Study on the spatiotemporal distribution patterns and influencing factors of cultural heritage: a case study of Fujian Province

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Abstract

The spatiotemporal distribution characteristics of cultural heritage reveal the trajectory of human activity changes, and a deep analysis of its natural and cultural factors holds significant reference value for the overall conservation and management of cultural heritages. This study focuses on the cultural heritage at the provincial level and above in Fujian, utilizing GIS spatial analysis to explore the spatiotemporal evolution of cultural heritages and their natural and human influencing factors. The research findings are as follows: (1) The distribution of cultural heritage in Fujian exhibits a clustering pattern, with dense areas transitioning from the upstream regions of the prehistoric and pre-Qin periods to the eastern coastal areas gradually. (2) The Ming and Qing dynasties have the highest number of cultural heritages, with the type of heritage transitioning from ancient sites in the early periods to ancient architecture, and in modern times, mainly important historical sites and representative architectural heritages. (3) The overall centroid coordinates of cultural heritage reveal a shift from the northern part of Fujian to the eastern and southern parts. (4) Natural factors significantly influence the distribution of cultural heritage, with a higher concentration in plain and hilly areas, on slight slopes with gradients between 0.5° and 2.0°, and on the southern and southeastern slopes, especially within a 1-kilometer radius of rivers. (5) The creation of cultural heritage during historical periods is closely linked to the regional history, culture, political, and economic environments. The positive development of these socio-cultural factors has a promotional effect on the quantity of cultural heritage. This study demonstrates the utility and applicability of GIS spatial analysis techniques in cultural heritage research, providing a methodological framework that can be adapted and applied internationally. The findings offer insightful data that can inform targeted conservation and development strategies for cultural heritage, ensuring their effective preservation and sustainable management across different regions.

Keywords Cultural heritage, GIS analytical tools, Spatiotemporal distribution, Natural and human factors, Fujian Province

Introduction

In the context of globalization and urbanization, cultural heritage research has become a hotspot for multidisciplinary collaboration. Cultural heritage not only bears witness to history but also symbolizes the spirit of a nation, playing a crucial role in enhancing cultural confidence and national cohesion. However, the fragile cultural heritage landscapes are facing increasingly severe threats due to the pressure of urban expansion [1]. Scholars have gradually extended their research from a single temporal dimension to a comprehensive spatiotemporal analysis, focusing on the spatial relationships and evolution between world cultural heritage, human urban civilization, and nearby towns [2, 3], as well as the distribution of natural disasters and their proximity to heritage sites [4].

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The scope of research continues to expand, from the spatiotemporal distribution and evolution of world cultural heritage [5, 6] to specific regions such as the Beijing-Tianjin-Hebei area [7], the Yellow River and Yangtze River basins [8–11], and various provincial and regional case studies [12–14]. In-depth investigations have been conducted on cultural heritage in land borders [15], marine heritage [16], agricultural heritage [17, 18], water conservancy engineering heritage [19, 20], modern architectural heritage [21, 22], industrial heritage [23–25], and mining heritage [26]. The research perspectives of regional historical landscapes and linear heritage corridors have established the connection between cultural heritage, natural environment, and historical culture. Historical landscapes, as the result of human-nature interaction, are receiving increasing attention [27, 28]. Particularly, large-scale cultural landscape heritage on the urban fringe faces challenges from the urbanization process [29]. Researchers have employed the urban historical landscape approach to conduct in-depth analyses of the distribution of tangible and intangible cultural heritage [30].

Existing studies tend to focus on specific types of cultural heritage, while comprehensive research that covers different historical periods and various types of heritage awaits further exploration and refinement. There is still space for additional research in the development of a universal research framework for cultural heritage and the exploration of innovative research methodologies. Fujian Province, with its rich human history and cultural heritage along China's southeastern coast, serves as an exemplary locale for such comprehensive research. Notably, while the province's Fujian Tulou sites [31, 32], Song-Yuan kiln sites [33], and wooden arch corridor bridges [34] have received significant scholarly attention, a holistic approach to cultural heritage analysis is lacking. This investigation harnesses the power of innovative GIS spatial analysis to examine the spatiotemporal distribution of cultural heritage and its interplay with natural and cultural determinants. The universality of GIS analysis allows for standardization and replication across diverse geographical and cultural settings, enabling the formulation of cross-regional conservation strategies.

Delving into the spatiotemporal patterns and their correlation with the environmental and cultural matrices illuminates the evolutionary trajectory and influence mechanisms of human-land relationships. The study introduces a globally adaptable methodological framework, derived from Fujian's case study, which has the potential to enhance international cultural heritage preservation efforts, offering a paradigm for broader application beyond the province's boundaries. This contributes to a more profound understanding of cultural heritage management on a global scale.

Materials and methods
Materials
The cultural heritage data for Fujian Province selected in this study primarily originate from provincial-level and above cultural heritage sources. Specifically, the data on cultural heritage sites were provided by the National Cultural Heritage Administration and provincial cultural heritage administrations up until May 2022. To comprehensively display the spatial layout of cultural heritage in Fujian, each distinct location of cultural heritage distributed across multiple cities was treated as an independent point feature in this study. For instance, the nationally protected Minbei Langqiao is actually composed of 12 units, distributed in Shouning County, Zherong County, Pingnan County, Gutian County, and Wuyishan City, among others, which can be recorded as 12 separate point features. We employed rigorous selection criteria, focusing specifically on cultural heritage sites that have been officially recognized as either national or provincial key heritage sites. Municipal and county-level heritage sites were not included in our research scope. For cultural heritage units that span multiple cities, we individually accounted for each distinct location to maintain geographical accuracy. Through this meticulous screening process, we identified a total of 1132 cultural heritage samples in Fujian Province. The comprehensive dataset comprises 190 national key cultural heritage sites and 942 provincial cultural heritage sites. Geospatial coordinate data for cultural heritage sites were obtained by conceptualizing each site as a point feature within a geographical spatial framework, with latitude and longitude coordinates extracted via the Gaode Coordinate Collection system. Subsequently, these data were converted to a unified coordinate system, and a spatial attribute database for cultural heritage in Fujian Province was established in ArcGIS software (Fig. 1). The digital elevation model (DEM) data were obtained from the Geographic Information System Cloud Platform of the Computer Network Information Center of the Chinese Academy of Sciences, used to analyze the impact of topography on the distribution of cultural heritage. The river data of Fujian Province were sourced from the stream and river fields of the Open Street Map's water system layer.

Methods
This study employs a range of spatio-temporal analysis methods to delve into the spatio-temporal distribution characteristics of cultural heritage in Fujian Province. The spatial analysis primarily utilized ArcGIS (Geographic
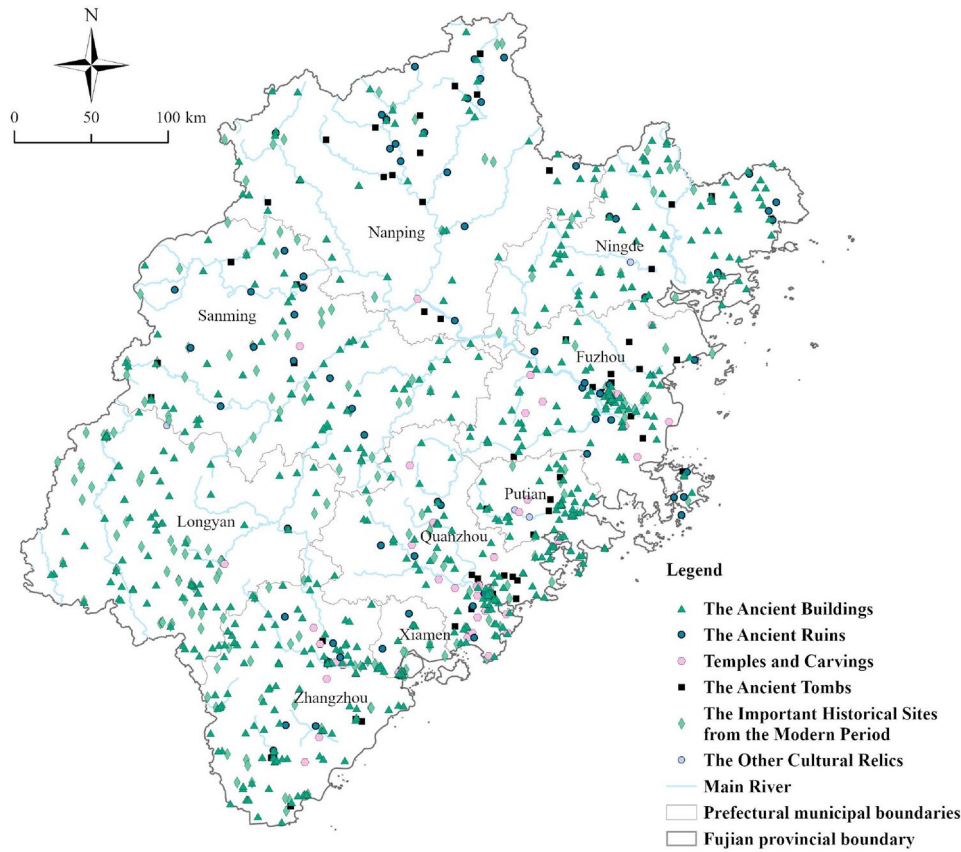
Fig. 1 Spatial distribution of cultural heritage in Fujian Province

Information System software) and was complemented by conventional mathematical and statistical methods.

Kernel density analysis

Kernel density analysis is a statistical tool that helps us understand the distribution of certain points, like cultural heritage sites, across a geographic area [35]. It's like placing thousands of detectors on a map, each one reporting the number of points it detects within a certain range. The detectors with more points report higher densities, and those with fewer points report lower densities. By combining all these reports, we get a density map that shows where cultural heritage sites are most concentrated.

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

In the equation, f(x) represents the kernel density, k(x) is the kernel function, h is the distance decay threshold (the bandwidth of the kernel density), n is the number of point features within the bandwidth, and x - x_i denotes

the distance between point x and point x_i. A higher value of f(x) indicates a denser distribution.

Average nearest neighbour analysis

The average nearest neighbor analysis is a method used to understand how close or far apart cultural heritage sites are from each other in Fujian Province [36]. It's like measuring the average distance between each site and its closest neighbor. If the average distance is small, it means the sites are clustered close together, and if the distance is large, it means they are more spread out. This helps us understand the overall pattern of how cultural heritage sites are distributed across the province.

$$\overline{r_0} = \sum_{i=1}^{n} \frac{\min d_{ij}}{n} \qquad (2)$$

$$\overline{r_E} = \frac{1}{2\sqrt{n/A}} \qquad (3)$$

$$R = \frac{\bar{r}_0}{\bar{r}_E} \tag{4}$$

In the formula: n represents the number of cultural heritage protection units within the area; A is the area of the study region; R is the nearest neighbour index; $\bar{r}_0$ is the observed nearest neighbour distance and $\bar{r}_E$ is the expected nearest neighbour distance. When $R > 1$, the features tend to be uniformly distributed; when $R = 1$, they tend to be randomly distributed; and when $R < 1$, they tend to be clustered.

Standard deviation ellipse analysis

Standard deviation ellipse analysis is a technique that uses ArcGIS to study the central tendency and spread of geographical elements across different historical periods [37]. It provides a visual representation of where the center of these elements is located, how far they tend to spread out from this center, and the general direction of their distribution. Essentially, it's like drawing an "average shape" around these sites to show their overall spatial pattern and how it evolves over time, giving us insights into the characteristics and spatial changes of cultural heritage throughout history.

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n}} \tag{5}$$

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}{n}} \tag{6}$$

Here, x_i and y_i are the coordinates of each feature, $\bar{x}$ and $\bar{y}$ are the centroid coordinates of the features, and n is the total number of features, revealing the changes in the central position and spatial evolution trends and directions of cultural heritage distribution over different periods.

Multi-ring buffer analysis

We utilized multi-ring buffer analysis to examine how cultural heritage sites are distributed in relation to rivers and roads. This method creates zones of varying distances around these linear features to see how many heritage sites fall within each zone [38], giving us a simple way to understand their spatial relationship. The formula is as follows:

$$B_i = \left\{x : d(X_i, Q_i) \leq R\right\} \tag{7}$$

In Eq. (7), Q_i represents the river or road, X_i is the coordinate point of the cultural heritage within the neighbourhood, d is the minimum Euclidean distance, and R is the buffer radius of the river or road.

Comprehensive historical literature analysis

The comprehensive historical literature analysis is utilized to delve into the rich contextual background of cultural heritage [39]. This method focuses on the religious, socio-political, and intellectual histories documented within heritage records. It incorporates regional studies and cross-references descriptive and normative materials to provide a rich contextual background. Furthermore, the study interprets historical images, reconstructing their spatial information on modern vector maps. Additionally, it involves the collection, extraction, organization, and translation of historical elements, overlaying historical maps onto current ones. By following the ancient site documentation style in Chinese local chronicles, the research records and analyzes historical sites, capturing the cultural significance and historical layers of the area. This integrated approach aims to provide a nuanced understanding of the historical and cultural heritage of the study area.

Cultural heritage distribution pattern in Fujian Province

Multi-period cultural heritage distribution pattern in Fujian Province

Characteristics of multi-period cultural heritage distribution

The cultural heritage in Fujian Province was classified into five distinct historical periods: Prehistoric to Pre-Qin, Qin and Han to Sui and Tang, Song and Yuan, Ming and Qing, and the Modern and Contemporary era. The data reveals a progressive increase in the number of heritage sites over time, with the Ming and Qing dynasties recording the highest number (658 sites), followed by a slight decline in the modern and contemporary era (254 sites). The Ming and Qing, along with the modern and contemporary periods, account for the majority of cultural heritage in Fujian, comprising 80.57% of the total sample.

To assess the spatial proximity of cultural heritage sites throughout these periods, we utilized the Average Nearest Neighbor analysis in ArcGIS (Table 1). This analysis measures the average distance between each site and its nearest neighbor. The findings indicate that, across all historical periods, the actual average distances between heritage sites are shorter than what would be expected by chance. This pattern suggests a clustering effect, where heritage sites tend to be closer to one another than would be expected randomly. The clustering is most

pronounced during the Ming and Qing dynasties and the modern and contemporary era, as evidenced by the significantly negative Z-scores of −21.73 and −11.89, respectively (Fig. 2) .
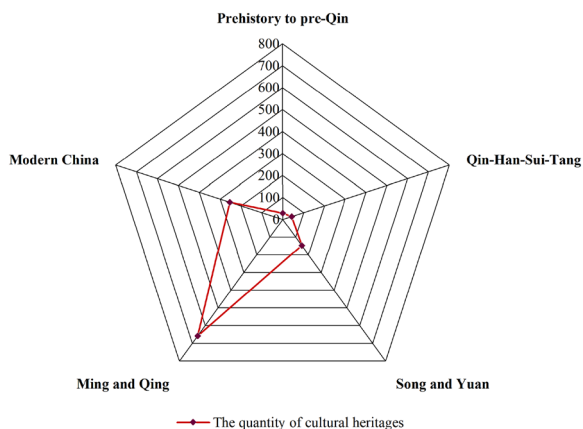
Multi-period cultural heritage distribution pattern in Fujian Province

The diversity of cultural heritage types in Fujian Province and the significant differences in their numbers across different historical periods were analyzed using the Kernel Density Analysis tool in ArcGIS, combined with regional historical, geographical, and cultural information. The kernel density distribution maps derived from the analysis reveal the distribution characteristics and temporal evolution trends of cultural heritage in Fujian Province.

During the Prehistoric to Pre-Qin period, due to its unique natural environment and relatively isolated geographical features, the level of cultural development in Fujian was relatively low and slow during the prehistoric era, with human activities primarily confined to hilly areas [40]. In this period, the total number of cultural heritage sites in Fujian was 29, accounting for 2.56% of the total sample. The majority of these sites (25) date

back to the prehistoric era, with the remaining 4 from the Pre-Qin period. The distribution of these sites shows a clustered pattern, as indicated by a nearest neighbor index of 0.62. The spatial distribution density of cultural heritage in this period was analyzed using the kernel density estimation method (Fig. 3a), revealing two main concentrations: one in the upper reaches of the Min River, including Pucheng and Wuyishan City; and the other in Mingxi County, Sanming City, located in the Shaxi and Jianxi river basins. Additionally, there was a concentrated distribution in Zhangzhou City, primarily along the Jiulong River. In terms of heritage types, the predominant categories were ancient sites (25) and ancient tombs (2), with an additional 2 grottoes and cliff carvings, specifically the rock paintings in Mingxi County and the cliff carvings in Hua'an County. This spatial distribution pattern reflects the early human dependence on water resources and mountainous areas, as well as the gradual expansion of human activity, which ranges with population growth and societal development.

During the Qin and Han to Sui and Tang dynasties, continuous warfare in the north since the Han dynasty led to a substantial migration of Central Plains populations to Fujian [41]. These immigrants played a positive role in promoting the local socio-economic development. In this period, a total of 43 cultural heritage sites were formed in Fujian Province, accounting for 3.80% of the total. Compared to the Prehistoric to Pre-Qin period, the high-density distribution area of cultural heritage in this period underwent significant changes, primarily concentrating along the coastal regions. The nearest neighbour index for this period was 0.63, indicating a clustered spatial distribution pattern. The distribution of heritage sites in the northern Fujian area was relatively concentrated, which may be related to the establishment of the Minyue kingdom during the Qin and Han dynasties [42]. For example, the Han city site in Wuyishan, northern Fujian, is a well-preserved ancient city site of substantial scale and is considered one of the most intact Han dynasty ancient city sites in South China. The high-density areas of cultural heritage in Fujian during this period were mainly distributed at the estuaries of the Min River in

Fig. 2 Radar chart of cultural heritage distribution quantity in different periods

Table 1 The nearest neighbour index of cultural heritage in Fujian Province across historical periods

Historical period	Average observation distance(m)	Expected average distance(m)	Nearest neighbor ratio *R*	Z score	pattern
Prehistory to pre-Qin	22284.8419	36110.5799	0.617128	−3.944425	Cluster
Qin-Han-Sui-Tang	20535.5106	32697.0742	0.628053	−4.66601	Cluster
Song Yuan	12514.7474	16384.7932	0.763803	−5.497141	Cluster
Ming Qing	5040.2088	9045.9232	0.55718	−21.73056	Cluster
The modern period	8284.8472	13581.9875	0.609988	−11.891206	Cluster
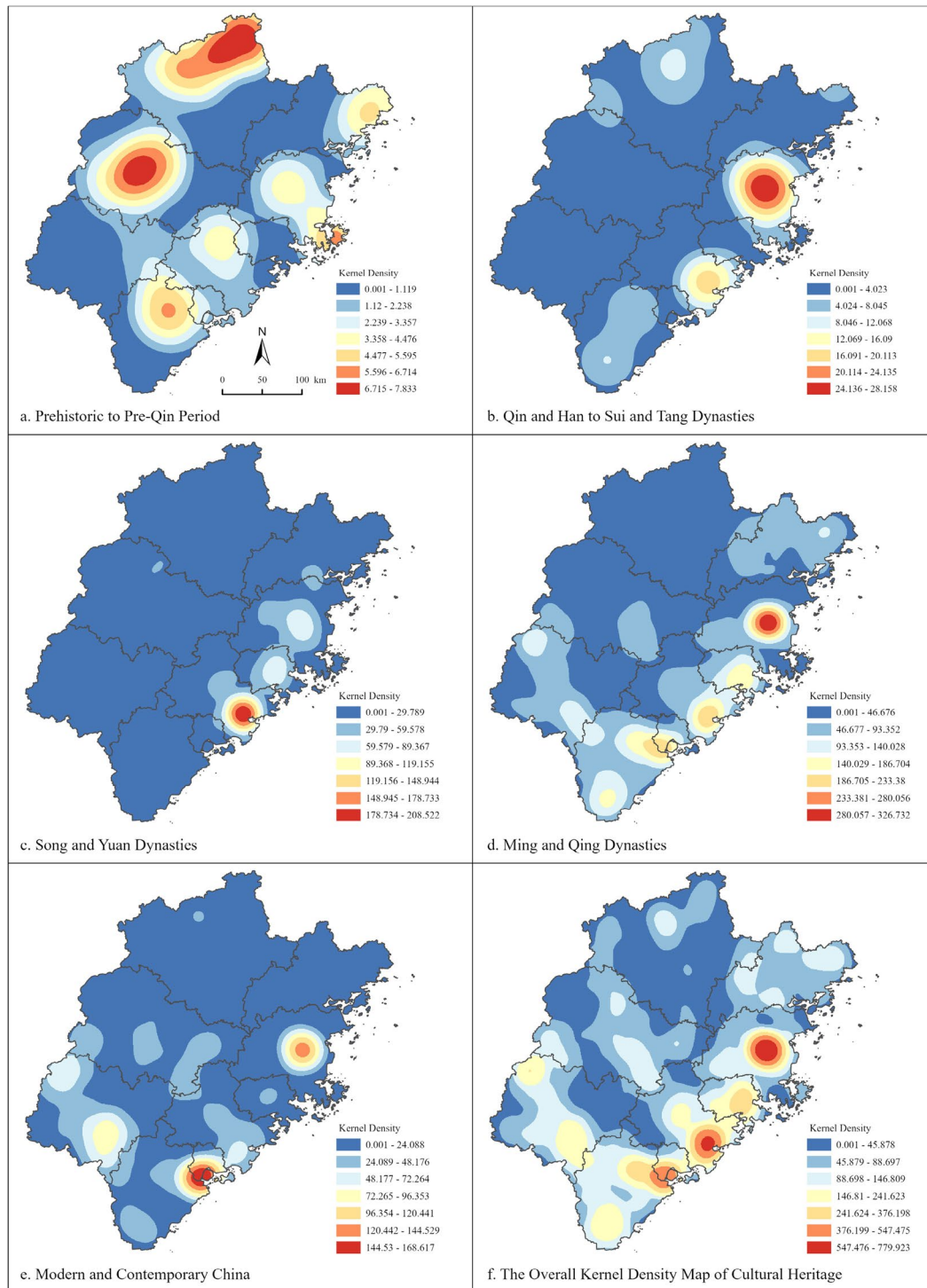
Fig. 3 Kernel density map of cultural heritage in Fujian Province

Fuzhou and the Jin River in Quanzhou, particularly in the Fuzhou area (Fig. 3b). During the Southern and Northern Dynasties, Fuzhou, as the administrative centre of the Minyue kingdom, was densely populated and developed early, with a high concentration of cultural heritage in the estuary area of the Min River. By the Tang dynasty, with land routes to the Western Regions blocked, Fuzhou's maritime trade and navigation gained development

opportunities, becoming the location of the Fujian Observer, with its maritime status surpassing that of Quanzhou Port for a time. During the mid-Tang dynasty, Fuzhou, along with Guangzhou and Yangzhou, was one of the three major international trade centres in the Tang dynasty, receiving attention from the Tang government.

In the Song and Yuan dynasties, the number of cultural heritage sites in Fujian Province significantly increased, reaching 148, accounting for 13.07% of the total. The nearest neighbour index for this period was 0.76, indicating that the distribution of cultural heritage still maintained a clustered pattern. The predominant type of cultural heritage in this period was ancient architecture, with 71 sites, followed by 30 ancient sites, and a considerable number of kiln sites, reflecting the economic and cultural development of the time (Fig. 4). The high-density areas of cultural heritage were mainly concentrated in the Quanzhou port (Fig. 3c), followed by Putian and other coastal areas of Fujian, closely related to maritime trade at that time. Cities such as Quanzhou, Fuzhou, and Jianning Prefecture were closely connected to domestic markets, with Quanzhou directly facing the overseas market, making Fujian's commercial network an important pivot in the Eastern market [43]. During the Song and Yuan dynasties, Fujian's agriculture and handicraft industry flourished, providing a solid foundation for the construction of the coastal port foreign trade network. In the late Northern Song dynasty, Quanzhou established the Office of Merchant Ships, becoming one of the most prosperous port cities in the world's maritime trade network from the 10th to 14th centuries [44]. Particularly by the end of the Southern Song dynasty, Quanzhou became the largest port in the East, serving as a hub for

China's economic and cultural exchanges with the world [45]. Maritime trade led to a dense network of ships near Quanzhou, with port facilities, warehouses, bridges, and lighthouses extensively distributed [46]. The historical sites of Quanzhou spanned a vast area from the coastal ports through the estuary plains to the inland mountainous regions.

In the Ming and Qing dynasties, the number of cultural heritage sites in Fujian Province sharply increased, reaching 658, accounting for 58.13% of the total. The nearest neighbour index for this period was 0.56, showing a significant clustered distribution pattern. The distribution of cultural heritage was mainly concentrated in the Fuzhou area, the capital of Fujian Province (Fig. 3d), followed by Putian, Quanzhou, Zhangzhou, and Xiamen. Additionally, the western and northeastern regions of Fujian also showed secondary cluster distribution characteristics. Fujian Province fully utilized its rich mountain and marine resources, making the commodity economy more prosperous. The thriving folk crafts and commerce provided a rich material base for the shipping industry [47]. Particularly during the early Yongle period to the sixth year of Xuande, Zheng He's seven voyages to the Western Seas made several stops at Fuzhou Port, greatly promoting its development [48]. Moreover, in the 23rd year of Kangxi's reign, the sea ban was lifted, and customs were established, with taxes levied on merchant ships at Min'an Town in Fuzhou. The following year, the management of the Fujian customs was divided into two parts, Fuzhou and Xiamen, establishing a dual-center customs management system. These policy measures provided solid support for the continued prosperity of Fuzhou. It is evident that the spatial distribution pattern of cultural
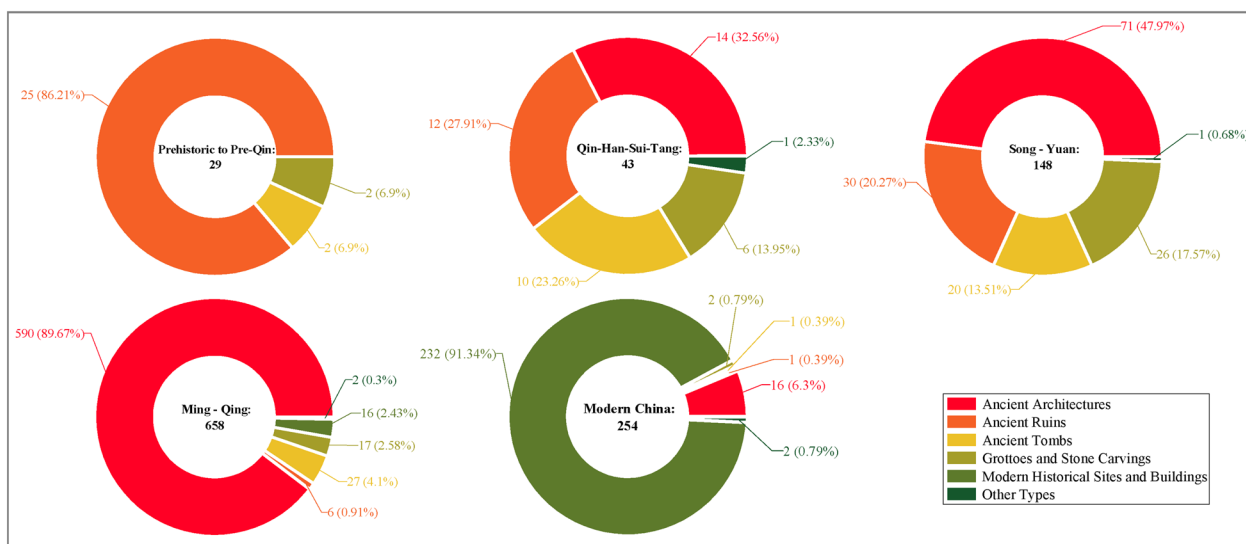

**Fig. 4** The composition of cultural heritage types over time

heritage in Fujian Province during the Ming and Qing dynasties showed a significant clustering characteristic centred around Fuzhou, closely related to the political, economic, and cultural development of the time.

In the modern and contemporary period, a total of 254 cultural heritage sites were recorded, accounting for 22.44% of the total. These cultural heritages were mainly important historical sites and representative buildings of the modern and contemporary era, with a particular emphasis on historical sites from the period of the War of Resistance Against Japanese Aggression. The spatial distribution of cultural heritage in this period showed a significant clustering characteristic, with a nearest neighbour index of 0.61. The distribution of cultural heritage was closely related to historical events. In the modern and contemporary era, the high-density areas of cultural heritage were centred around Xiamen, Fuzhou, and the western regions of Fujian (Fig. 3e). Xiamen, a vital port city, has been not only a key player in modern and contemporary history but also a major accumulator of cultural heritage [49]. Fuzhou, as the provincial capital, has consistently been a political, economic, and cultural hub, attracting a concentration of cultural relics. Furthermore, the western regions, particularly Longyan City and Changting County, have emerged as significant cultural heritage distribution areas due to their strategic geographical position and the historical significance of events that occurred there.

The distribution centre of cultural heritage in Fujian Province by period

The spatial distribution of cultural heritage in Fujian Province underwent a series of changes across different historical periods. The ArcGIS software and calculation formulas were used to obtain the standard deviation ellipses and centroid coordinates for cultural heritage in Fujian during five historical periods (Fig. 5). The centroid of cultural heritage from the Prehistoric to Pre-Qin period was located at the northern border of Youxi County, Sanming City, and the southern border of Yanping District, Nanping City (118.36°E, 26.38°N). During the Qin and Han to Sui and Tang dynasties, the centroid shifted to the southwest of Minqing County, Fuzhou City (118.60°E, 26.06°N). In the Song and Yuan dynasties, it moved to the west of Yongtai County, Fuzhou City (118.60°E, 25.78°N). The Ming and Qing dynasties saw the centroid shift to the southwest of Dehua County, Quanzhou City (118.15°E, 25.58°N), and in the modern and contemporary era, it moved to the border of Datian County, Sanming City, and Yongchun County, Quanzhou
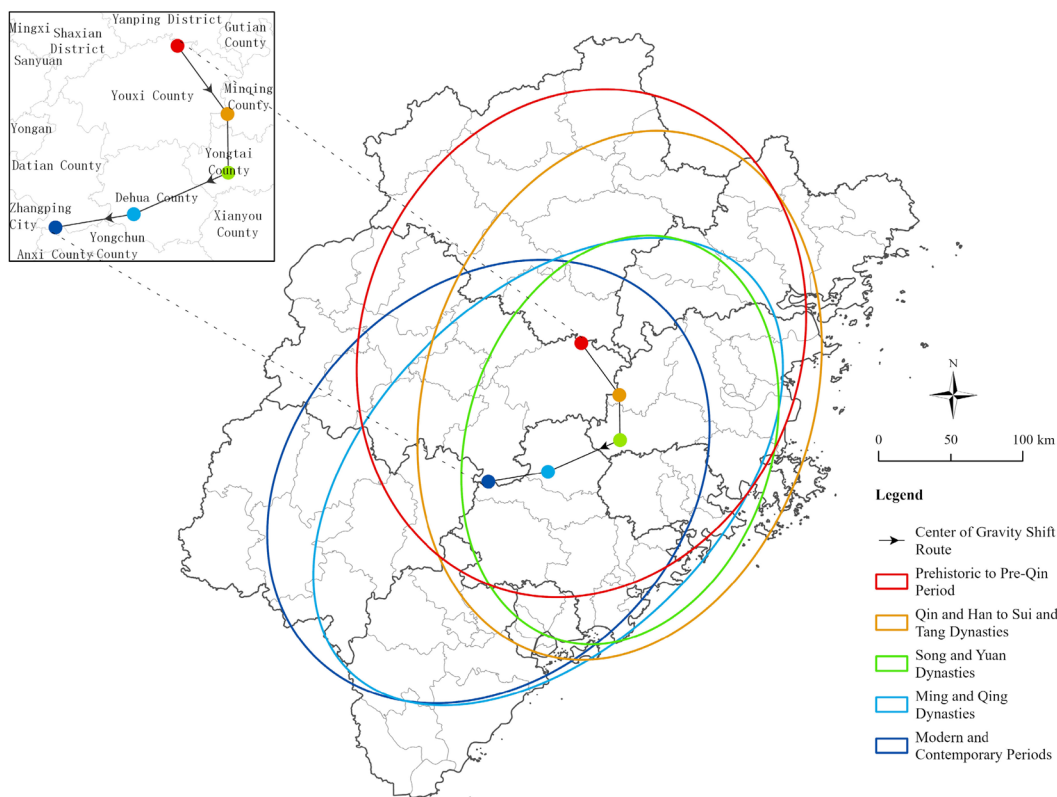
Fig. 5 The shift of distributional centres of gravity of cultural heritage in Fujian Province in five periods

City, near Zhangping City (117.78°E, 25.52°N). The overall trajectory of the centroid coordinates across historical periods indicates a gradual southward shift of the distribution centre of cultural heritage in Fujian, from the northwest to the south, and finally to the southwest. The distribution centre was in the border area of Nanping City and Sanming during the Prehistoric to Pre-Qin period, within Fuzhou during the Qin and Han to Song and Yuan periods, and then shifted to Quanzhou City.

The standard deviation ellipse analysis reveals that the spatial distribution of cultural heritage in Fujian underwent significant changes across different historical periods. During the Prehistoric to Pre-Qin era, cultural heritage sites were predominantly clustered in northern Fujian, with the distribution ellipse showing a slight northeastern tilt and a compact shape, indicating a concentrated distribution pattern. In the Qin and Han to Wei and Jin period, the focus of cultural heritage shifted southeastward towards the Fuzhou area. The ellipse orientation changed slightly, and the distribution became more concentrated, suggesting a shift in the region's cultural center. The Song and Yuan dynasties witnessed a continued southward movement of the centroid. The distribution remained concentrated, with little change in the ellipse's orientation, reflecting a stable period of cultural development in the southern regions. A significant transformation occurred during the Ming and Qing dynasties. The centroid shifted slightly westward, but more notably, the ellipse's orientation changed dramatically, aligning more closely with a northeast-southwest axis. This period exhibited the most concentrated distribution of cultural heritage, likely due to population growth and political stability. In the modern and contemporary era, the distribution pattern showed signs of dispersal. The centroid continued its southwestward movement, while the ellipse's orientation remained similar to the previous period but with a less concentrated distribution. This change reflects a more widespread development of cultural sites across the province. These spatial transformations over time provide insights into the historical trajectory of Fujian's political, economic, and cultural development, highlighting the shifting focus of cultural activities and the evolving importance of different regions within the province.

Distribution pattern of multi-type cultural heritage
The distribution pattern of multi-type cultural heritage in Fujian Province reveals significant regional variations across different types of cultural heritage. The cultural heritage in Fujian can be categorized into six types: ancient architecture, ancient sites, grottoes and stone carvings, ancient tombs, modern historical sites and representative buildings, and other heritages. Among the 1,132 cultural heritage sites, ancient architecture is the most prevalent with 691 sites, accounting for 61.04% of the total. This is followed by ancient sites (74, 6.54%), ancient tombs (60, 5.30%), grottoes and stone carvings (53, 4.68%), modern historical sites and representative buildings (248, 21.91%), and other types (6, 0.53%).

Due to the similarity between the distribution of modern cultural heritage and the previously mapped core density of cultural heritage from the modern period, and the limited number of other types of cultural heritage, this paper focuses on the spatial distribution characteristics of the first four types of cultural heritage using kernel density analysis (Fig. 6).

Ancient architecture, as a tangible representation of historical and cultural heritage, reflects the architectural art and technological achievements of different historical periods. In Fujian, ancient architecture is predominantly represented by temples, pagodas, and traditional residential buildings [50]. The distribution of ancient architecture is closely related to the historical development and socio-economic conditions of each period. For example, the concentration of ancient architecture in the Fuzhou area during the Ming and Qing dynasties reflects the political and economic prosperity of that era (Figs. 7, 8).

Ancient tombs in Fujian, shaped by topography, geomorphology, and human settlement patterns, are vital cultural heritage that reveal information about ancient social structures, burial customs, and cultural beliefs [51]. These tombs are typically located in areas favorable for human habitation, reflecting ancient migration patterns. Similarly, historical sites such as ancient city sites, battlefield sites, and industrial heritage sites are essential for understanding the historical processes and socio-economic development of the region. The distribution of these sites is closely linked to historical events and human activities, with ancient city sites often situated in resource-rich and strategically important areas with convenient transportation [52]. Additionally, cliff carvings and grottoes, influenced by suitable rock formations, transportation routes, and religious activities, offer insights into the religious beliefs, artistic expressions, and cultural exchanges of ancient societies. Modern historical sites and representative buildings, primarily from the modern era, are noteworthy but will not be elaborated upon here.

Regional differences in the distribution of cultural heritage in Fujian Province
The distribution of cultural heritage in Fujian Province is marked by significant regional variations, which are further refined to better reflect the unique features of heritage distribution across different areas [53]. In terms of the total number of cultural heritage sites, the highest concentrations are found in Longyan City's Changting
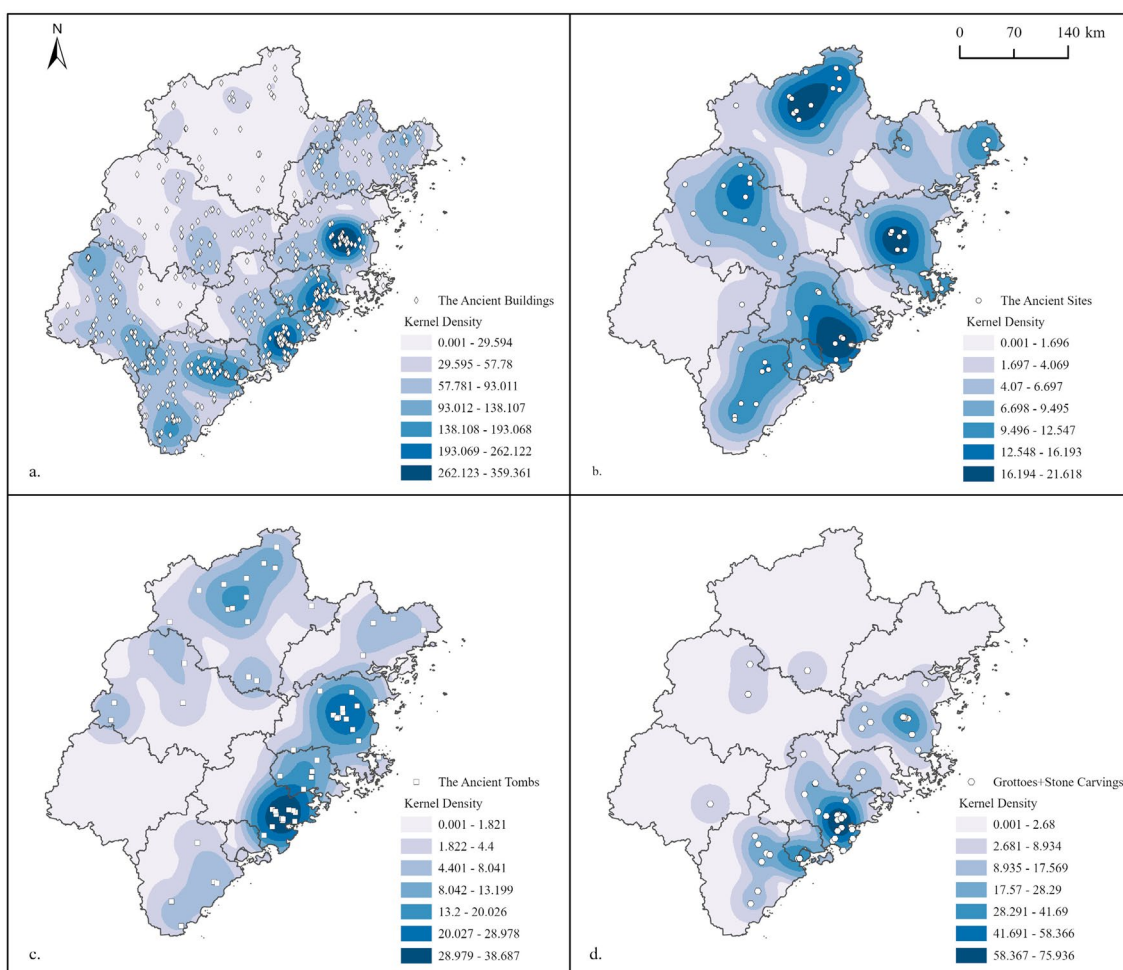
Fig. 6 Kernel density of different types of cultural heritage in Fujian Province

County and Yongding District, as well as Siming District in Xiamen (Fig. 8). The distribution of ancient architectural heritage is predominantly found in Zhangzhou, Fuzhou, Longyan, Ningde, and Quanzhou, among other regions (Fig. 9). These structures predominantly consist of ancestral halls, pagodas, temples, bridges, and residential buildings.

Prehistoric sites, including ancient civilization remains and Tang Dynasty kiln sites, are spatially concentrated in the northern part of Nanping, notably in Pucheng County and Wuyishan City, as well as Guangze County, Jianyang District, and Songxi County. Additionally, Fuzhou's coastal areas, specifically Fuqing City and Pingtan County, also serve as hotspots.

Ancient tomb sites are primarily concentrated in the northern part of Nanping, including Pucheng County, Wuyishan City, and Songxi County; as well as in the coastal areas of Quanzhou, covering the districts of Fengze, Licheng, and Luojiang within the administrative region of Quanzhou City, and also in Jinjiang City and Hui'an County.

The distribution of grotto temples and stone carvings, which encompass Buddhist figures, cliff carvings, and stone inscriptions, is largely centered in Quanzhou. The rich cultural heritage of the Song and Yuan dynasties, as well as Huian's maritime cultural genes, undoubtedly represents the imprints of prosperous times and the product of cultural integration. The religious stone inscriptions also reflect devout beliefs, and Quanzhou's profound religious culture is evidenced by its numerous temples and religious sites.

The hotspots for modern cultural heritage in Fujian Province are predominantly located in the western regions of Longyan and Sanming, which are renowned for their revolutionary history and rich red heritage. Additionally, Xiamen Island is a significant cultural heritage hotspot, with the majority of its heritage sites constructed during the late Qing Dynasty and the Republic
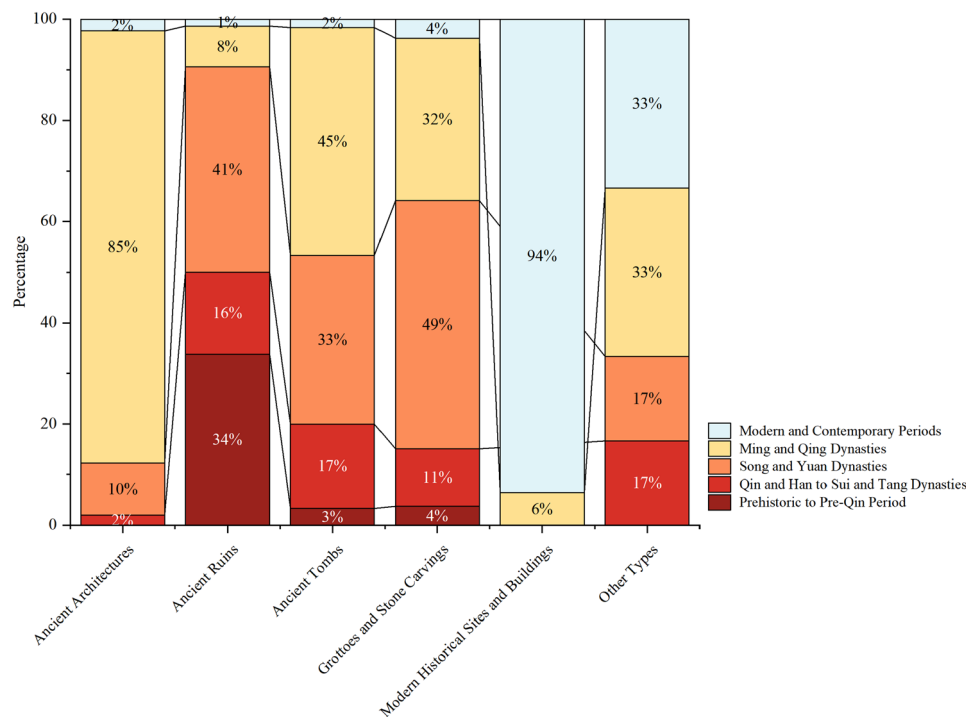
Fig. 7 Percentage of period composition for each heritage type in Fujian Province

of China period. This era witnessed the development of various important buildings, such as foreign consulates, hospitals, chapels, and villas, mainly concentrated in Gulangyu Island and the Xiagang area of Siming District. The historical context of Gulangyu as a "tenancy of nations" and the influx of overseas Chinese facilitated the integration of local and foreign cultures, leading to the creation of a wealth of modern cultural heritage sites with Western architectural influences that profoundly shaped Xiamen's cultural landscape [54].

Analysis of factors affecting Fujian's cultural heritage

Natural and geographical factors

Altitude and topography factors

The topography and geomorphology of Fujian Province have significantly influenced the distribution of cultural heritage. Overlaying the Fujian Province DEM with cultural heritage distribution data reveals a decreasing trend in heritage sites with elevation, as evidenced by categorical statistical analysis (Fig. 10). In the plains area below 200 m, the number of cultural heritage is the highest, reaching 636, accounting for 56.18% of the total. The hilly area (200 ~ 500 m) has 316 cultural heritage, accounting for 27.92%. The mountainous area (500 ~ 1000 m) has 172 cultural heritage, accounting for 15.19%. The distribution of cultural heritage in the highland area above 1,000 m is

the least, with only 8 sites, accounting for 0.71%. The distribution of cultural heritage in Fujian Province tends to be in low-altitude areas, which is attributed to the well-developed river systems and fertile soils in the plains and hilly regions. Historically, these areas have been more frequented by human activities, leading to the formation and preservation of more cultural heritage.

Due to the scarcity of ancient topographical data, modern information is utilized to analyze the factors influencing the distribution of heritage sites across different historical periods. From the perspective of elevation distribution characteristics across different historical periods, cultural heritage from the Prehistoric to Pre-Qin period is more prevalent in the hilly areas. As history progressed, the distribution of cultural heritage in the hilly areas gradually decreased, reflecting the shift of early inhabitants from the hilly regions to the plains. However, in the modern and contemporary era, there is a slight increase in the number of cultural heritage in the hilly areas, which is related to the requirements of warfare and changes in human activity patterns.

Slope factors

The distribution of cultural heritage in Fujian Province is closely related to terrain slope. By overlaying the slope data derived from the DEM with the cultural heritage distribution map, the distribution patterns of cultural
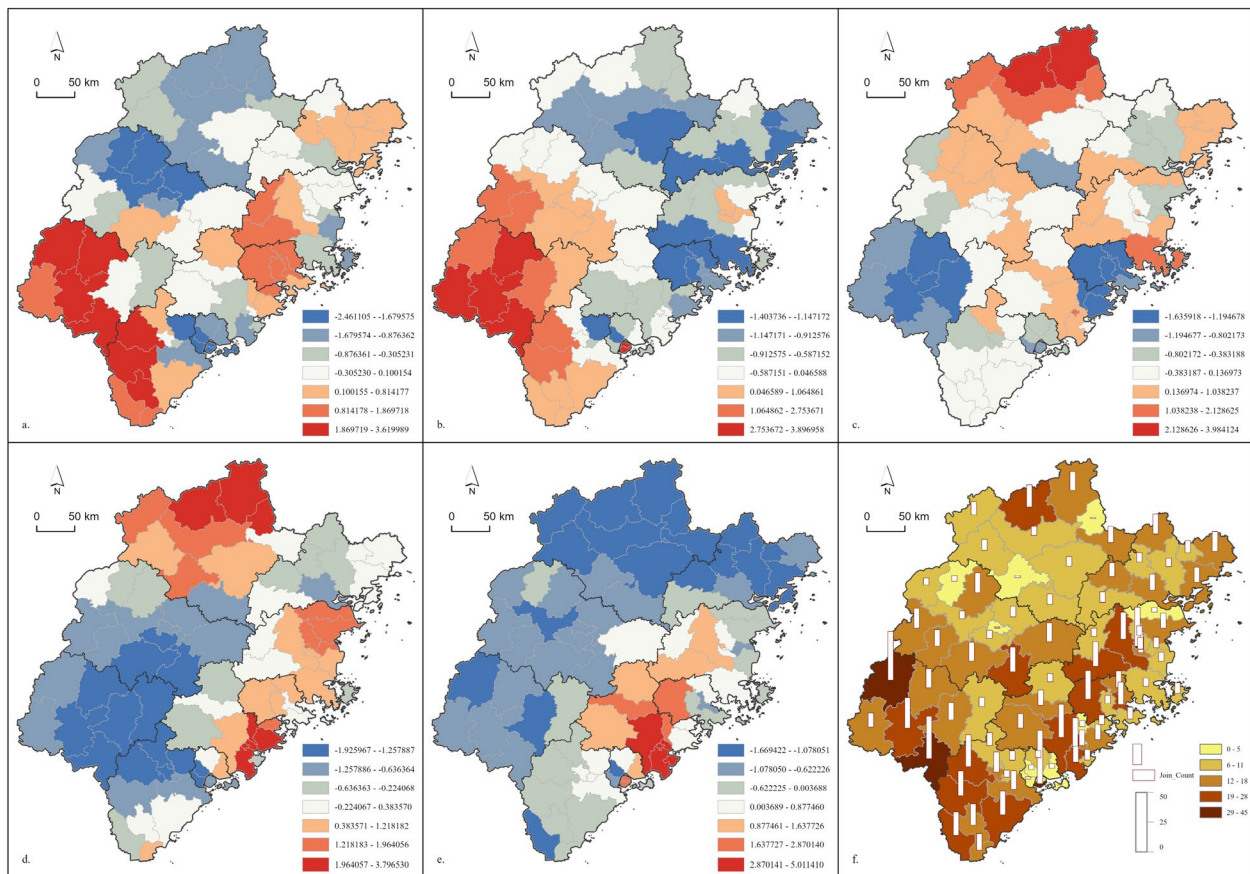
Fig. 8 Regional differences in the distribution of different types of cultural heritage within Fujian Province: a.ancient architecture; b.modern historical sites and representative buildings; c.ancient ruins; d.ancient tombs; e.grottoes and stone carvings; f.overall distribution of the number of cultural heritage sites

heritage across different slope levels are revealed. The distribution of cultural heritage in Fujian Province is predominantly concentrated in three types of slope areas: plains, gentle slopes, and moderate slopes, accounting for 20.49%, 42.76%, and 23.06% respectively. Particularly, the number of cultural heritage sites is highest in the gentle slope terrain and decreases as the slope increases (Fig. 11). Despite the prevalence of steep and very steep slopes in Fujian Province, the rugged topography in these areas hinders human activity, leading to a lower concentration of cultural heritage, which comprises only 12.81% and 0.88% of the total, respectively. This indicates that the distribution of cultural heritage is closely related to the convenience of human activities and terrain slopes, with flat and gentle slope areas having more cultural heritage due to their suitability for habitation and agricultural activities.
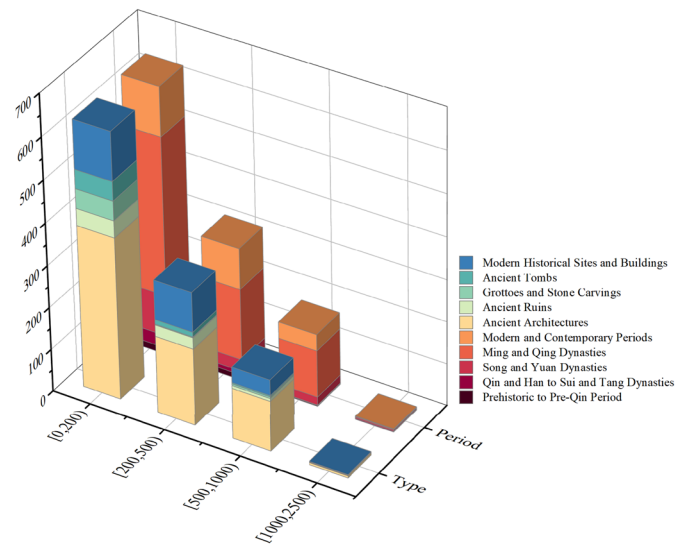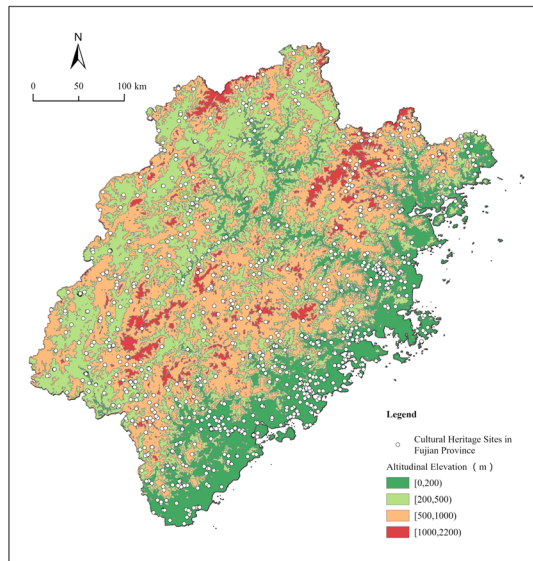
Aspect factors

There is a significant relationship between the spatial and temporal distribution of cultural heritage in

Fujian Province and the aspect element. Due to differences in sunlight duration, angle, temperature, precipitation, and the impact on crop growth and human settlement environments, the distribution of cultural heritage across various aspects exhibits certain regularities. According to the data in Fig. 12, the distribution of cultural heritage across aspects in Fujian Province is relatively balanced. Still, the southern and southeastern aspects have a higher distribution, accounting for 18.73% and 14.66% respectively. In comparison, the distribution on the north and northeast aspects is less, with 8.13% and 8.22% respectively. This distribution characteristic is related to the northeast-southwest orientation of the terrain in Fujian Province. The aspect distribution of cultural heritage also shows differences across historical periods. During the Prehistoric to Pre-Qin period, ancient sites were mostly distributed on the southeastern aspect, which may be related to the preferences of early humans for sunlight and climate at that time. From the Qin and Han to the Sui and Tang
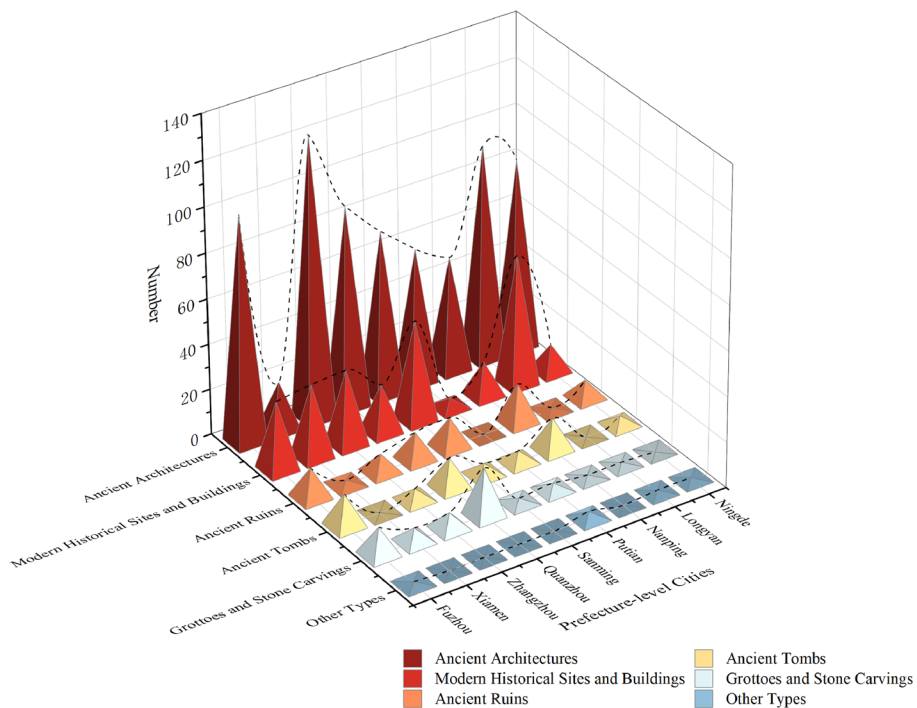
Fig. 9 Distribution of the number of different heritage types in different prefectural municipalities in Fujian Province
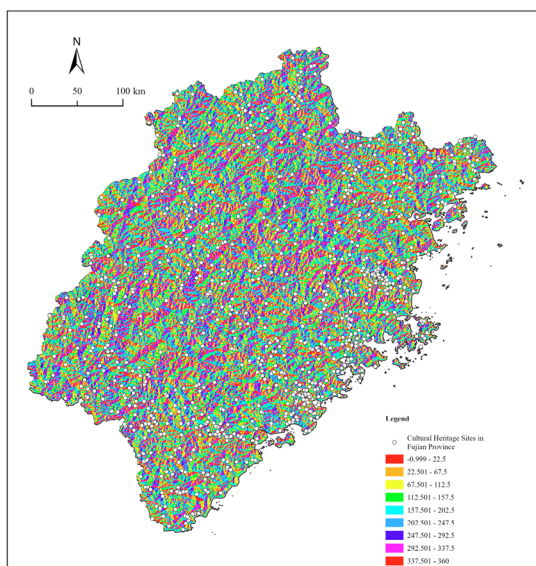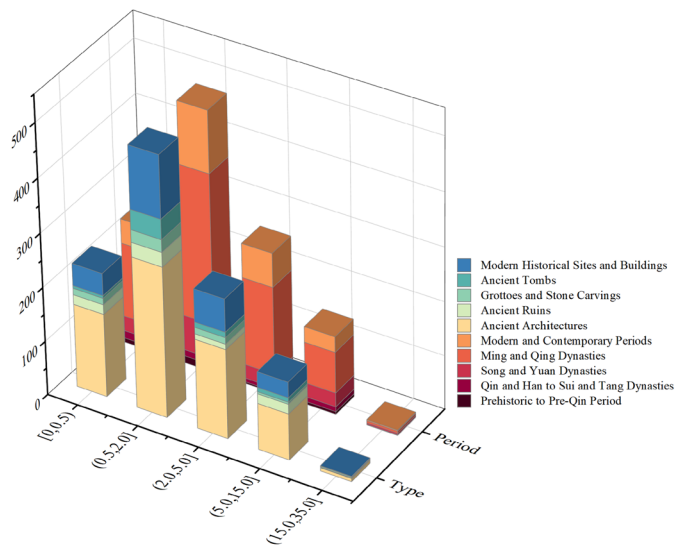

Fig. 10 Distribution of cultural heritage under the influence of elevation factors

dynasties, the southeastern aspect had the highest distribution, followed by the southern aspect, and ancient tombs were also mostly distributed on the southeastern aspect. During the Song, Yuan, Ming, and Qing dynasties, the southern aspect was predominant, and this aspect was also where most of the cultural heritage types such as ancient architecture and ancient tombs were located. Modern important historical sites and representative buildings were mostly distributed on the east and northwest aspects.
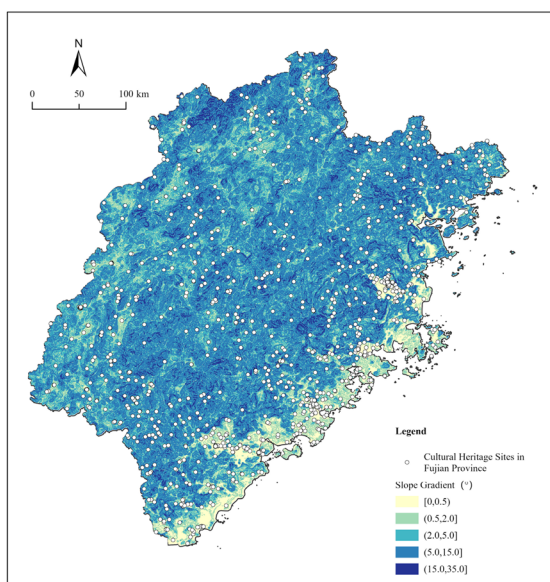
Fig. 11 Distribution of cultural heritage under the influence of slope factors
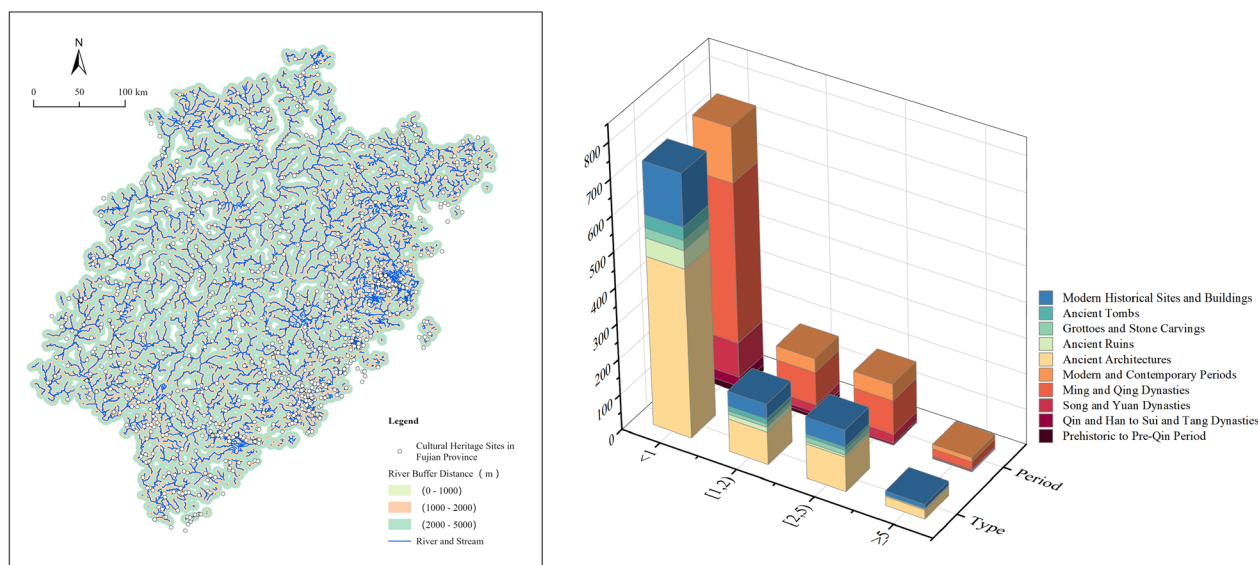

Fig. 12 Distribution of cultural heritage under the influence of slope orientation factors
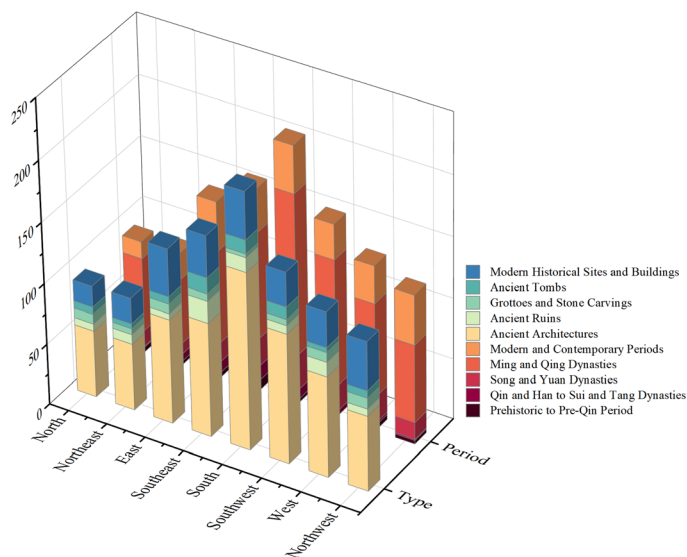
River system factors

The distribution of cultural heritage in Fujian Province is closely associated with river buffer zones. As a key element in the development of civilization, rivers not only provide the necessary water source for the livelihood and production of residents but also play a significant role in transportation, which has had a crucial impact on the selection of building sites and the concentration of heritage [55]. Fujian Province boasts a complex network of inland water systems, with a total of 763 rivers with a catchment area of over 50 square kilometres, with a combined length of 24,629 km. In particular, the "Five Rivers and One Creek" (Minjiang, Jiulong River, Jinjiang, Ting River, Sai River, and Mulan Creek) as the main rivers of Fujian Province have nurtured a wealth of cultural heritage. This study utilized open-source map data (OSM) and combined it with ArcGIS software to manually supplement some missing stream data and set the range of river buffer zones based on ancient walking speeds (5 km per hour).

Fig. 13 Distribution of cultural heritage under the influence of riverine factors

The data analysis results (Fig. 13) indicate that the distribution of cultural heritage exhibits a significant hydrophilic characteristic, with the majority of cultural heritage units (744, accounting for 65.72% of the total) concentrated within a 1-kilometer buffer zone of rivers. Within the 1 to 2-kilometer buffer zone, there are 172 heritage sites, 174 sites in the 2 to 5-kilometer range, while the number of cultural heritage sites beyond 5 km sharply drops to 42. Cultural heritage sites located more than 5 km from rivers, such as military castle sites, revolutionary sites, coastal Mazu temples, and stone carvings, are less constrained by natural geography. Residents of villages located in high-altitude mountainous areas often use mountain springs for water, while those in coastal villages tend to dig wells or process seawater, thus still managing to resolve issues such as accessing water for drinking and cooking despite being distant from major rivers and streams [56].

Sociocultural factors
#### Historical and cultural factors
The production of cultural heritage during historical periods is inextricably linked to the regional historical, cultural, and political environments. Cultural heritage serve as carriers of local history and culture, reflecting the regional historical and cultural background and political environment [57]. Conversely, these factors also influence the creation and preservation of cultural heritage, thereby affecting its spatial distribution. In terms of the historical and cultural environment, the number of ancient architecture and grottoes and stone carvings, which date back to the Sui, Tang, and Five Dynasties periods, notably increased. This surge can be attributed to the ruling class's strong advocacy for Buddhism during this era.

In considering historical and cultural factors, this study focuses on the imperial examination system and the presence of ancient academies, given the scope and reliability of ancient data. The number of successful candidates in the imperial examinations and the quantity of academies serve as objective indicators of the socio-economic and cultural vitality in various regions, reflecting the level of historical and cultural development. Drawing from the Historical Database of Successful Candidates in the Imperial Examinations, the data was filtered to include candidates who passed the "jinshi" examination and were from Fujian. The number of successful candidates from each dynasty is as follows: Tang Dynasty, 2 individuals; Song Dynasty, 7; Yuan Dynasty, 14; Ming Dynasty, 2298; and Qing Dynasty, 1399. This substantial rise in numbers compared to previous dynasties indicates a flourishing period of scholarly achievement and cultural development in Fujian during these eras. Furthermore, utilizing the Confucian culture research materials from the China Research Data Service Platform (CNRDS), a quantitative study of the Confucian cultural atmosphere across Fujian's regions was conducted. The data on academies was sourced from the "Dictionary of Chinese Academies", which documents academies from the Tang to the Qing dynasties. This resource was used to tally the number of academies in various Fujian regions, which to some extent reflects the historical emphasis on education in these areas.

A statistical analysis comparing the number of cultural heritage sites and successful candidates in the Ming and Qing dynasties in Fujian reveals that both are predominantly concentrated in Fuzhou (Fig. 14), followed by Quanzhou and Putian, and then Zhangzhou, which corresponds to the kernel density distribution of cultural heritage during the Ming and Qing periods. When comparing the number of cultural heritage sites with the

number of academies across Fujian's regions, a general trend of consistency is observed (Fig. 15). However, Nanping has the highest number of academies, which deviates from the trend in cultural heritage distribution. This discrepancy can be attributed to the significant influence of the renowned Neo-Confucian scholar, Zhu Xi, of the Southern Song Dynasty. He founded the Kaoting Academy in Nanping's Jianyang [58], where he completed important works such as the Commentary on the Four Books, establishing the foundation of the Neo-Confucian system and earning Nanping the title of "the land of Neo-Confucianism". Due to the widespread dissemination and influence of Zhu Xi's Neo-Confucian thoughts, the academy culture in the Nanping region was preserved and developed.
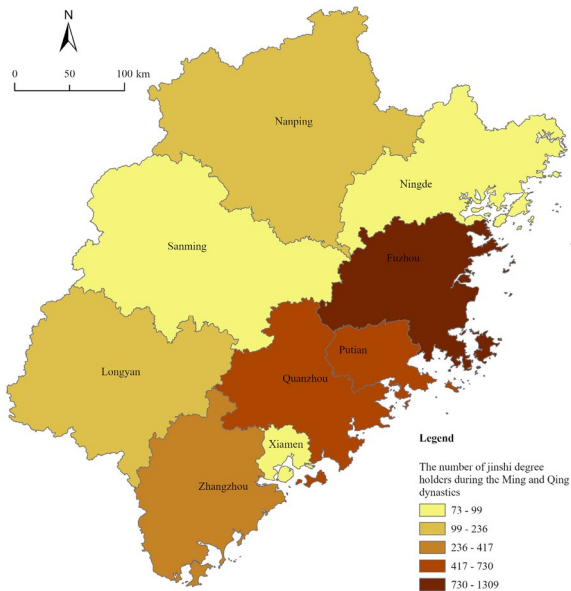
Fig. 14 The number of jinshi from Fujian Province in the imperial examinations during the Ming and Qing dynasties

The relationship between ancient cities and cultural heritage

The relationship between ancient cities and cultural heritage in Fujian Province is elucidated through a statistical analysis of the distribution of cultural heritage sites at varying distances from ancient urban centres (Fig. 16). The distances are categorised into four bands: <10 km, 10–20 km, 20–30 km, and ≥ 30 km. The overall analysis reveals a concentration of cultural heritage within a 10-kilometre radius of cities, accounting for 37.81% of the total, with a decreasing trend in distribution as the distance from urban centres increases. This pattern indicates that cultural heritage is predominantly located in the cores and peripheries of ancient prefectural and county cities, with a gradual decline in presence as one moves further away.
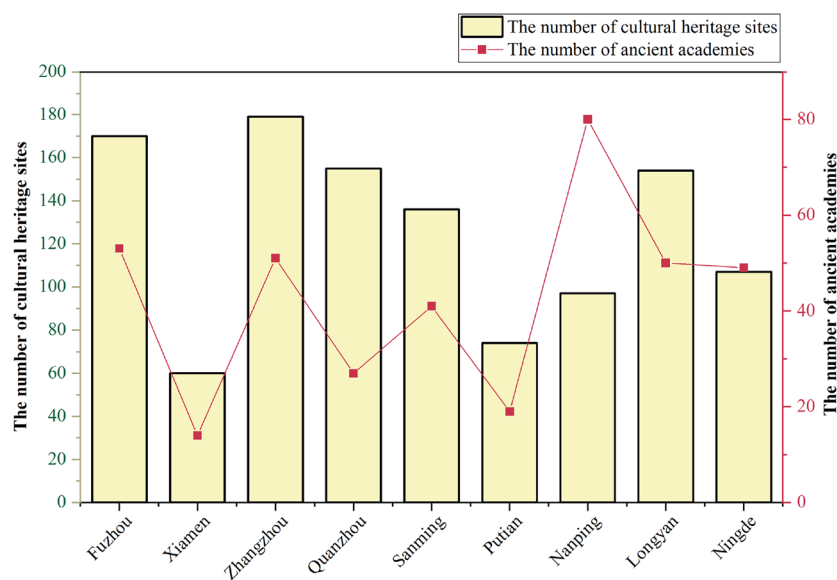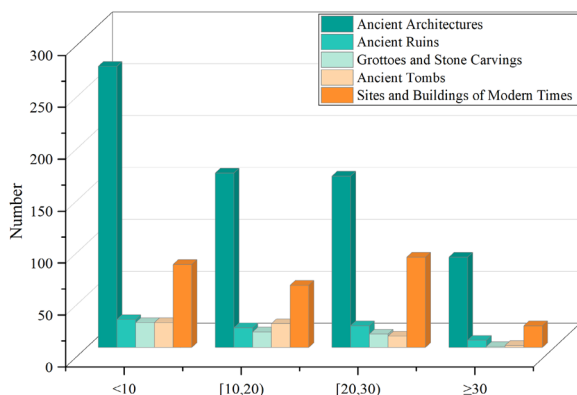

Fig. 15 Regional statistics on the number of ancient academies in Fujian
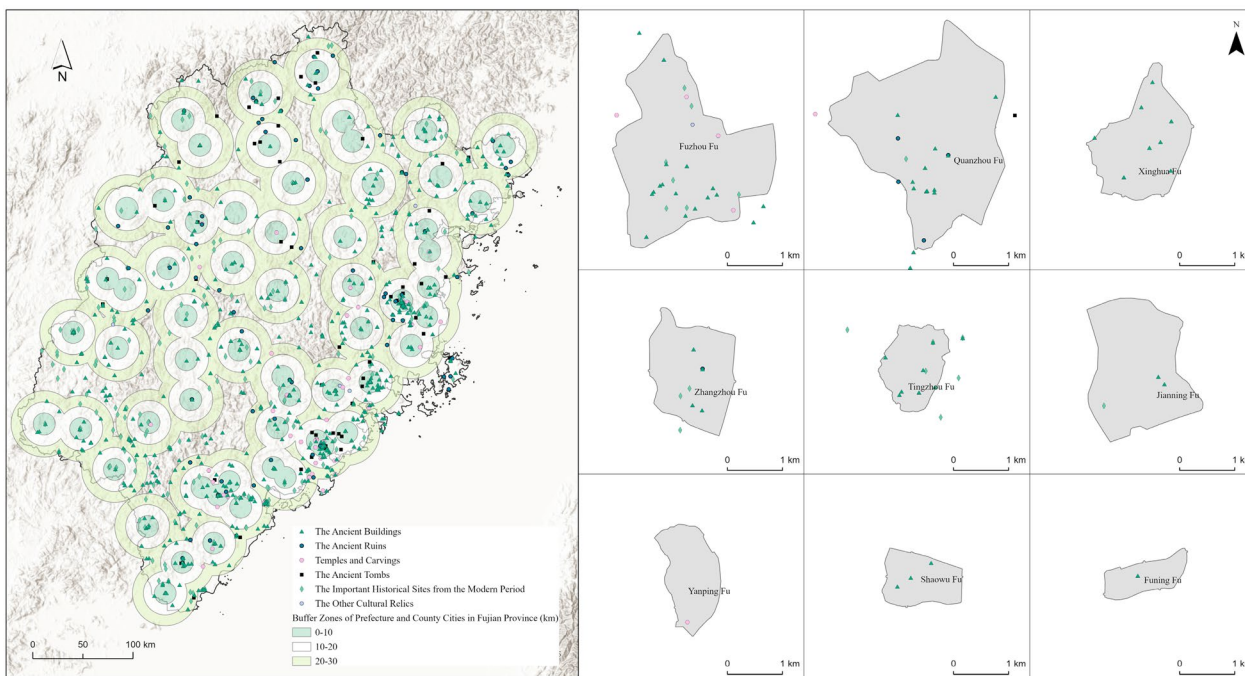
Fig. 16 Analysis of ancient prefecture city morphology and buffer zones in Fujian
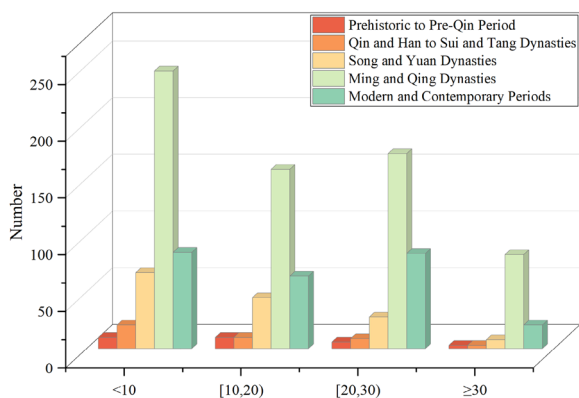

Fig. 17 The number of cultural heritage sites by type within ancient city buffer zones

Ancient architectural heritage is predominantly found within 10 km of cities (Fig. 17), comprising 39.22% of the total, followed by the 10–20 km range at 24.31% and the 20–30 km range at 23.88%, suggesting a preference for these structures to be clustered in the vicinity of ancient urban areas. The distribution of ancient ruins is relatively uniform, with the highest proportion located within 10 km, at 36.49%, echoing the trend observed in ancient buildings and indicating a proximity to cities. Grotto temples and stone carvings

are heavily concentrated within the 10-kilometre zone, at 45.28%, likely due to their status as significant cultural hubs, often situated in historically core areas on the outskirts of cities. Ancient tombs also show a similar trend, with a higher concentration within 10 km (40.00%) and the 10–20 km range (38.33%), while the number decreases significantly in the 20–30 km range (18.33%).

In contrast, modern historical sites are most numerous in the 20–30 km range, accounting for 35.08% of the total, with 87 sites in this category. This distribution suggests that modern historical sites are not confined to urban proximity and reflects the strategic thinking of the time, with relics of the war of resistance against Japan located in remote bases away from major cities. From a diachronic perspective, cultural heritage sites within < 10 km of cities consistently represent the highest proportion of the total for each period, reaching peaks of 48.84% in the Qin and Han to Sui and Tang dynasties, 45.27% in the Song and Yuan periods, and 37.23% in the Ming and Qing dynasties (Fig. 18).

In summary, the central and surrounding regions of ancient prefectural and county cities in Fujian Province serve as the primary loci of cultural heritage concentration. This distributional characteristic underscores the intimate relationship between the formation of cultural heritage and the historical development of urban centres.

Fig. 18 The number of cultural heritage sites by period within ancient city buffer zones

Economic factors

The impact of economic development on the production and lifestyle of the populace during historical periods is determinative. Consequently, epochs with higher levels of economic development tend to possess a greater abundance of cultural heritage resources [59]. The level of economic development is also closely linked to the preservation and utilization of contemporary cultural heritage. Under the current system of cultural heritage protection, the primary source of funding for the conservation of immovable cultural heritage is governmental financial expenditure [60]. The judicious exploitation of cultural heritage not only ensures adequate resources for the routine maintenance and restoration of heritages but also stimulates local economic growth. A comparison of the per capita GDP and the number of cultural heritage sites across various regions in Fujian in 2023 has revealed a positive correlation between the two variables (Fig. 19). The mismatch between the number of cultural heritage sites and economic factors in Xiamen can be attributed
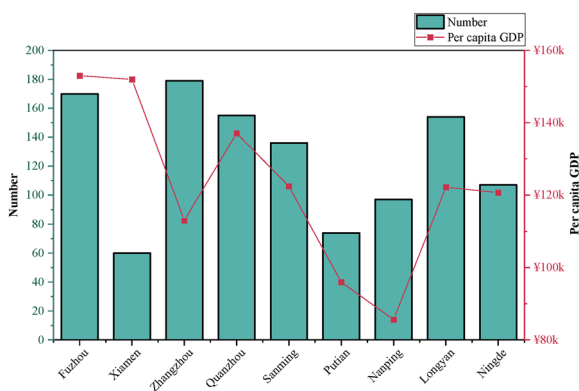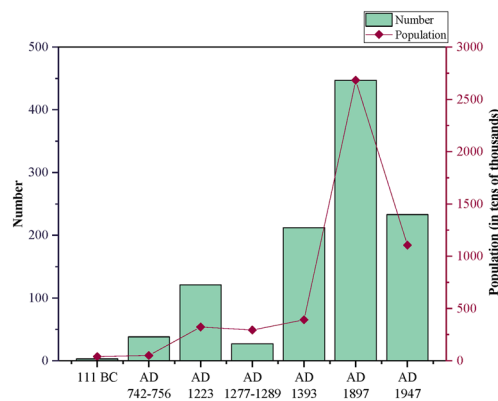
to its smallest land area among the several prefecture-level cities, which affects the density of cultural heritage sites relative to its economic output.

Population and land cover factors

The population serves as a fundamental condition for societal and economic advancement, as well as an indicator of its maturation [61]. Cultural heritage is ultimately the product of human creation, hence demographic shifts play a crucial role in shaping the distribution of cultural heritage. A comparative analysis was undertaken to examine the relationship between historical population sizes in Fujian and the quantity of cultural heritage. The analysis reveals that epochs with higher population counts in Fujian's history corresponded to greater amounts of cultural heritage (Fig. 20). For example, the Ming and Qing dynasties witnessed the highest historical population in Fujian, reaching nearly 26.83 million, and concurrently, the largest number of cultural heritage sites. In contrast, during the Republic of China era, a significant decline in population was accompanied by a decrease in the number of heritage sites. These patterns indicate that demographic changes have a profound impact on the spatial distribution of cultural heritage.

The land cover types in the locations of cultural heritage sites in Fujian Province (Fig. 21) primarily include water areas, trees, crops, built areas, bare ground areas, and rangelands areas [62]. Among these, built areas have a substantial impact on all types of cultural heritage, with a total proportion of 88.87%. The influence is particularly pronounced on ancient buildings, which account for 92.47% of cultural heritage sites under this land cover type. This high percentage likely reflects the significant impact of urbanization on the distribution of ancient buildings. Additionally, the land cover type of Trees has a considerable influence on ancient sites and grotto

Fig. 19 Comparison of GDP per capita and the number of cultural heritages distributed in each prefecture-level city

Fig. 20 Trend of cultural heritage quantity and population change in historical periods
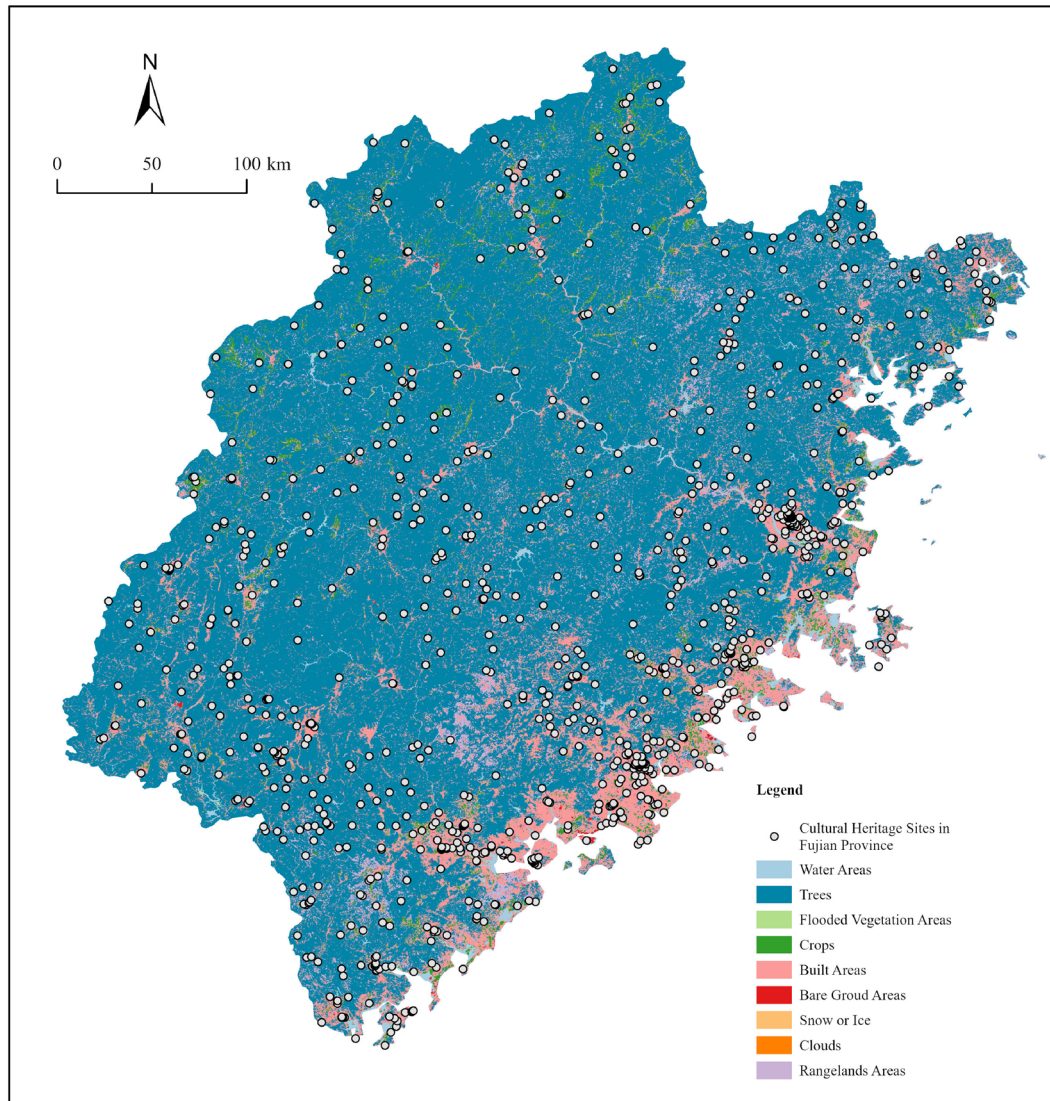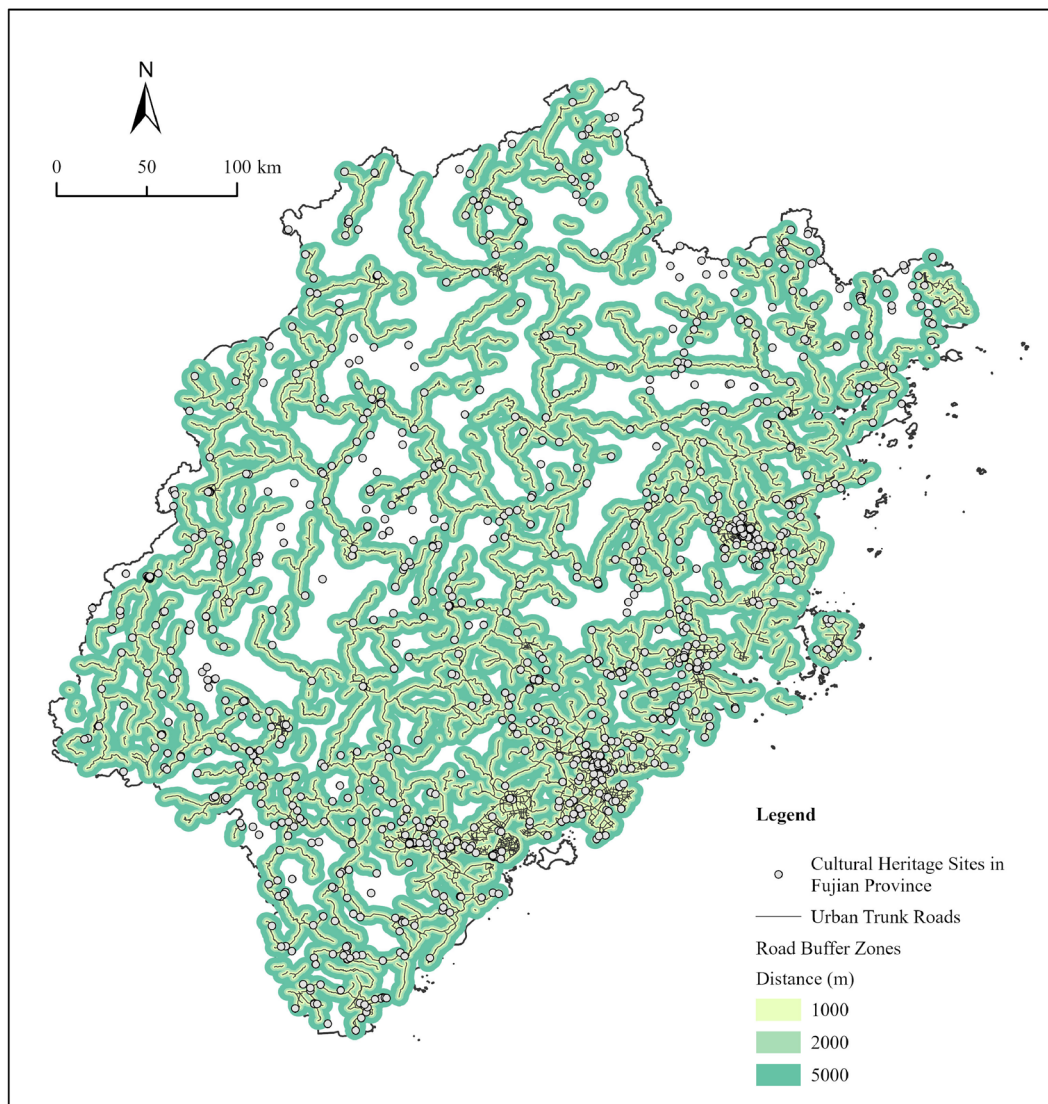
Fig. 21 Cultural heritage sites in Fujian under the influence of land cover factors

temples, accounting for 13.51% and 9.43% of cultural heritage sites in these categories, respectively. This suggests that these cultural heritage sites are often surrounded by areas with substantial greenery.

Transportation factors

The spread of culture and trade is inseparable from the road network, with the emergence of cultural heritage core areas partly due to the continuous expansion of the centre's civilization to the periphery. Areas where transportation converges often experience economic prosperity, and roads serve as a marker of social and economic development as well as population aggregation, hence the relatively dense distribution of cultural heritage [63].

Due to the lack of detailed data on ancient transportation routes in Fujian, modern datasets are employed for analysis. A buffer zone analysis was conducted for the main traffic thoroughfares within Fujian Province at radii of 1 km, 2 km, and 5 km (Fig. 22). The results show that within the 1 km, 2 km, and 5 km buffer zones of the main roads, there are 772, 115, and 142 cultural heritage sites, respectively, accounting for 91% of the total sample. The highest number of cultural heritage sites is found within 1 km, indicating that the spatial distribution of cultural heritage in Fujian Province exhibits a decreasing trend from urban main roads to the periphery. This demonstrates that the distribution of cultural heritage has a distinct transport-oriented characteristic.

Fig. 22 Buffer zone of main roads in Fujian Province

Conclusions

This study, based on 1,132 provincial-level and above cultural heritage sites in Fujian Province, employs GIS spatial analysis methods to investigate the spatiotemporal evolution and influencing factors of cultural heritage in Fujian Province during historical periods. The research conclusions are as follows:

1. In terms of spatial distribution, cultural heritage exhibits a clustered distribution pattern, forming specific spatial clusters. The concentration area of cultural heritage has gradually shifted from the upper reaches of the Minjiang River in the prehistoric and pre-Qin periods to the lower reaches and has become concentrated in coastal cities such as Fuzhou, Quanzhou, Putian, and Xiamen.

2. In terms of temporal distribution, the number of cultural heritages has fluctuated, with a relatively abundant quantity during the Ming and Qing dynasties. Regarding the types of cultural heritages, ancient sites predominated in the early periods, while the number of ancient buildings gradually increased from the Qin and Han to the Sui and Tang dynasties, reaching a peak during the Ming and Qing dynasties. In modern and contemporary times, important historical sites and representative buildings have become the main types.

3. The spatiotemporal evolution of the cultural heritage layout indicates that the centre of gravity of cultural heritage distribution has shifted with historical development, from the northwest to the south and finally

towards the southwest, exhibiting a trend of transfer from northern Fujian to eastern and southern Fujian.

4. Natural factors have played a crucial role in the distribution of cultural heritage. Cultural heritage is mainly concentrated in plains below 200 m and hilly areas between 200 and 500 m, with the highest number of cultural heritages found on gentle slopes with gradients between 0.5° and 2.0°. The distribution is more concentrated on south-facing and southeast-facing slopes and is most dense within 1 km of rivers.

5. Sociocultural factors significantly influenced the distribution of cultural heritage. Historical culture, economy, and population factors had a positive impact on the spatial and temporal distribution of cultural heritage sites. The central and surrounding areas of ancient cities were the primary locations for the concentration of cultural heritage. Built areas had a significant impact on cultural heritage, with the highest number of heritage sites found within 1 km of major roads.

This study explores the spatiotemporal distribution patterns and influencing factors of cultural heritage in Fujian, addressing gaps in previous research and providing valuable insights for future heritage protection and utilization. The application of GIS spatial analysis proves to be a robust tool for examining cultural heritage distribution across diverse geographical and cultural contexts, facilitating cross-regional comparisons and informing universally applicable conservation strategies. The framework established herein serves as a globally applicable model for cultural heritage preservation and management, fostering a deeper understanding of conservation practices worldwide. This methodological approach not only bolsters regional cultural heritage management but also provides invaluable reference for international conservation efforts. Future research should focus on expanding the scope to include lower-level heritage sites, incorporating historical geographical data, and exploring the framework's application in diverse global contexts to refine its universal applicability. Ultimately, this study contributes significantly to advancing the field of heritage geography, offering a path forward for more effective, context-sensitive, and globally relevant approaches to cultural heritage management.

Author contributions
Conceptualization: JF, HM; Methodology: JF, HM; Validation: JF; Writing - Original Draft Preparation: JF. All authors have read and agreed to the published version of the manuscript. Corresponding author: Correspondence to Huasong Mao.

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