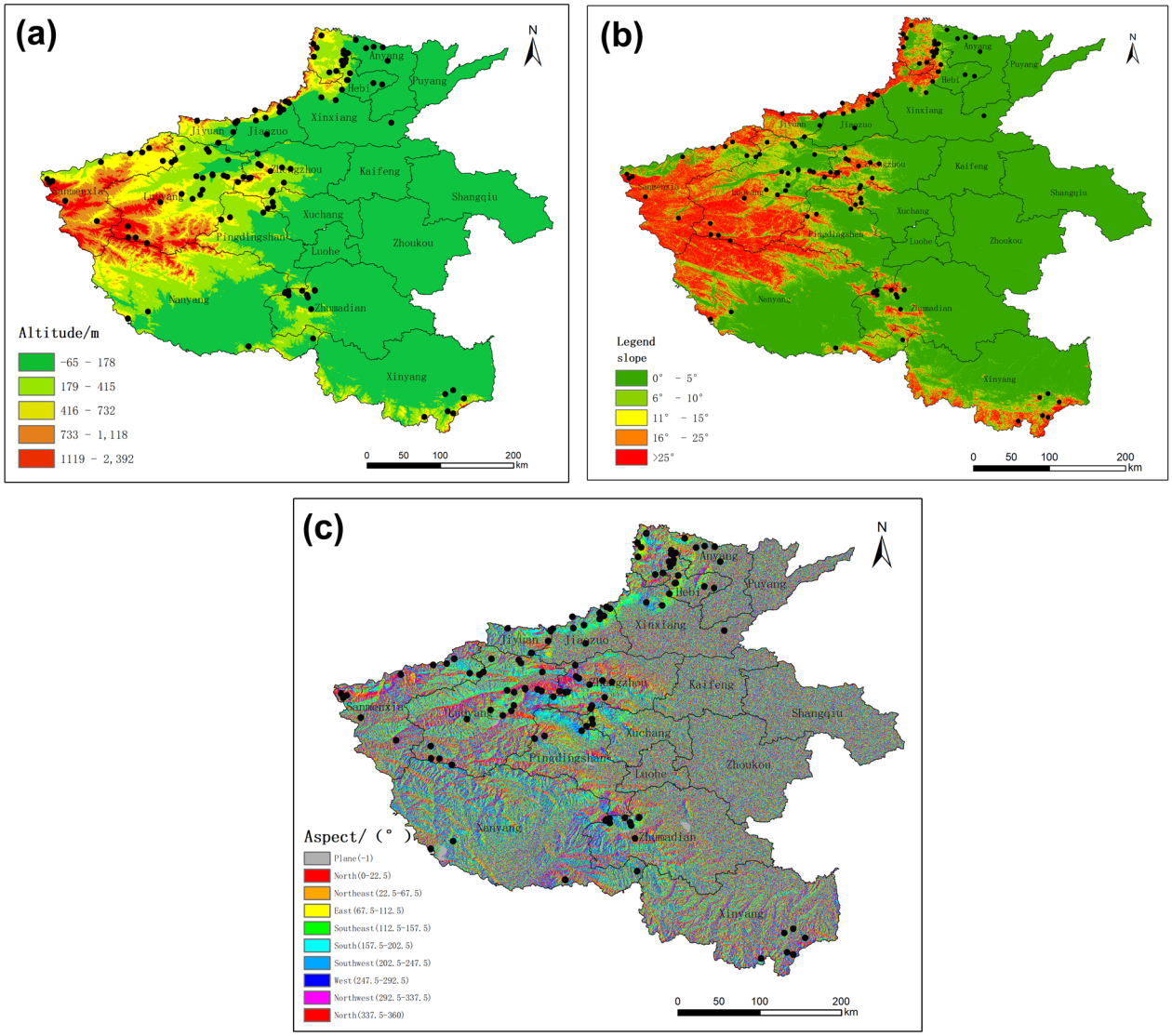

Fig. 7 Schematic of grotto temples (including cliff statues) distribution affected by the **a** geographic attitude, **b** angles of slope, and **c** direction of slope

The slope direction reflects the orientation of the local surface in the three-dimensional space and is directly related to the duration and intensity of the sunshine. China is located in the northern hemisphere. From the perspective of sunshine, the slope direction is due south, the southwest belongs to the sunny slope, and the southeast and the west belong to the semi-sunny slope [51]. Both can get enough sunlight and are suitable for living. According to the slope direction diagram of grotto temples (including cliff statues) (Fig. 7c), grotto temples (including cliff statues) in Henan Province are mostly distributed on the sunny and semi-sunny slopes, because grotto temples are used to support a good place for monks to practice meditation [52].

Table 1 Distribution of grotto temples and river buffer zones in Henan province

Distance/km	2	4	6	8	10	> 10
Numbers	17	29	17	14	11	31
Accumulated proportion	14.3	38.7	52.9	64.7	73.9	100

River system

Water Source is the main one of the factors affecting the spatial distribution of grottoes temples (including cliff statues) [53, 54]. GIS is used to draw the distribution map of the river buffer zones and the grottoes temples (including cliff statues) in Henan Province and analyse river buffer area by considering the distance to the riverbanks from 2km, 4 km,6 km,8 km,10 km to study the relationship between the grotto temples and the rivers. According to the results (Table 1), there are over than 73% of the grotto temples (including cliff statues) are distributed within 10 kms, which demonstrated that rivers have a strong restrictive effect on the distribution of the grotto temples (including cliff statues). The grotto temples have an obviously hydrophilic characteristic [55]. The reason should be that closing to the rivers brings convenience to monks' daily life and benefit to promote Buddhism with the water transportation. Furthermore, there are also 31 grotto temples (taking up 26.1%) distributing the area which are far more than 10 km from the riverbanks. However, most of those grotto temples are located in higher positions as a result of the abundant water sources and changes in the location of some grotto temples in Henan Province.

Stratum lithology

The lithological characteristics of the strata directly affect the artistic style and forms of expression of grotto temples [56–58]. According to the analysis of the distribution of grotto temples (including cliff statues) in Henan Province, it is found that grotto temples are mainly distributed in the limestone stratum areas in the western and northern regions of Henan Province. In western Henan represented by the Longmen Grottoes and northern Henan represented by the Anyang Grottoes [59], stone carving techniques are used to meticulously carve the grottoes to form beautiful stone carving art. This is mainly because the mineral composition of the carbonate rock body in the Cambrian limestone stratum in this area is relatively simple, and the mechanical strength is large, which is suitable for fine carving (Fig. 8) [9].

Political factors

According to Fig. 2, grotto temples (including cliff statues) are mainly distributed in western and northern Henan, accounting for 63.5% of the total. From the perspective of location, the grotto temples (including cliff statues) around Luoyang and Yedu (near today's Anyang City), the capital cities of the Northern Wei, Sui and Tang

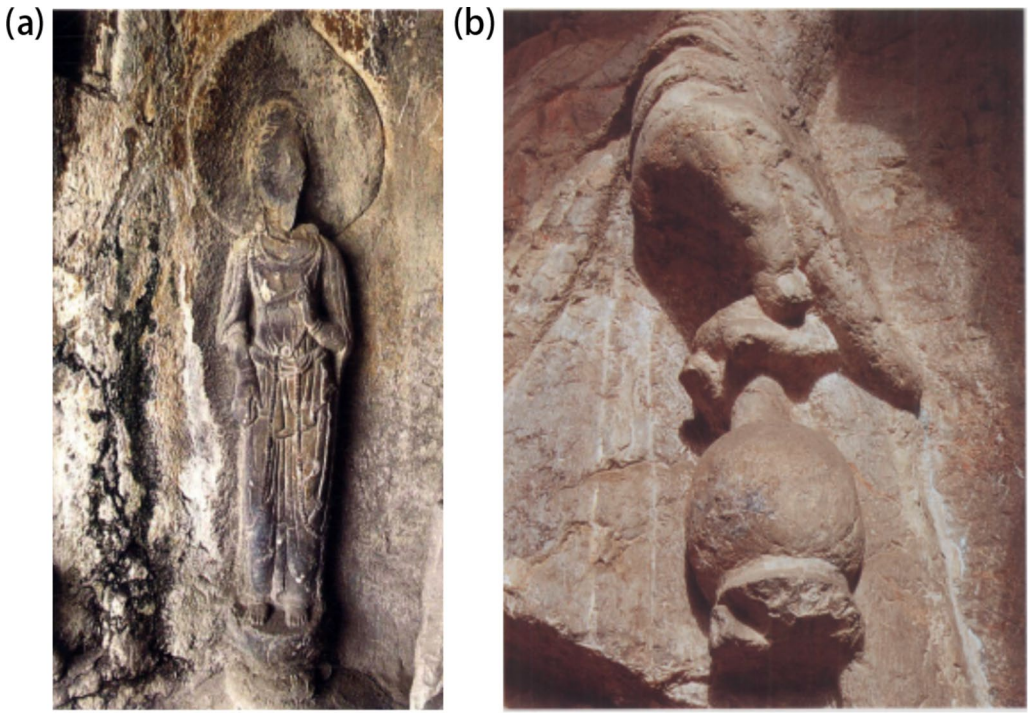

Fig. 8 Graceful Buddhist statues based on limestones: **a** Right Bodhisattva on back-wall in Niche 304; **b** Part of left Bodhisattva on the back-wall, in Cave 104 (Northern Binyang Cave) (reprinted from Liu Jinglong, *Complete works of statues in Longmen Grottoes*, Beijing: Cultural Relics Publishing House, 2003)

Dynasties, are characterized by high density, early excavation and continuity. The shift map of the distribution center of the grotto temples (Fig. 6) also clearly shows that the time migration path of the grotto temples is radiating from Luoyang and Anyang to other areas, showing that the excavation of the grotto temples is affected by the capital city, and then radiating the change trend around.

The reason is closely related to the support of imperial power for the excavation of grotto temples. The Buddhist monk Faguo of the Northern Wei Dynasty advocated that "the emperor is the present Tathagata (the initial description in ancient Chinese as Additional file 1: S1) [60], which has reflected the relationship between imperial power and Buddhism. Statistics show that the vast majority of the 119 grotto temples (including cliff statues) were funded by dignitaries, especially the Longmen Grottoes Group as a typical representative. After the Sui and Tang dynasties, people in areas far away from the capital would choose to worship statues in natural caves, and the trend of popularization and popularization of grotto temples began.

Traffic factors

Traffic is also a necessary factor for the prevalence of Buddhism in Henan. Buddhism was introduced into the Central Plains from the Western Regions. The areas where Buddhism is densely distributed are all areas with convenient transportation. In terms of spatial distribution, the western and northern regions of Henan belong to the densely distributed areas of grotto temples. The traffic route in the west of Henan Province takes Luoyang as the center to the west, passes through Xiaoshan, passes Lingbao, and crosses the north foot of Huashan to reach Qinchuan for 800 miles; To the east, you can reach the Jianghuai and Shandong regions, to the south, to Jingchu, to the north, to the Yellow River, and to the Sanjin through Taihang [61]. Along the traffic line, there are ten grottoes of large and small size, such as Mianchi Grottoes, Hongqing Temple Grottoes, Hutou Temple Grottoes, etc.; Longmen Grottoes closed by Yique; Gongxian Grottoes along the Yellow River [62].

North Henan is located at the eastern foot of the Taihang Mountains, and the famous "Taihang Xingdao" is scattered in the Taihang Mountains, connecting the Shanxi Plateau and the Hebei Plain. According to the "Kuo Di Zhi", the Taihang Mountains, which stretches thousands of miles across the Hebei prefectures from Henei (today's Qinyang) to Youzhou (today's area around Beijing), are the backbone of Northern China. According to 'Li Dao Ji', from Jinyang (today's Taiyuan city) to Qinyang, through Luoyang, you must pass through Taihang Mountain. The part of Taihang Mountains located between Huaizhou (Qinyang) and Zezhou county, control the north–south traffic (the initial description in ancient Chinese as Additional file 1: S2) [33]. According to "Shu Zheng Ji", Taihang Mountain starts from Henei in the south to Youzhou in the north, with a total of more than 100 mountains. These mountains are named after the location and all of them are named Taihang Mountains. It stretches across multiple provinces and cities. There are eight passages: the first is Guanxing (in Jiyuan County), the second is Taihangxing (see Henei County), The third is Baixing (in Huixia County) and the fourth is Fukouxing (in Cizhou)·(the initial description in ancient Chinese as Additional file 1: S3) [33]. Along the road, there are dozens of grottoes, such as Qianzui Grottoes in Qi County, Junxian Cliff Statues, Wuyan Mountain Grotto Temples in Hebi City, Xiangyu Temple Grottoes in Weihui, and Anyang Grottoes.

Conclusion

The spatial distribution of grotto temples (including cliff statues) is the result of natural factors such as topography, geomorphology, transportation, as well as human factors such as regime transfer. Grotto temples (including cliff statues) in Henan Province have obvious agglomeration characteristics in spatial distribution, which are concentrated around the capital at that time, such as Luoyang in western Henan and Anyang in northern Henan, reflecting the direct influence of the authorities on the excavation of the grotto temples. In addition, benefiting from convenient transportation, the grottoes in western Henan are mainly distributed on the east–west traffic arteries, while the grottoes in northern Henan are mainly distributed around the south-north traffic arteries in the eastern foot of the Taihang Mountains. The site selection of the grotto temple reflects the emphasis on the suitable environment for human habitation, which is related to the fact that the Grotto Temple has the function of monks living in meditation. Most of the grotto temples are located at an elevation of 179–800 m, facing the south and southwest of the sunny slope and the southeast and west of the semi-sunny slope; on the middle and gentle slopes with a slope of 10–25°.Grotto temples (including cliff statues) in Henan Province have a good continuity in the distribution of time. Although there are differences in the number of grotto temples (including cliff statues) in different periods due to wars, natural disasters, etc., they continued to develop in time. The development direction and center of Henan Grotto Temple (including cliff statues) changed little during the Northern Dynasties, Sui and Tang Dynasties, and Song and Yuan Dynasties, mainly in the west and north of Henan. However, in the Ming and Qing dynasties, the direction and center changed greatly, gradually shifting to the south and the number increased significantly due to the development of politics, culture and economy

at that time [63]. The changes in time distribution are in line with the changing characteristics of the political and cultural center at that time.

This study makes up some the shortcomings in the research on the spatial and temporal distribution of grotto temples (including cliff statues) in Henan Province and provides meaningful reference for the overall protection and sustainable development of grotto temple space in Henan. In addition, there are differences and correlations between the artistic characteristics of and construction dates of grotto temples (including cliff statues) in different regions of Henan Province. This study mainly analyses and studies the spatiotemporal distribution characteristics and related influencing factors of grotto temples from a macro perspective, but the protection plan for spatial integration has not yet been deeply explored. Future research can be expanded from the following two aspects: (1) Systematically exploring the overall and regional protection plans and strategies of Henan grottoes, in order to form a multi-level spatial protection system that runs through the three major spatial systems of production, life, and ecology. (2) There are connections between the statue patterns and artistic styles of grottoes in different periods, and methods such as correlation analysis and social network analysis are used to comprehensively interpret the spatiotemporal distribution characteristics.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40494-023-01044-w.

Additional file 1: Initial description in Ancient Chinese for some important quotation which were translated into English in the content.

Additional file 2: Flowchart with the main phases of the proposed work.

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Yu Li completed entire paper independently including the collection and analysis of data, preparation of figures, writing and reviewing the manuscript.

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Availability of data and materials
All research data obtained during this study are included in this article. Raw data are available on request.

Declarations

Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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