THE SPATIAL PATTERN OF GROTTOES IN CHINA AT THE COUNTY SCALE: A CASE STUDY OF ANYUE COUNTY

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ABSTRACT:

Grottoes in China are crucial components of immovable cultural heritage. According to the 2020 national survey conducted by the State Administration of Cultural Heritage, the Sichuan-Chongqing region boasts a total of 2,850 grottoes and rock carvings, accounting for approximately half of the national total. Among these, Anyue County, situated in the central part of Sichuan Province, stands out as one of the most concentrated and distinctive areas for grottoes in the Sichuan-Chongqing region. Therefore, conducting a spatial pattern analysis of grottoes holds significant theoretical and practical value for the protection and cultural dissemination of cultural heritage in Anyue County. Building upon the spatial distribution of grottoes in Anyue County, this study integrates multiple geospatial data sources, such as water systems and elevation. By employing methods such as buffer analysis, kernel density analysis, and standard deviation ellipse analysis, it delineates the spatial distribution pattern in Anyue County and preliminarily identifies their Spatial distribution rules. The findings of this study are as follows: (1) Within the administrative boundaries of Anyue County, grottoes exhibit a distribution pattern characterized by "less in the west and more in the east" and "one belt with three cores." (2) Grottoes and rock carvings in Anyue County primarily concentrate within a 1500-meter range on both sides of rivers, with the number decreasing as the distance from the rivers increases. Moreover, there are significantly fewer sites near inward-flowing rivers compared to outward-flowing rivers. (3) Natural factors influence the distribution of grottoes, with the number of grottoes being much lower in higher-altitude areas than in lower-altitude areas.

1. INTRODUCTION

Grottoes in China represent a comprehensive art treasure trove that integrates architecture, sculpture, and murals (Yang, 2023). These immovable cultural relics are situated in open or semi-open natural environments, such as the Mogao Grottoes in Gansu Province (Wang et al., 2021), the Jindeng Temple Grottoes in Shanxi Province (Lu et al., 2020), the Yungang Grottoes (Liu et al., 2011), and the Dazu Rock Carvings (Wang et al., 2017). Statistics indicate that there are a total of 5,987 grottoes in China, comprising 2,155 grotto temples and 3,832 rock carvings (grotto temples and rock carvings are collectively referred to as grottoes in this paper). These grottoes are distributed across various spatial regions, including the northern Central Plains region, northern Shaanxi region, Hexi region, Longdongnan region, southern region, Sichuan-Chongqing region, Tibet region, and Xinjiang region. Grottoes were introduced into China during the Wei and Jin Dynasties and experienced many periods spanning the Southern and Northern Dynasties, Sui and Tang Dynasties, Five Dynasties, Northern Song Dynasty, Southern Song Dynasty, Yuan Dynasty, Ming Dynasty, and Qing Dynasty. With the deepening integration of geographic information technology and the field of cultural heritage, the analysis of spatial patterns of cultural heritage has become an essential scientific method for understanding temporal and spatial evolutionary characteristics, as well as the relationship between cultural heritage, human history, and the natural environment (Wang et al., 2015).

Many scholars have conducted analyses on the spatial distribution patterns of cultural heritage. For instance, Che et al.

utilized a combination of statistics and spatial analysis to evaluate the spatiotemporal characteristics and transportation accessibility of World Heritage sites in China. Yang(2023) employed a GIS system to analyze the spatial distribution characteristics and spatiotemporal evolution of technology in Gansu grottoes across the Wei, Jin, Ming, and Qing dynasties while discussing the main factors influencing their development. Li et al.(2022), using GIS spatial analysis methods, investigated the spatial and temporal distribution characteristics and spatial structure of 2,102 national material cultural heritage sites in the Yellow River Basin. Wang et al(2021). analyzed the spatial distribution characteristics and influencing factors of UNESCO-listed World Architectural Heritage sites at both global and regional levels. Zhang et al(2022)., also utilizing GIS spatial analysis methods, studied the spatial distribution characteristics of the Intangible Cultural Heritage of Music (ICHM) and the main factors influencing its distribution in western Hunan, Central China.

Notably, Anyue County stands out for its significant spatial density of grottoes within its administrative boundaries. However, compared to existing research, there are substantial differences in both the quantity and spatial scale of grotto cultural relics in Anyue County. Furthermore, there is currently a lack of research on the spatial distribution patterns of grottoes in Anyue County, which hinders a comprehensive understanding of their distribution patterns, variations, and formation mechanisms at the county level. Therefore, this study focused specifically on Anyue County and its grottoes, aiming to contribute to the theoretical and practical aspects of cultural

heritage preservation and dissemination. It holds significant research value and importance.

This study built upon previous research on grottoes and concentrates on Anyue County as the study area. By using three methods of geographic spatial analysis, it aimed to investigate the spatial distribution characteristics and factors influencing them. The research provided a deeper understanding of the mechanisms underlying the spatial evolution of grottoes. Its goal was to offer scientific evidence and decision-making support for the protection and sustainable development of these cultural relics, as well as to provide a comprehensive understanding for future conservation planning.

2. STUDY AREA AND DATA COLLECTION

2.1 Study Area

The area of Anyue County is located in the northeastern part of Ziyang City, Sichuan Province (Figure 1). The county is bounded by longitudes 105°7'32" E to 105°33'41" E and latitudes 29°49'51" N to 30°11'1" N. It covers an approximate area of 2,690 square kilometers. Anyue County has an elevation ranging from 247.0 to 551.2 meters above sea level. It is situated in a transitional zone between the basin and the mountains, characterized by a predominance of red sandstone rock formations. These cliffs are relatively brittle and suitable for intricate carvings, providing a favorable medium for the artistic creations of grottoes (some of which are recognized as national cultural heritage sites, as shown in Figure 2). Additionally, Anyue County is bordered by the Tuojiang River to the west and the Fujiang River to the east, with the watershed of these rivers running through the entire region from northwest to southeast. As of 2020, Anyue County is administratively divided into 2 sub-district offices, 32 towns, and 12 townships. It is renowned as the birthplace of stone cave art in China and boasts the highest concentration of ancient Buddhist statue sites in the country (Chen et al., 2020).
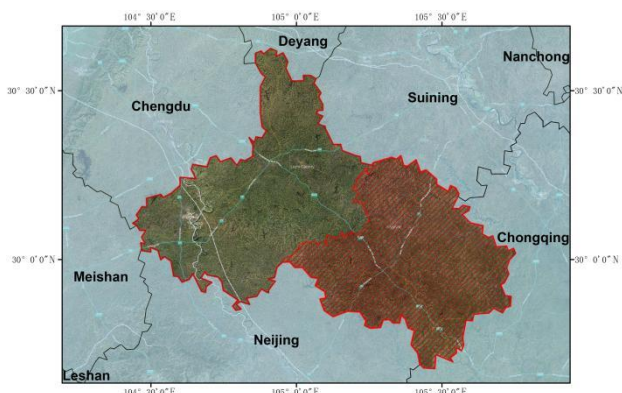
Figure 1. The study area, Anyue County (Outlined Area), Ziyang City (highlighted with red border), Sichuan Province. China
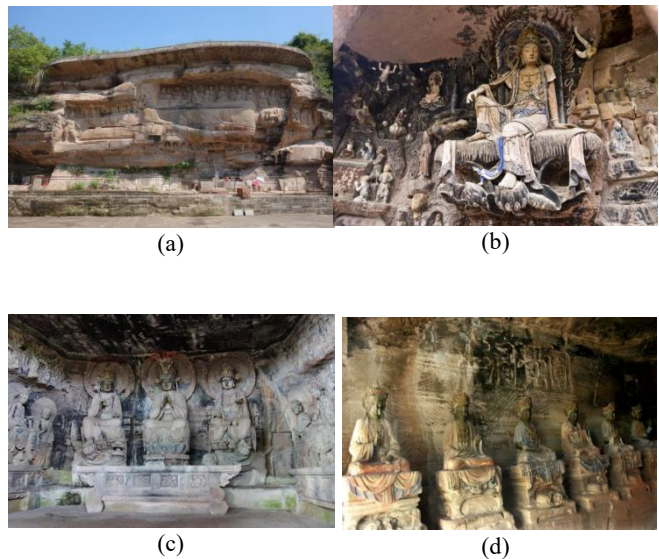
Figure 2. Four famous national protected cultural relics in Anyue Grottoes. (a) WoFoYuan, (b) PiLuDong, (c) HuaYanDong and (d) YuanJueDong

2.2 Data Collection

The data processing environment of this study is the ArcGIS10.8 platform. The globe coordinate system of all spatial data was unified as WGS1984. The data used in this paper include the vector data of the 148 locations of grottoes, elevation data, county administrative unit boundaries, and river systems in Anyue County. The location of points uses Autonavi's API (Application Program Interface) map to query the coordinates of detailed unit names and then enters the coordinates in the vector map of Anyue County. The boundary data of provinces, counties, and townships are obtained by vectorization based on the standard map No. GS (2016) 1698 downloaded from the standard map service website of the National Administration of Surveying, Mapping and Geographic Information. The 12.5m resolution DEM elevation map is obtained from ALOS Dem elevation data. Water system data can be downloaded through the Open Street Map water system to obtain the water system map layers and water system layer data within the administrative scope of Anyue County. The detailed information on the dataset please see Table 1.

Table 1. The data sources used in the study.

Data Items	Forms	Reference
Administrative boundaries	.shp(polygon)	http://bzdt.ch.mnr.gowcn /
Digital Elevation Model	.tiff	https://search.asf.alaska.edu/
Water system dataset	.shp(line) .shp(polygon)	https://download.geofabrik.de/
Grottoes	.shp(point)	*Anyue Grottoes /The Bashu Grottoes on Earth/ Research on the Tang and Song Dynasty Grottoes in Anyue/*Field trips

3. METHODS

In this study, several spatial analysis methods were employed to assess the characteristics of grotto cultural relics in Anyue County. The objective was to evaluate the level of clustering and understand the spatial distribution patterns of these discrete points. Kernel density analysis was utilized to measure the spatial distribution density of grotto cultural relics in Anyue County. This analysis helps assess the degree of aggregation and identify areas with higher concentrations of grotto cultural relics. Standard deviation ellipse analysis was employed to determine the distribution direction and trend of grotto cultural relics in Anyue County. It aimed to identify if there is a narrow and specific direction to the distribution of these relics, providing insights into their spatial arrangement. Buffer zone analysis was employed to examine the spatial proximity between grottoes and river systems in Anyue County. By creating polygons with different radius widths, this analysis aimed to determine the extent to which grottoes are located near river systems. Elevation analysis was conducted to investigate the potential impact of surface elevation on the spatial distribution of grotto cultural relics in Anyue County. By overlaying digital elevation models (DEM) with data on the location of grotto cultural relics, this analysis aimed to identify any correlation between elevation and the distribution of these relics. These spatial analysis methods were chosen to provide a comprehensive understanding of the spatial distribution patterns and factors influencing the grotto cultural relics in Anyue County(Figure 3).
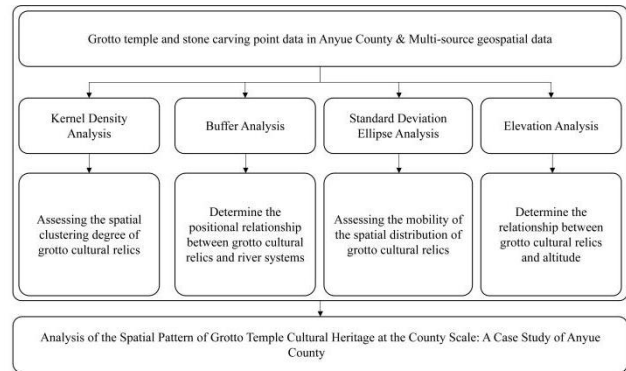
Figure 3. The process of spatial pattern analysis

3.1 Buffer Analysis

Buffer analysis is used to determine the spatial proximity or proximity of different geographical elements by creating polygons of different radius widths based on 3 types of points, lines, and surfaces (Zhou et al.,2020). The calculation formula is as follows:

$$\begin{cases} M_i = \{x : d(x, O_i) \leqslant R\} \\ O = \{O_i : i = 1,2,3,\cdots,n\}, \\ M = \bigcup_{i=1}^{n} M_i \end{cases} \quad (1)$$

where R = The longest radius of M_i
d = Polygon radius, taking the Euclidean distance
M_i = The set of all points within the polygon buffer with d as the radius
O = Multi-object set of spatial targets
M = Multi-object merging with radius R

3.2 Kernel Density Analysis

Kernel density estimation is an exploratory tool used to measure the density of spatial distribution for features within a given area. It is frequently used to assess the level of clustering exhibited by point data within a defined region, thereby providing insights into the spatial aggregation pattern of discrete points (Getis et al,2010). The calculation formula is as follows:

$$f(x) = \frac{1}{nh} \sum_{i=1}^{n} k\left(\frac{x - X_i}{h}\right), \quad (2)$$

where $f(x)$ = Estimated kernel density at the valuation point x

k = Kernel functions
$x - X_i$ = Distance of the valuation point X_i
h = Width
n Number of points in the bandwidth range

3.3 Standard Deviation Ellipse

Standard deviation ellipse is a spatial statistical technique used to study the mobility of the spatial distribution of cultural relics, It can be used to identify the orientation and trend of point data, allowing the assessment of whether the distribution of features is elongated and possesses a specific direction (Yuill,1971 and Scott,2009). The calculation formula is as follows:

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n}}, SDE_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{Y})^2}{n}},$$

(3)

where $\{x_i, y_i\}$ = Coordinates of element i

             $\{\bar{X}, \ \bar{Y}\}$ = Average center of the elements

             n = The total number of elements

4. RESULT AND ANALISYS

Due to factors such as topography, geomorphology, and resource conditions, the spatial distribution of grotto cultural relics in Anyue County displays a noticeable regional differentiation pattern. In general, it exhibits a distinct pattern characterized by "fewer in the west, more in the east, and clustering in the east while dispersing in the west." This pattern can be identified by employing kernel density estimation to assess the density of geographical objects. By conducting this analysis, it becomes possible to identify spatial clusters and dispersed areas of grottoes (as shown in Figure 4).
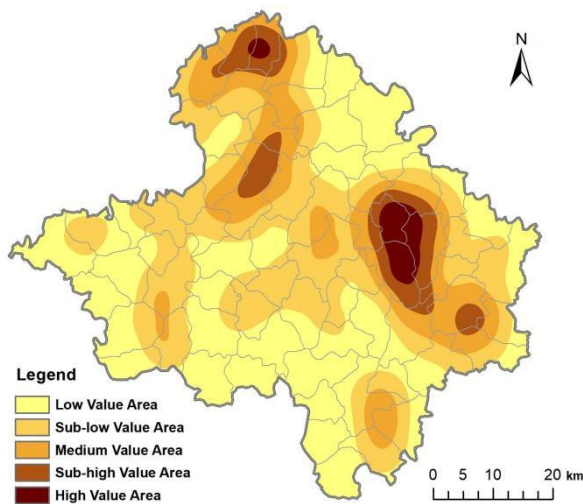

Figure 4. Kernel density map of grottoes in Anyue County

The kernel density distribution map of grottoes in Anyue County illustrates a concentrated distribution pattern, resulting in a spatial distribution characterized by "one belt and three cores." This pattern consists of two primary high-density core area and one secondary core areas, with all three core areas primarily located along the northeastern border of Anyue County (as depicted in Figure 5).
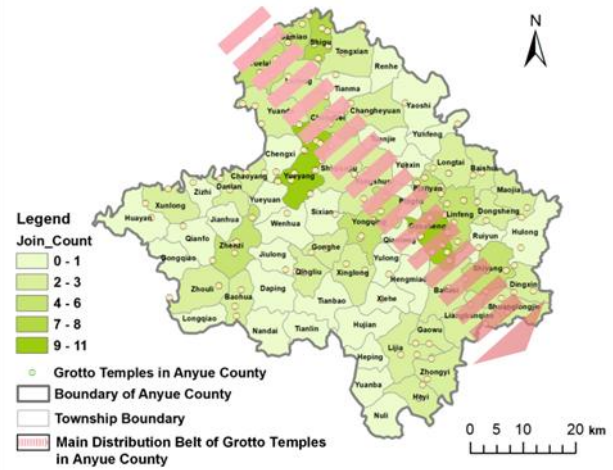

Figure 5. Spatial distribution of grottoes in Anyue County

The area with the highest density and distribution density of grottoes is located in the Gaosheng Township area in the eastern part of Anyue County and the Shigu Township area in the northern part. The eastern high-density core area contains 9 grotto cultural relics, accounting for 6.08% of the total. The northern high-density core area includes 7 grotto cultural relics, accounting for 4.72% of the total. The secondary core area is situated in the Yueyang Town area in the northern part of Anyue County, with 5 grotto-like cultural relics representing 3.38% of the total. Main distribution belt of grotto temples in Anyue County extends from Shigu Township in the north, passing through Laifeng Township, Yueyang Town, Shiqiaopu Town, Yongshun Town, Yongqing Town, Gaosheng Township, and Shiyang Town, all the way to Shuanglongjie Township, which borders Dazu District in Chongqing. This zone encompasses the high-density core area of Shigu Township, the secondary core area of Yueyang Town, and the high-density core area of Gaosheng Township.

By conducting separate kernel density analyses on the grottoes in Anyue County during the Tang, WuDai, Song, Ming, and Qing periods, it is observed that the spatial distribution patterns of grotto cultural relics during these historical periods align with the overall density distribution pattern (as shown in Figure 6). The high-core area of Shigu Township in the northern part of Anyue County first emerged during the Tang period. The high-core area of Gaosheng Township in the eastern part of Anyue County developed during the Song and Ming periods. The secondary core areas of Yueyang Township in the northern part of Anyue County emerged during the Qing period. At this point, the distribution of grottoes in Anyue County formed three core areas along a line, marking the initial formation of the main distribution belt of grotto cultural relics in the area. During the Wudai and Ming periods, the primary core areas of grottoes in Anyue County were also located within this key distribution belt.

(a)   (b)

(c)   (d)

(e)
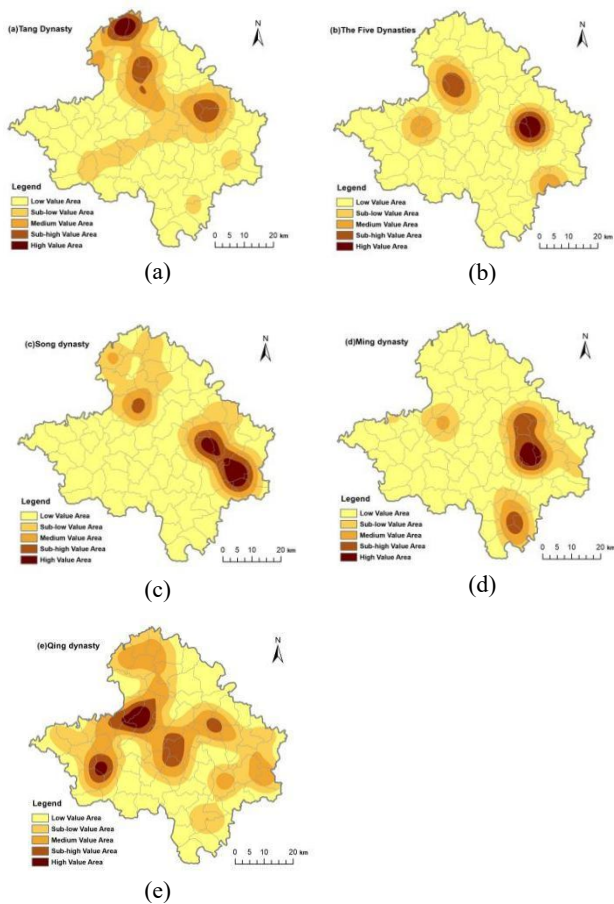
Figure 6. Kernel density map of grottoes in Anyue County during different historical periods

Based on the analysis of the chronology and quantity of grottoes, it can be observed that during the Tang to Song periods, there were 85 grotto cultural relics, accounting for 57.43% of the total. In the Ming period, there were 28 grotto cultural relics, accounting for 18.92% of the total. In the Qing period, there were 35 grotto cultural relics, accounting for 23.65% of the total. Among the 148 grotto cultural heritage sites in Anyue County, 9 of them are national-level cultural relics protection units. Notably, 8 out of these 9 units were constructed during the Tang to Song periods, indicating that this era marked the peak of development and prosperity for grottoes in Anyue County.

By analyzing the spatial distribution and dispersion state of the grottoes in Anyue County using standard deviation ellipses, it is observed that the grottoes are primarily concentrated in the central and northern parts of the county. The rotation angle of the ellipse signifies the dominant direction of distribution. As the long axis of the ellipse extends from northwest to southeast, it indicates that this direction serves as the predominant orientation for the spatial distribution of Anyue grottoes, with the highest concentration. Conversely, the short axis, perpendicular to it and stretching from southwest to northeast, represents the direction with the least spatial distribution (as depicted in Figure 7).
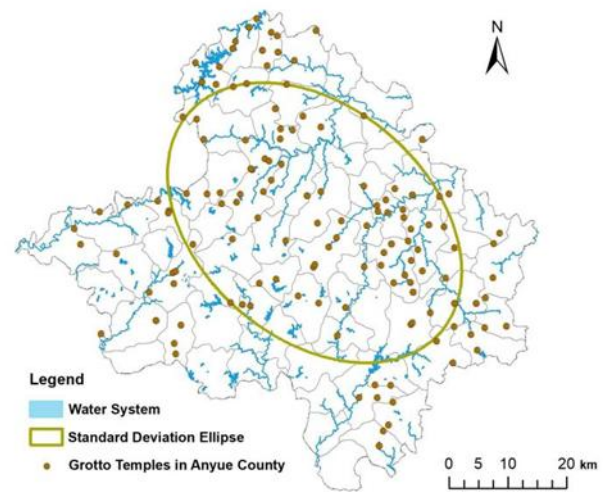

Figure 7. Elliptic analysis of the standard deviation of grottoes in Anyue County

There are no major rivers passing through Anyue County, but there are more than 70 small tributaries in the Tuojiang River and Fujiang River systems. Most of these rivers originate from the watershed between the Tuo River and Fu River and are primarily concentrated in the northeastern part of the county, coinciding with the area of higher grotto density. These rivers flow in two main directions, southwest and northeast of the mountain range respectively, before eventually converging and exiting the county.

In this study, a radius of 1500m was utilized to count the number of grottoes within the river basins of Anyue County (as presented in Table 2). The distribution map of water systems within the county was overlaid with the distribution map of grottoes. Subsequently, the water systems within the county were analyzed using three levels of buffers with equal intervals of 500m. This analysis resulted in the creation of vector entities representing the buffer zones. Based on this, the distribution of grottoes within different buffer zones was counted and recorded (as shown in Figure 8).

Table 2. The number of grottoes in different buffer zones

Buffer Width/m	Quantity
0-500	47
500-1000	31
1000-1500	22
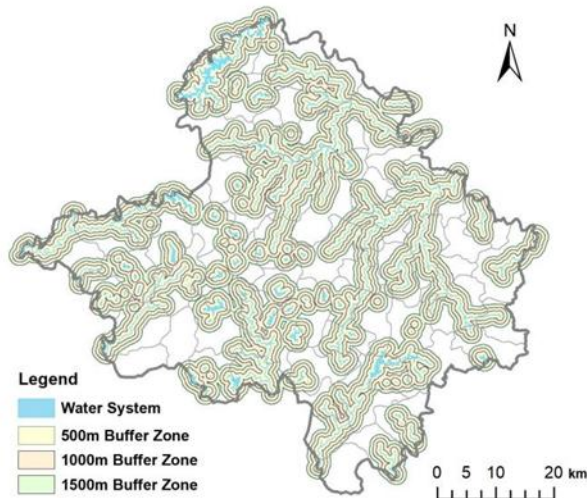
Figure 8. Analysis map of river buffer zones in Anyue County

According to Table 2, it is evident that the number of grottoes within a 1500m radius of the water system constitutes 63.51% of the total. Among them, 31.76% of the grotto cultural relics are situated within a 500m distance from the rivers. In the analysis of the 3-level buffer zones, the highest count of grottoes is observed within the 0-500m buffer zone of the water system, and the number of grottoes decreases as the buffer zone radius increases. This indicates that rivers, being crucial natural resources and transportation channels for human society, exert a significant influence on the distribution of grottoes in Anyue County, with proximity to the rivers playing a crucial role.

Based on Figure 8 and Table 3, it becomes evident that the grotto cultural relics in Anyue County predominantly follow the distribution pattern along the water systems. They exhibit a dense concentration in the outflow areas and a sparse distribution in the inflow areas. In the Fujiang River basin, which includes locations such as Shufangba Reservoir, Tongxian River, Changhe River, Longtai River, and Shiyang River, the grotto cultural relics within a 1500m radius account for 52% of the total grotto cultural relics in Anyue County's river basins. On the other hand, in the Tuojiang River basin, encompassing the Mengxi River, Daqingliu River, and Xiaoqingliu River, only 14% of the total grotto cultural relics in Anyue County's river basins are found. This indicates that the number of grotto cultural relics in the internal river basins is comparatively small when compared to the external river basins, highlighting a distinct difference between the two.

Table 3. The number of grottoes in the river basin of Anyue County

Water System		Amount
Tuojiang River Basin	Meng-xi River	9
	Da-qingliu River	2
	Xiaoqing-liu River	3
Fujiang River Basin	Shu-fangba Reservoir	8
	Tong-xian River	3
	Chang-he River	10
	Long-tai River	13
	Shiyang River	18

When the distribution map of grottoes in Anyue County is overlaid with the 12.5m topographic elevation map of Sichuan

Province (as shown in Figure 9), a distinct elevation boundary line becomes apparent. The southwestern region of Anyue County predominantly falls within the elevation range of 322m to 501m, while the northeastern region exhibits relatively lower elevations ranging from 205m to 322m. Additionally, the distribution of grotto cultural relics in Anyue County demonstrates a decreasing trend with increasing elevation, resulting in a corresponding decrease in quantity within the respective elevation ranges (as presented in Table 4). The majority of grottoes within the county are concentrated in the lower elevation range of 205m to 363m, accounting for 78.38% of the total number of sites.

Table 4. Elevation statistics table for grottoes in Anyue County

Elevation/m	Amount	Percentage
205-276	45	30.41
276-322	38	25.68
322-363	33	22.30
363-406	19	12.84
406-501	13	8.78
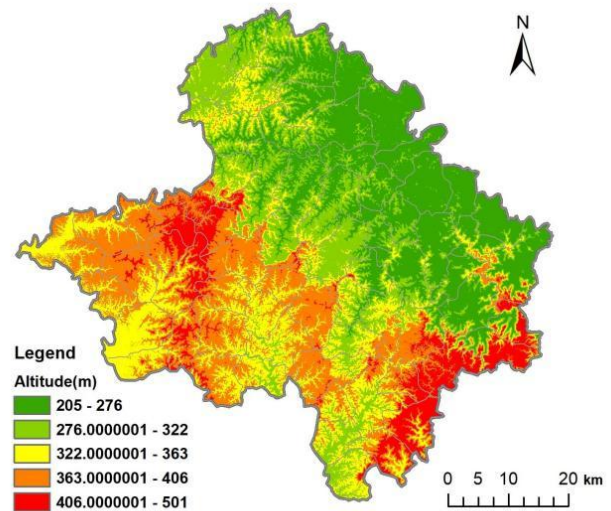
Figure9. Elevation Analysis of Grottoes in Anyue County

5. DISCUSSION

The spatial pattern of grottoes in the Anyue region exhibits distinct regional variations and unique characteristics. The changes in the quantity of grottoes across different historical periods also demonstrate specific attributes. The formation of such spatial structure and quantity differences can be attributed to the influence of both natural environmental factors and political-economic factors.

In China, a close relationship exists between grottoes, rivers, mountains, and urbanization. Water sources, as essential natural resources for human production and livelihood, play a vital role in the selection of geographical locations for grotto cultural relics. Human settlements tend to be situated in low-lying areas (Bi et al., 2013), and variations in topography and landforms can impact the intensity of human development and utilization activities (Liu, 2022). Therefore, grotto cultural relics are often constructed near or along rivers at lower elevations. Rivers provide convenient access to water sources and transportation

conditions, which are conducive to the formation and development of grottoes. Many renowned grottoes, such as the Longmen Grottoes and the Maijishan Grottoes, are located near or along rivers. Thus, studying the relationship between the spatial distribution of grottoes in Anyue County and rivers and elevations holds significant importance.

Although it is challenging to determine the historical population distribution in each township of Anyue County, from a historical heritagel perspective and based on the results of the sixth national population census in 2010, the town of Yueyang, with the largest resident population in Anyue County, also exhibits the highest distribution of grotto cultural relics in the county at present.

During the early construction of the Anyue Grottoes, Buddhism experienced flourishing development in China, and the strong support and patronage from the royal court provided robust guarantees for the construction of grottoes. Historical records indicate that Buddhism in China reached its peak during the Tang Dynasty, and during this period, the number and scale of grotto cultural relics in Anyue reached historical highs. Additionally, the political stability and commercial prosperity of Anyue created favorable conditions for grotto construction. During the Tang Dynasty, Anyue held significant political and military importance and received attention and protection from the royal court. Furthermore, Anyue served as a crucial transportation hub in southern Sichuan during the Tang and Song Dynasties, experiencing commercial prosperity. This provided a safe and stable environment for grotto construction in Anyue during the Tang and Song periods. However, the Ming and Qing Dynasties witnessed frequent wars in Anyue County, resulting in population decline and economic recession. The grottoes in Anyue gradually fell into disrepair during this period. The wars inflicted significant damage on the preservation and protection of the grottoes in Anyue. It was not until modern times that restoration and protection efforts were initiated for the Anyue grottoes. The heyday of the Anyue Grottoes greatly promoted the development of Anyue City, but the period of turmoil also led to the decline of the grottoes and the county. The Anyue Grottoes serve as important witnesses for studying the history of Buddhist development, and the history of Anyue, as well as valuable resources for exploring ancient Chinese culture, religion, art, and architecture. Therefore, the preservation and study of the Anyue Grottoes hold great significance.

6. CONCLUSION

Based on the study of historical documents, geographical data, and field investigations of the grottoes in Anyue County, current statistics show that there are a total of 148 stone carving relics, including 9 national-level sites, 18 provincial-level sites, 3 municipal-level sites, and 12 county-level sites. To further understand the historical evolution and geographical locations of the grottoes in Anyue County, GIS technology was employed to analyze the spatial distribution of the grottoes, aiming to gain insights into their overall distribution in the county. By collecting geographical information on the protected sites of grotto cultural relics in Anyue County and utilizing ArcGIS software, a systematic analysis of their spatial distribution characteristics was conducted, leading to the following conclusions:

(1) The distribution of grotto cultural relics in Anyue County is uneven within the county. The eastern part and northern part of Anyue County, particularly GaoSheng Township and Shigu

Township, have the highest concentration of distribution as the primary core area. The northern part of Yueyang Township serves as a secondary core area. The rest of the grotto cultural relics in the county exhibit scattered and uneven distribution. The overall distribution pattern shows a distinct characteristic of "few in the west, more in the east, with an aggregation in the east and scattering in the west," and demonstrates a "one belt, three core areas" distribution pattern along the northeastern boundary of Anyue County, extending from the northwest to the southeast.

(2) The overall development trend of grottoes in China began in the Wei-Jin Northern and Southern Dynasties period and reached its peak during the Sui and Tang Dynasties. In the late Tang and Song Dynasties, there was a peak period of excavation in the southern region, followed by a gradual decline. As an important gathering place for grottoes in southern China, Anyue County has been found through statistical analysis to have started its excavation during the Tang Dynasty. The large number of grotto cultural relics in Anyue County, it has had a certain influence on the temporal measurement of grotto cultural relics nationwide.

(3) Natural factors influence the distribution of grotto cultural relics in Anyue County. The number of grotto cultural relics in higher-altitude areas is much lower than in lower-altitude areas. Additionally, grotto cultural relics are often found in geographical locations close to river systems. Within the 1500m radius buffer zone along the rivers, the number of grotto cultural relics gradually decreases as the distance from the river increases. Furthermore, the quantity of grotto cultural relics near the inland river basin is much lower than in the downstream river basin.

The application of GIS-based spatial analysis methods in the study of grotto cultural relics holds great potential. It allows for a deep exploration of the spatial distribution patterns and characteristics of grotto cultural relics, as well as an investigation into their developmental history, spatial evolution, and influencing factors. This approach provides a scientific basis and decision-making support for the protection and sustainable development of grotto cultural relics, thus significantly promoting the conservation and sustainable development of grottoes and stone carving cultural heritage in China. It holds both theoretical significance and practical value.

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