

Article

GIS-Based Analysis of the Regional Typology of Neolithic Archaeological Cultures in the Taihu Lake Region of China

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Abstract: The study of the evolution of regional typology of archaeological cultures is essential in understanding the trajectory of cultural evolution from a temporal and spatial perspective. In this paper, we focused on the Taihu Lake region, one of the six major regional typologies of Neolithic archaeological cultures in China. By utilizing archaeological site data from the Neolithic Era in this region, our study investigates the evolution of typologies in archaeological cultures at both regional and sub-regional scales. From a broad perspective, quantitative methods were used to explore the cultural evolution process in the Taihu Lake region. The degree of social integration and intercultural inheritance can be reflected through the size of the site and the superimposition of cultural layers. In addition, climate and environmental data were combined to investigate its driving factors. Moreover, GIS (Geographic Information System) analysis methods were used to cluster and partition the cultures in the Taihu Lake region. By identifying distinct groups of sites, it is possible to deconstruct and analyze the interior of the cultures to study their distribution patterns and to explore the exchanges and expansions within the cultures. By integrating both research approaches, our study provides a comprehensive analysis of the evolutionary characteristics of the regional typology of archaeological cultures within the Taihu Lake region. These findings contribute to the development of quantitative methods for studying the evolutionary trajectory of archaeological cultural systems.



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Keywords: GIS analysis; regional typology of archaeological cultures; Taihu Lake region of China; neolithic era

1. Introduction

Archaeology is an important support for understanding the origin and history of mankind and passing on civilization. Regional typology of archaeological cultures is used to restore the original historical appearance through the division of cultural types the in-depth understanding of cultural connotations and the exploration of their interrelationships within a temporal and spatial framework [1]. The study of the regional typology of archaeological cultures can provide insight into the historical process of the evolution or demise of archaeological culture, which is a kind of spatiotemporal exploration of culture, and what lies behind it is the orderliness and regularity of the creation and evolution of archaeological culture [2].

The Taihu Lake region, as one of the six major regional typologies of Neolithic archaeological cultures [1], holds significant importance in the origins of ancient Chinese civilization. Acting as a relatively independent geographical unit, this region is a crucial research area for Neolithic cultural archaeology. Encompassing the Majiabang, Songze, and Liangzhu cultures, which share a common lineage and serve as a comprehensive framework for studying prehistoric culture systems [3], the Taihu Lake region is an optimal subject for investigating the evolution of regional typologies in archaeological cultures.

With the increasingly widespread application of GIS in the field of archaeology, its spatial analysis methods provide powerful data processing and information analysis methods for the study of cultural evolution in archaeology and are of great significance for both qualitative and quantitative analysis [4]. By applying GIS to the study of spatial distribution and evolutionary processes of archaeological cultures, researchers can explore the underlying patterns and gain a deeper understanding of cultural evolution. Focusing on the Taihu Lake region, this study aims to investigate the spatial and temporal distribution characteristics and evolutionary patterns of Neolithic cultures in this area. The objective is to scientifically reconstruct and interpret the trends of prehistoric cultural evolution and the mechanisms that influenced them; gain a deeper understanding of the generation, inheritance, and evolutionary processes of the regional civilization around Taihu Lake; and provide a foundation for the protection of archaeological culture sites.

2. Related Work

Since the mid-19th century, the concept of “archaeological culture” has been established in Western archaeology and has become a fundamental unit for studying history through the investigation of remnants and artifacts worldwide [5]. Later, the concept of “cultural zones” [6] was proposed as a way of constructing archaeological and cultural sequences in different regions and arranging archaeological materials spatially and temporally with the help of artifact typology, in which the principle of “similarity as proximity” evolved into the theory of cultural zone typology, which was matured with the incorporation of methods such as propagation theory and typology. On this basis, Su Bingqi (1981) defined the theory of “regional typology of archaeological cultures” based on the distribution and characteristics of over 6000 prehistoric sites and dozens of cultures in six major geographical regions of China, thus forming a crisscrossing archaeological cultural development system in both time and space dimensions [1].

The Taihu Lake region is one of the six major archaeological cultural systems in Chinese prehistory, and it can be divided into different layers of cultural subdivisions within it. Wang Yonglei (2013) combined geographic factors and typical artifact characteristics to divide the Taihu Lake region in the Majiabang period into three regions: the Hangjiahu region, the Susong region, and the region west and south of the Taihu Lake [7]. Mu Dongxu (2017) divided the Songze Culture in the Taihu Lake region into five subregions based on the differences in typical artifacts from different regions [8]. Regarding the zoning of archaeological cultures in the Taihu Lake region, although there have been numerous research findings, there is currently no widely accepted consensus among scholars. Previous research on regional division primarily focused on the material cultural aspects centered around pottery and referenced natural geographic units to establish zoning for cultural areas. In terms of methodology, qualitative methods have been commonly used to determine cultural zoning, while quantitative methods have been rarely explored. In terms of results, most of the zoning boundaries are fuzzy, and when represented on maps, only rough outlines are drawn, which does not facilitate clear delineation of the zoning boundaries. Cultural zoning is a foundational work for conducting regional studies, and dividing these different-sized cultural zones and gaining a deeper understanding of their contents helps us explore the spatial distribution and evolutionary relationships between different cultural areas.

With the introduction of geometric methods and GIS archaeological spatial analysis methods, research on archaeological cultural regions is also moving towards quantification and modeling. The complex and ever-changing natural environment is considered an objective prerequisite for forming cultural zones [9]. Chen (2018) divided the site cluster for ranking based on the area of the site [10]. Hermon (2017) used a fuzzy logic-based approach to represent the spatiotemporal associations of archaeological cultures [11]. Zheng (2008) [12] used stacking coefficients to explore the inheritance and spatial transfer patterns of human settlements in the Three Gorges Reservoir Area of Chongqing, China, from the Paleolithic to the Tang and Song dynasties, to assess the degree of human social

evolution and to analyze the trajectory and evolution patterns of cultural inheritance. Using GIS spatiotemporal analysis methods, Li (2013) analyzed and compared the evolution patterns of different cultural regions in the Han River Basin of southern Shaanxi, China, during the Neolithic Era from both vertical and horizontal distribution perspectives [13]. Song (2022) studied the spatiotemporal relationship of cultural sites in the Hetao area of China during the Neolithic Era from the aspects of agglomeration, distribution density, and center of gravity displacement [14]. From these examples, it can be seen that GIS spatial analysis methods can provide quantitative and scientific analytical tools from a spatiotemporal perspective for studying the development and evolution of regional typology of archaeological cultures.

In summary, the theory of cultural typology is based on archaeological culture and promotes research on social hierarchy, cultural inheritance relationships, and spatial pattern evolution related to archaeological culture. The nature of archaeological district culture includes temporal and spatial attributes, characteristic artifacts, and cultural interactions, including social environment, social organizations, and their evolutionary mechanisms. Within the same cultural district, different archaeological cultures often have a relationship of inheritance and development, and at the same time, the zoning of each culture is not static. With the application of new technologies and methods, research on regional culture is gradually shifting from qualitative to quantitative. Integrating principles of archaeology, archaeological research, and GIS spatiotemporal analysis can make the study of archaeological cultural regions more scientific. However, current archaeological research lacks effective utilization of archaeological data and comprehensive quantitative research on archaeological cultural regions.

Focusing on both the regional and sub-regional scales of sites and site clusters, the purpose of this study is to investigate the evolution of archaeological cultural area series in the Taihu Lake region. On the one hand, we start from the archaeological culture sequence as a whole and explore the degree of social integration and the response relationship with the natural environment from the scale of the sites and the superposition of cultural layers; on the other hand, we carry out a zoning study based on GIS to analyze the degree of spatial and temporal aggregation within a single culture and its cultural appearance, to reveal the evolution process of the archaeological culture within the region. By combining the overall Neolithic culture and the internal zoning of the Taihu Lake region, this study not only focuses on the overall culture but also takes into account the individuality of each zone, which can reflect the evolution of the prehistoric culture more comprehensively and thus provide qualitative and quantitative research and analysis bases for the reproduction of the prehistoric civilization in the Taihu Lake region.

3. Materials and Methods

3.1. Research Area

As mentioned earlier, the Taihu Lake region, as an important area among the six major regional typologies of Neolithic, serves as a regional cultural center in the prehistoric Lower Yangtze River area. The scope of this area varies depending on the research period and perspective. In a broader sense, it includes the lower Yangtze River region and the Qiantang River basin. In a narrower sense, it specifically refers to the Taihu Lake basin, which roughly encompasses the plain areas west of the East China Sea, east of Maoshan, south of the Yangtze River, and north of the Qiantang River [15]. Due to the richness of archaeological excavation materials and the stability and independence of archaeological culture development, this study adopts the latter definition as the research area. Figure 1 shows the distribution range of the study area in this paper, and Figure 2 depicts the approximate extent of the Taihu Lake region.



Figure 1. Scope of the study area.



Figure 2. Taihu Lake region.

For a long time, the Chinese archaeological community has conducted in-depth excavations and explorations of the Neolithic sites and cultures in the Taihu Lake region. They have confirmed that three prehistoric archaeological cultures, namely the Majiabang Culture, Songze Culture, and Liangzhu Culture, successively existed in the region. These cultures are part of the same lineage and exhibit orderly succession, providing a clear and complete sequence of social development. Among them, the Majiabang Culture is the earliest Neolithic culture discovered in the Taihu Lake region. An in-depth understanding of its distribution and evolutionary process will help us understand the origin of civilization in the Taihu Lake region [16]. The Songze Culture represents an important transitional stage from the Majiabang Culture to the Liangzhu Culture in the Taihu Lake region. However, due to relatively thin sedimentary deposits, there are only a few sites with simple contents associated with the Songze Culture. Therefore, research on the Songze Culture has always been a relatively weak aspect of archaeological and cultural studies in the Taihu

Lake region [17]. The Liangzhu Culture represents the peak of archaeological and cultural development in the Taihu Lake region following the Songze Culture. During this period, the archaeological remains in terms of quantity and distribution were unprecedented. It was also during this period that the Taihu Lake region entered the threshold of the civilized era [18]. The study of these three cultures is of great significance in exploring the origin of Chinese civilization and the laws and characteristics of socio-cultural development.

3.2. Data

This study utilized Chinese archaeological texts as the primary data source and focused on the Taihu Lake region as the research area. The original data for this study were collected and organized from various sources, including the “Atlas of Chinese Cultural Relics” [19], the “Dictionary of Chinese Archaeology” [20], the results of the Third National Cultural Relics Census, and 587 Neolithic site entries related to the Taihu Lake region from Baidu Baike, an online encyclopedia. Using information extraction methods [21], meaningful words or phrases such as site names, geographical locations, chronological periods, historical dynasties, area sizes, and excavated artifacts were selected as archaeological entities from the texts. These entities provided the foundational information of the sites for this research.

3.3. Methodology

This study was conducted from two perspectives. On the one hand, from a macro scale, it explored the social organization, civilization evolution, and inheritance relationships of various archaeological cultures in the Taihu Lake region by analyzing the area size and cultural layer accumulation of archaeological sites. It incorporated methods such as rank-size analysis and superimposition coefficient to provide preliminary insights into the macro-level aspects of these archaeological cultures. On the other hand, using GIS spatial analysis methods, it divided the Majiabang Culture, Songze Culture, and Liangzhu Culture within the Taihu Lake region into different blocks based on site aggregation, geographical location, topography, and hierarchy. It quantitatively described the range and distribution direction of the core distribution areas in each cultural sequence, explored the evolution trends of spatial and temporal distribution patterns, and focused on the transformation of cultural characteristics during the development of cultural sequences. Finally, by combining these two research perspectives, it comprehensively analyzed the evolutionary characteristics of archaeological culture sequences in the Taihu Lake region.

3.3.1. Methods for Quantifying Archaeological Cultural Hierarchies

The size of archaeological sites is typically positively correlated with the thickness of cultural layers. Regions with rich archaeological remains are often geographically advantageous and have larger site sizes. Therefore, site size can reflect the social hierarchy of the archaeological culture it belongs to. Through quantitative analysis of the rank distribution of site sizes, the hierarchical distribution of site sizes in a specific culture can be revealed. The “rank-size” analysis method examines the correlation between site size and its rank order, quantitatively analyzing the hierarchical distribution of site sizes during different cultural periods. By comparing the measured data curve with the expected straight line, the level of social complexity of the culture in the region can be inferred [22]. First, the site sizes are sorted from largest to smallest. The first rank is the site with the largest size, the second rank is the site with the second largest size, and so on. According to the “rank-size” rule, the size of a specific site with rank order r is equal to the size of the largest site divided by r . The statistical results can be represented by a straight line in a log-normal distribution. Different curves reflect different levels of social integration, which have been comprehensively explained [23]. The “rank-size” analysis method has been widely used in the study of Paleolithic and prehistoric settlements worldwide [24].

3.3.2. Methods of Analyzing Cultural Inheritance in Archaeology

Cultural coexistence and diachronic evolution can reflect the internal differences within social organizations. This is manifested in the superimposition of cultural layers, which can demonstrate the development, evolution, and fusion processes of archaeological cultures with neighboring cultures. The continuity of archaeological cultures can be explored by the number of cultural types included in the sites. The accumulation of cultural layers in the Neolithic period can be divided into two types: one is sites with only one cultural layer, known as single-type sites [25]; the other is sites containing cultural layers from different periods, known as superimposed sites [26]. Huang (1996) [27] proposed the concept of the cultural superimposition coefficient, which is calculated using the following formula:

$$C_{\frac{a}{b}} = \frac{n}{N} \quad (1)$$

Here, a denotes an early culture site; b is a late culture site from a neighboring culture period; n refers to the number of sites with category b overlaid on category a ; and N is the total number of sites in category a . The superimposition coefficient is an important indicator for investigating the rate of reuse of early sites in later periods, and it is used to quantitatively determine whether there have been changes in the location of sites during historical development. Due to the differences in natural conditions in different regions, there can be variations in the patterns of archaeological cultural succession and inheritance [28]. Therefore, conducting a longitudinal analysis of cultural complexes by considering the natural environment is crucial. In this study, the types and quantities of cultural artifacts found at the sites are used to investigate the continuity of archaeological cultures.

3.3.3. Methods of Cultural Zoning in Archaeology

To determine the spatial zoning of archaeological cultures, in this study, Tyson polygons are utilized to delineate the geographical scope of Neolithic sites. The Tyson polygon method is an important analytical method for elucidating the relationship between the spatial location of a site and its geographic environment, the extent of the site domain, and the spatial and temporal distribution and evolutionary process of settlements. It has been widely applied in the study of settlement morphology [29,30]. The basic principle is to assume that two neighboring contemporaneous sites have equal possibilities to develop and control the intermediate zone. Therefore, the extent of their development and control of the intermediate zone can be delineated between the two sites by a vertical bisector line, forming a Tyson polygon that serves as the theoretical control zone for that settlement. This method is consistent with the resource-oriented development model of archaeological settlements and can effectively elucidate the degree of control of the settlement over the region [31].

Based on the Tyson polygon, the kernel density estimation can be used to show the dense area of the site more intuitively and clearly, and it is easy to find the pattern. Kernel density estimation estimates the probability density of a given point by calculating the sum of the contributions to the probability density from data points located in the vicinity of the point, calculated as follows:

$$Density = \frac{1}{(radius)^2} \sum_{i=1}^n \left[\frac{3}{\pi} \cdot pop_i \left(1 - \left(\frac{dist_i}{radius} \right)^2 \right)^2 \right] \quad (2)$$

Here, *Density* is the kernel density estimation result; *radius* denotes the given radius distance; *pop_i* is the population field value of point i , which is an optional parameter; $i = 1, \dots, n$ are the input points; and *dist_i* is the distances between point i and the (x, y) position. The specified field value and the distance from the predicted position together determine the weight factor for point i . For all points i within the radius distance, the computed results are summed up and the final sum is the kernel density estimate.

3.3.4. Methods of Analyzing the Evolutionary Patterns of Archaeological Culture

By analyzing the distribution direction and trend of sites in each subdistrict, we can derive the evolution pattern of their spatial and temporal distribution direction [32]. The ArcGIS 10.4 standard deviation ellipse calculation tool is used in this study to investigate the dispersion level and spatial distribution direction of the three major cultural site clusters within the Taihu Lake region during the Neolithic period. By analyzing the distribution direction and trend of sites in each region, the evolutionary pattern of their spatial distribution can be determined (Gong, 2002) [33]. To be able to clearly show the directionality and dispersion of the sites within the limited map space, we chose the standard deviation ellipse of 1_STANDARD_DEVIATION, which can contain 68% of the site point data.

4. Results

4.1. Archaeological Cultural Hierarchies Based on Rank–Size Analysis

A rank–size plot is generated based on the calculation of site area, where the x-axis represents the rank of site area and the y-axis represents the area of the site in square meters. The SETSIZE curve represents the site area, the SIZEUP curve represents the maximum estimated value of the site area, and the SIZELO curve represents the lowest estimated value of the site area. The lognorm line represents the uniform log-normal line of the logarithmic function. The A coefficient refers to the area between the SIZEUP and SIZELO curves, and this coefficient can be used to measure the deviation between the “rank–size” curve and the uniform log-normal line. Figure 3a–c show the “rank–size” plots of three cultural periods.

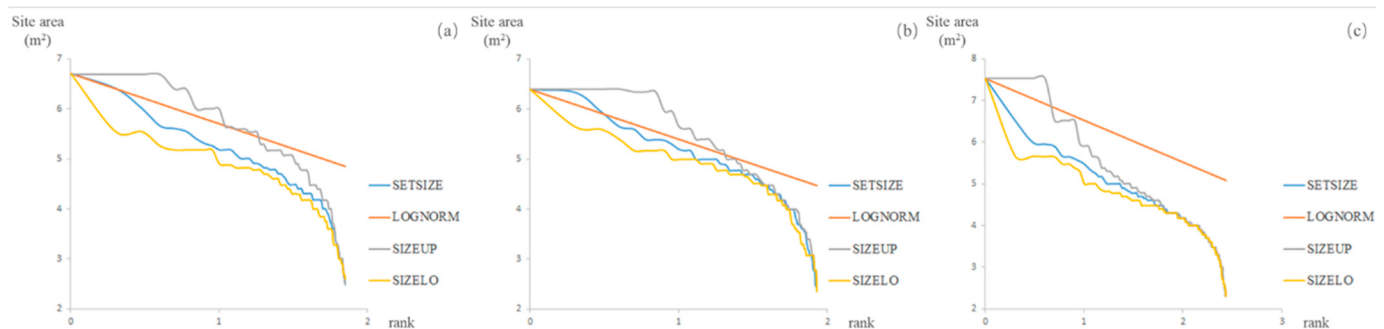


Figure 3. The rank–size graphs of the Majiabang, Songze, and Liangzhu Culture sites. (a) Majiabang Culture sites, (b) Songze Culture sites, and (c) Liangzhu Culture sites.

By analyzing the rank–size plots of site areas in each cultural period, we find that the rank–size curve of the Majiabang Culture site (Figure 3a) exhibits subtle primacy characteristics ($A = -0.523$) and is closer to the uniform log-normal line. The distribution of large site areas indicates a certain regularity in the hierarchical organization of large sites and suggests a higher degree of integration and the presence of dominant centers in the region. The rank–size curve of the Songze Culture site area (Figure 3b) shows that only the initial larger sites exhibit a convex rank–size pattern, while the overall trend is concave ($A = -0.223$). This indicates a higher degree of integration among the site clusters in the Taihu Lake region during this period. Larger sites may have had more resources and a certain advantage, exerting influence on surrounding settlements and possibly leading to resource competition and conflicts. In the later part of the curve, the concave pattern of smaller sites suddenly becomes stronger, suggesting the existence of a more dominant central settlement in the region. The rank–size curve of the Liangzhu Culture site area (Figure 3c) is significantly different from the previous two periods, showing prominent primacy characteristics ($A = -0.935$). This indicates a trend toward a unified settlement system during the Liangzhu period, which is consistent with the significant social differentiation, unified beliefs, and the emergence of a regional early state during

this period. A large amount of labor was concentrated in the largest site, which is closely related to the extensive construction activities carried out in the highest-ranked Liangzhu site, such as palaces, altars, and water conservancy systems.

4.2. Analysis of Cultural Inheritance in Archaeology Based on Superposition Calculations

As mentioned in Section 3.3.2, superimposed sites are stable and continuous cultural inheritances formed by long-term human habitation in a certain area. In this paper, we focus on the discussion of continuously superimposed sites. In the Taihu Lake region, there are 12 sites with overlapping Majiabang–Songze cultures, 37 sites with overlapping Songze–Liangzhu cultures, and 10 sites with overlapping Majiabang–Songze–Liangzhu cultures, as shown in Figure 4.

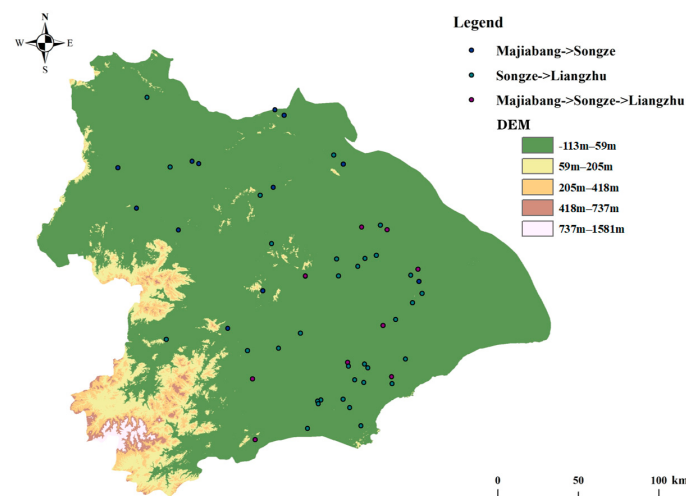


Figure 4. Distribution of superimposed sites around the Taihu Lake region.

The results of the superposition coefficients of sites in each period were calculated as shown in Table 1.

Table 1. Stacking factor.

Parameters	Majiabang–Songze	Songze–Liangzhu
Number of early culture sites (N)	74	88
Number of category a sites overlying category b sites (n)	22	447
Stacking factor (C)	0.30	0.53

From the table, it can be observed that the superimposed sites from the Majiabang–Songze period are dispersed, with fewer sites in the southwestern part of Taihu Lake. Moreover, the stacking factor of the Majiabang–Songze period is 0.3, which is relatively low, indicating that a large number of people relocated from their original settlements, resulting in the discontinuation of most early sites. This suggests that there may have been significant changes in climate and environment during this period, forcing the ancestors to move from their original habitats. Some studies show that compared to the stable and warm humid climate of the Majiabang period, there were fluctuations in temperature and precipitation in the early and middle periods of the Majiabang–Songze period, with extreme climates such as sudden cooling and severe drought [34]. Most of the superimposed sites from the Songze–Liangzhu period are concentrated in the southeast and east of Taihu Lake, with few sites in the southern and northern parts of the lake. The stacking coefficient of this period is as high as 0.53, implying a good succession of sites, with more than half of the sites continuing and developing. Compared with the Majiabang–Songze period, the number of superimposed sites in the eastern and southeastern parts of Taihu Lake

increased significantly, reflecting the good and stable natural environment here, which was more suitable for the survival and development of the ancestors. However, there are still a large number of sites that have not inherited the location of the earlier sites, which may be related to the changes in local geographic conditions and access to factors of production.

4.3. Archaeological Cultural Subdivisions

4.3.1. Majiabang Culture Subdivision

We analyzed the kernel density of 74 Majiabang Culture sites and superimposed the Tyson polygons and kernel density analysis results, as shown in Figure 5. From Figure 5, it can be found that the sites show a spatial pattern of “multi-core distribution”, and at the same time, there are also some smaller and denser Tyson polygons distributed in the figure. Next, the polygons belonging to the same site group will be merged, and the basis for the merger is as follows: first, the Tyson polygons belonging to the sites with a distance of less than 10 km from each other will be merged; second, according to the density value of the core density of the site, the Tyson polygons belonging to the same level of isotopic surfaces will be merged; and third, the natural geomorphology will be taken into account, such as the river and mountainous areas of the blockage. The merged Majiabang Culture zones are shown in Figure 6.

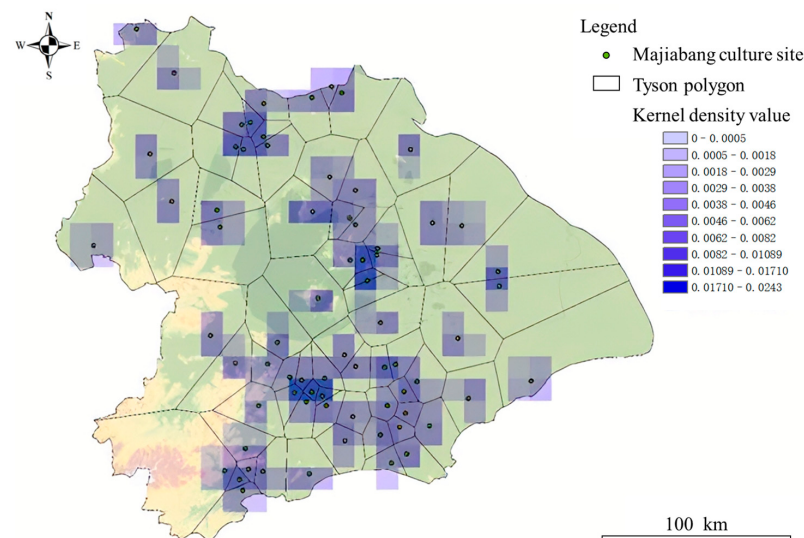


Figure 5. The results of the Tyson polygon stacked kernel density analysis.

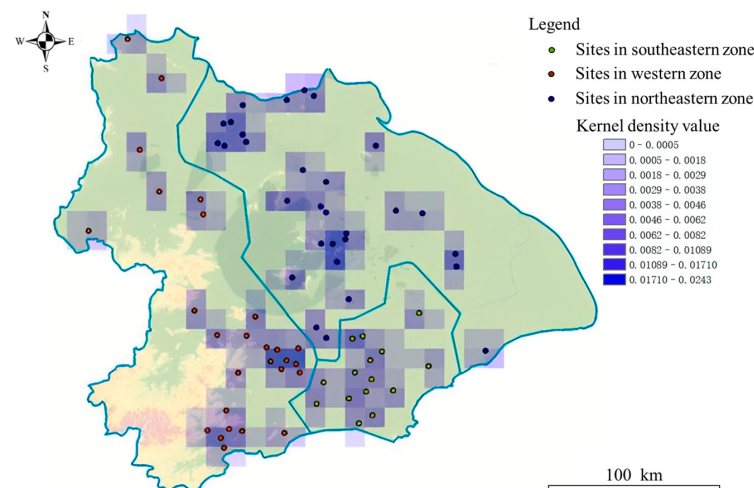


Figure 6. Majiabang Culture zones.

Based on the results, we divided the Majiabang Culture in the Taihu Lake region into three small zones, namely the western zone (27 sites), the northeastern zone (32 sites), and the southeastern zone (15 sites).

4.3.2. Songze Culture Subdivision

Similar to the research method of Majiabang Culture zoning, we created Tyson polygons for 85 Songze Culture sites, combined with the results of the kernel density analysis, merged the Tyson polygons based on the rules, and finally completed the zoning. The results are shown in Figure 7.

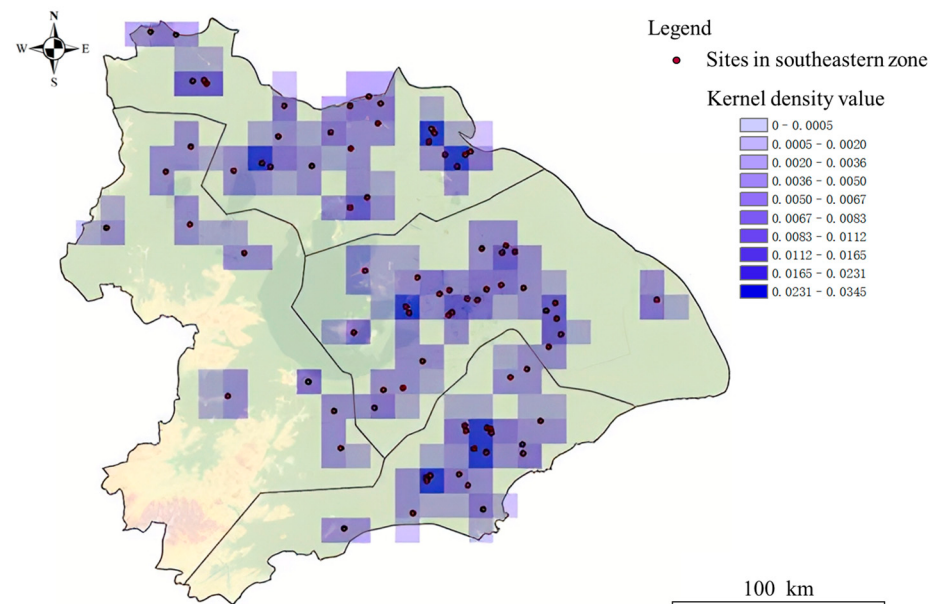


Figure 7. Songze Culture zones.

Based on the results, we divided the Songze Culture in the Taihu Lake region into four small zones, namely the north zone (twenty-eight sites), the south zone (twenty-one sites), the west zone (nine sites), and the east zone (twenty-seven sites).

4.3.3. Liangzhu Culture Subdivision

The number of Liangzhu Culture period sites in the Taihu Lake region is relatively large, the distribution is relatively centralized, and there is a hierarchical division of settlements. Different levels of settlements have a management and control relationship with each other, and in the space, the low-level settlements are shown as the arching of high-level settlements, which provides the basis and prerequisites for the investigation of the spatial and temporal distribution pattern of archaeological sites. Therefore, instead of using Tyson polygons to divide each site directly, we first determine the high-grade sites in the site cluster consider them as the center of the settlement and then carry out the intra-cultural zoning based on the previous method.

Decision tree classification is a basic algorithm for spatial data mining [35], which is suitable for dealing with a large amount of site data and is utilized in this paper to assess sites of unknown grade. Taking into account the importance of jade artifacts in Liangzhu Culture, in this study, the site area, the type of remains, and the type of jade artifacts (including the three types of jade ceremonial artifacts, namely jade cong, jade bib, and jade battle-axe) were used as the set of characteristic variables for constructing the decision tree. The sample data were selected from high-grade sites and non-high-grade sites that are generally recognized in the academic community [36,37]. The total number of training samples was 29 (70% of the data as the training set and 30% of the data as the test set), and the decision tree model is visualized as shown in Figure 8, where HS denotes

high-grade sites and n_HS denotes non-high-grade sites. The significance of the data in the second and following rows is as follows: the first column is the value of the site area, the second column is the number of types of remains, the third column is the number of types of valuable artifacts, and the fourth column corresponds to the site grade (1 for high grade and 2 for non-high grade). The classification accuracy of the constructed decision tree was evaluated, and the evaluation index is the accuracy of the classification of the test set. After evaluation, the accuracy rate was 0.9, and the decision tree was considered to be qualified, and the model could be used to determine the high-grade sites in the Liangzhu Cultural heritage sites.

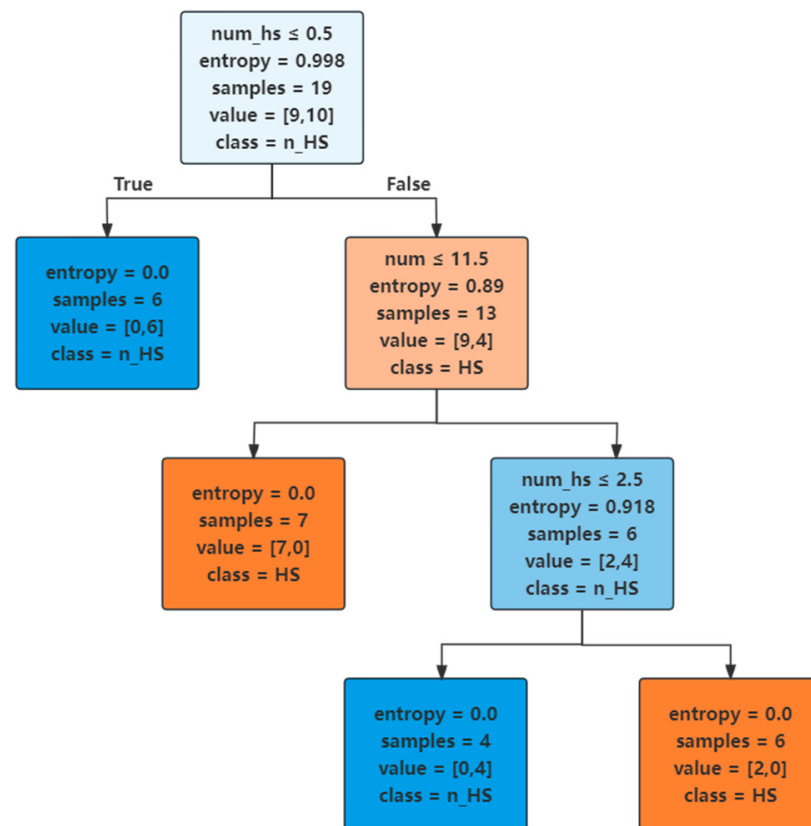


Figure 8. Decision tree.

By inputting the area of each site, the number of types of remains, and the number of types of valuable artifacts into the model, we finally identified 24 high-grade sites from the 293 Liangzhu Culture sites. These high-grade sites were utilized to generate Tyson polygons (Figure 9) to determine their control ranges based on the consideration of site grades. After overlaying the Tyson polygon with the kernel density results and merging them according to certain rules, the Liangzhu cultural division was obtained, as shown in Figure 10. The probability density surface of the Liangzhu cultural sites based on kernel density is depicted in the figure, and the local maxima in the image could be potential areas of site clustering. From this, it can be observed that the Liangzhu cultural sites exhibit a clear clustering effect.

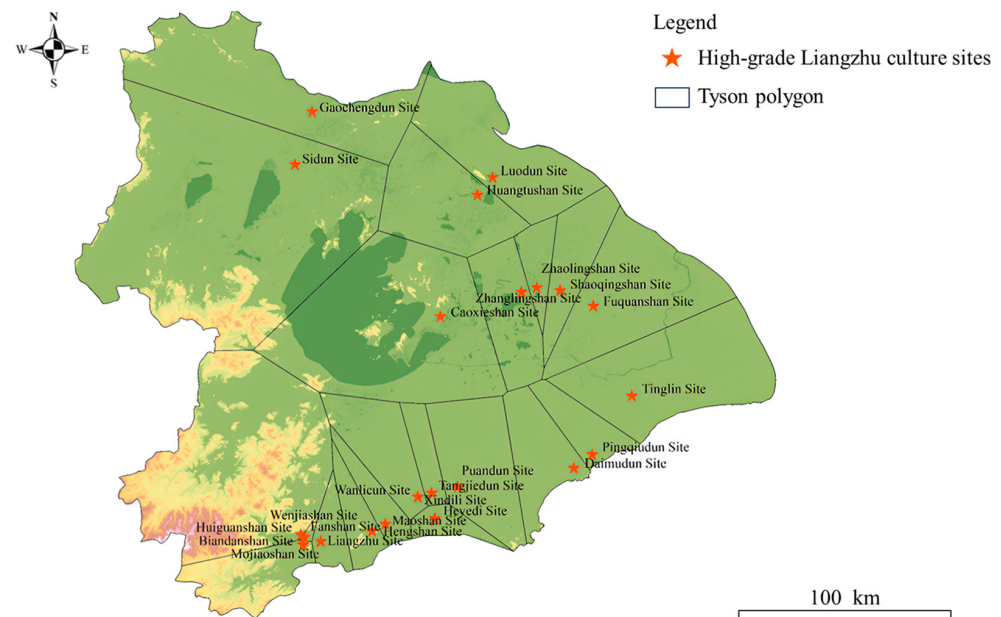


Figure 9. Liangzhu high-grade site Tyson.

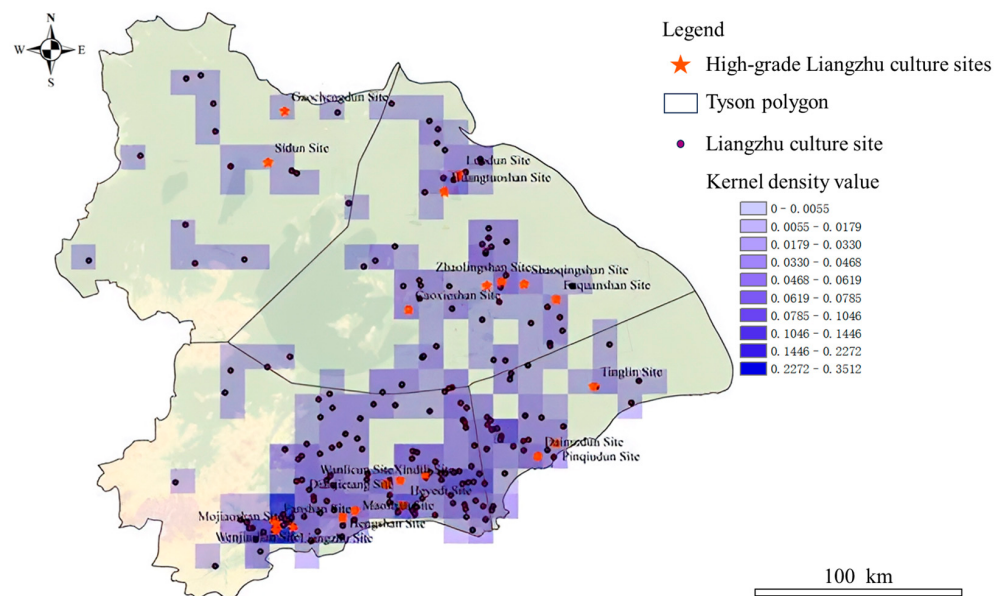


Figure 10. Liangzhu Culture zones.

Based on the results, we divided the Liangzhu Culture in the Taihu Lake region into four small zones, namely the northeast zone (64 sites), the southeast zone (44 sites), the northwest zone (16 sites), and the south zone (169 sites).

4.4. Characteristics of the Distribution of Archaeological Culture in the Direction of Each Subdistrict

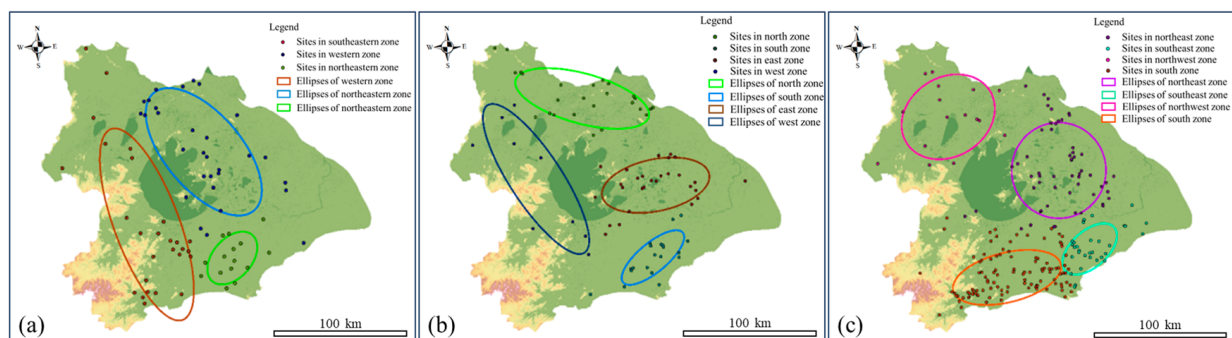
In this paper, the standard deviation ellipse was used to obtain the distribution pattern and directional characteristics of cluster groups in each subdistrict, as well as the core area in which the cluster groups were located. The specific parameters of the standard deviation ellipse are shown in Table 2, where the rotation angle of the ellipse reflects the spatial distribution trend of the site.

Table 2. Standard deviation ellipse parameters for sites by culture period.

Archaeological Culture Types	Subdivision of Sites	Flatness	Angle of Rotation
Majiabang	West Zone	0.68	158°
	Northeast Zone	0.51	138°
	Southeast Zone	0.36	42°
Songze	West Zone	0.70	146°
	East Zone	0.53	78°
	South Zone	0.63	50°
	North Zone	0.64	105°
Liangzhu	Southeast Zone	0.45	49°
	Northeast Zone	0	0°
	South Zone	0.56	76°
	Northwest Zone	0.20	59°

In archaeological site spatial distribution studies, the flatness of the standard deviation ellipse refers to the ratio between the long and short axes of the ellipse. A higher flatness indicates that the sites exhibit a more significant distribution trend along a certain direction in space, while the variation in distribution along another direction is smaller. Therefore, by observing the flatness of the standard deviation ellipse, we can better understand the directional characteristics and spatial distribution patterns of site distribution.

As shown in Figure 11 and Table 2, sites from the Majiabang Culture period in the Taihu Lake region exhibit an overall pattern of multi-core, low-density distribution, with the presence of aggregation zones and a tendency to expand in the north–south direction. In the western zone, the sites are primarily distributed along the northwest–southeast direction, with a direction angle of 158° for the standard deviation ellipse, indicating the highest flattening rate and the most pronounced directionality. The northeastern zone has the highest number of sites, distributed along the northwest–southeast direction, with a direction angle of 138° for the standard deviation ellipse and a flattening rate of 0.51, suggesting a relatively stronger directionality in the distribution of the sites. The southeastern zone has the fewest sites, mainly distributed along the northeast–southwest direction, with a flattening rate of 0.36 for the ellipse and less significant directionality in the size distribution. Further research indicates that the climate during this period was warm and humid, and the terrain primarily consisted of plains and depressions, resulting in discontinuous spaces suitable for human habitation [38]. Additionally, due to abundant food resources, high land carrying capacity, relatively low population pressure, weak intercommunity collaboration and dependence, and the absence of large-scale labor-intensive agricultural production, there was a lack of driving force to promote social integration and complexity, resulting in a more dispersed spatial distribution of the site-intensive areas during this period.

**Figure 11.** Schematic of standard deviation ellipses for cultural sites in each subdistrict. (a) Majiabang Culture, (b) Zongze Culture, (c) Liangzhu Culture.

Due to the continuity of culture, the number of sites from the Songze Culture has increased compared to the Majiabang period. The directional distribution trends in each zone are generally consistent with those of the Majiabang period. The sites are predominantly concentrated in the northern and southern parts of the eastern region of Taihu Lake, with fewer sites in the western region. Overall, there is a trend of east–west expansion, with the presence of site-intensive areas and continuous distribution patterns. In the western zone, the standard deviation ellipse shows the highest flattening rate of 0.70, indicating a sparse distribution and significant directionality. The rotation angle is 146° , indicating a pronounced northwest–southeast distribution. In the eastern zone, the size distribution is relatively dense, with the smallest flattening rate of 0.53 for the standard deviation ellipse, slightly tilted toward the northeast–southwest direction, with a rotation angle of 78° . The northern zone has the highest number of sites, showing a characteristic distribution along the northwest–southeast direction. The flattening rate of the standard deviation ellipse is 0.64, and the directionality is relatively significant, with a rotation angle of 105° . During this period, the previously dense site-intensive area in the western part of Taihu Lake has disappeared, indicating that people’s main activities have shifted from the western to the eastern part of Taihu Lake.

During the Liangzhu Culture period, the spatial distribution of sites in the Taihu Lake region was mainly concentrated in the southern region of the lake. The overall directional distribution was not as significant as the previous two cultural periods. Compared to the site-intensive areas of the Majiabang and Songze periods, the sites during this period showed a trend of southward migration, and the spatial distribution range of the sites also expanded. Among them, the site distribution in the southeastern zone was relatively dense. The northeastern zone had the smallest rotation angle of 0 and a flattening rate of 0, indicating a lack of directionality. The southern zone accumulated most of the Liangzhu Culture sites, with the highest flattening rate of 0.56 for the standard deviation ellipse, showing a directional distribution trend of northeast–southwest, with a rotation angle of 76° . The northwestern zone had the fewest sites, with no significant directionality. The flattening rate of the standard deviation ellipse was 0.2, slightly tilted towards the northeast–southwest direction, with a rotation angle of 59° . The coverage of the site-intensive areas of the Liangzhu Culture expanded, forming multiple aggregation centers. The continuity and density of the core areas were significantly higher than the previous two cultural stages.

From a global perspective, the archaeological sites in the Taihu Lake region during the Neolithic period experienced an overall expansion toward the east and south, spreading throughout the entire basin and showing a multi-centered trend. According to the analysis using the rank–size method, social structure also influenced the layout of the sites. The simpler the social structure, the weaker the communication and cooperation between tribes. However, as the social structure became more complex, the communication and connections between tribes became closer. During the Majiabang period, which was a primitive and egalitarian society, settlements that were close to each other tended to cluster, while those that were more distant were more dispersed. During this period, the number of sites was small and the density was low, showing a dispersed pattern with multiple centers. In the Songze period, as the productivity of society continued to develop, the social structure shifted from egalitarianism to social hierarchy, although a complex society had not yet formed. People had closer connections, the distribution range of site-intensive areas expanded, and continuity increased. During the Liangzhu period, a complex chieftainship society formed, and the relationships between chieftainships became stronger. The distribution of sites showed a centripetal characteristic, and on this basis, the Yuhang-Liangzhu site cluster formed, with significant improvements in continuity and density compared to the earlier periods.

5. Discussion and Conclusions

This study explores the evolutionary characteristics of the archaeological culture system in the Taihu Lake region from two perspectives: global distribution and internal partitioning.

In terms of global distribution, the Majiabang Culture primarily radiated to the southern and northern foothills of Taihu Lake, with some distribution in the southeastern area as well. There were dense, clustered distributions of sites. However, during the transition from the Majiabang period to the Songze period, there was a significant mass relocation of human populations from their original settlements, resulting in the discontinuation of many early sites. This is particularly evident in the southern region of Taihu Lake, where most sites disappeared with the cultural development. The geographical distribution, continuity, and site density of the Songze Culture changed, with a more concentrated distribution in the northeastern and southeastern areas of Taihu Lake. The range of distribution of central settlements and settlement clusters also became broader. During the transition from the Songze period to the Liangzhu period, there was better continuity of sites, with over half of the sites continuing and developing, while some sites in the north were abandoned. The early inhabitants settled in the eastern and southern areas of Taihu Lake, and the number of sites increased exponentially, with a high spatial concentration, particularly in the southern and eastern parts of Taihu Lake. Multiple central settlement clusters were formed successively, continuously expanding to the surrounding areas. Throughout the spatial and temporal changes in the entire Taihu Lake area, since the Majiabang Culture, the number of sites in the west, south, and southeast of Taihu Lake increased, and had a brief development in the area west of Ningzhen and. Songze period sites in the whole region, especially in the Yangtze River, along with the emergence of many new settlements. In the Liangzhu period, the southern part of Taihu Lake became the most densely distributed area.

In the social hierarchy evolution of the archaeological culture in the Taihu Lake region, during the Majiabang period, there were no significant differences in the settlement hierarchy in the region. However, there was a certain regularity in the hierarchical organization of large sites and the presence of dominant centers. During the Songze period, several super-large central settlements emerged, and the hierarchical differences became increasingly apparent, with some sites covering areas of over one million square meters, becoming important centers of that time. The hierarchical differences in artifacts also served as an important indication of social complexity. In the Liangzhu period, multiple high-ranking sites with large scales, abundant unearthed artifacts, and numerous jade objects appeared across the entire Taihu Lake watershed, and the settlement system tended to be unified. The hierarchical division of settlements in the Liangzhu period became more refined, with ordinary settlements generally surrounding central settlements. After several thousand years of cultural evolution and inheritance, the Taihu Lake region eventually ushered in the early civilization society of the Liangzhu culture, which integrated material expression, social systems, belief systems, etc. It not only became a prehistoric culture that led China into the stage of civilization but also played an irreplaceable role in the formation of the diverse and integrated Chinese civilization.

In terms of the evolution of the spatial and temporal patterns within the Neolithic culture system in the Taihu Lake region, the site as a whole experienced a process of expansion from east to south, with the site spreading and distributing to the entire watershed in a multi-center distribution. In this paper, the Majiabang Culture is divided into three blocks for study. Overall, the number of sites is small, the density is sparse, with multi-core discrete distribution, each block has one or two obvious gathering areas, and the trend of outward expansion is obvious, mainly showing the trend of expansion in the north-south direction. The Songze culture was divided into four blocks; in this cultural period, human interaction increased, with increasingly close contact, specifically manifested in the block site density area continuity enhancement, the distribution range expansion, and the subdistricts, and in the Majiabang period, the direction of the distribution trend was consistent. The Liangzhu Culture period formed a complex society, the community had an enhanced connection, there was a site of continuity of the gathering area, and the density of the previous period significantly increased, but the overall distribution of the direction of the culture was not as significant as in the first two periods, probably due to the culture

reaching the peak of the external expansion of the task being accomplished, and at the same time, subject to the geographic environment, unable to further expand outward.

Based on the above research, it can be concluded that as the cultural sequence develops, the coverage area of archaeological sites in the Taihu Lake region expands, the number of settlements increases exponentially, and the hierarchical differences between settlements become increasingly apparent. The directional expansion of each section gradually weakens, while adaptability to the environment increases, migration phenomena decrease, and the degree of social integration increases. Ultimately, the region crosses the threshold into the early civilization stage.

In addition, there may be an unavoidable issue regarding the data sources used in this study. As several scholars have pointed out, nationwide survey data may not be entirely reliable in terms of site density [39,40]. In the case of the Taihu Lake region, complex geological factors and passive archaeological excavations during the Neolithic period could potentially impact the distribution patterns of archaeological sites. Therefore, the authors suggest that, in terms of data sources, sampling and archaeological knowledge-based verification should be carried out for sites in areas with anomalous distributions. During the data application and analysis process, corrections need to be made to parts involving site spatial information using the proposed methods, while the analysis based on cultural information (time period) is less affected by this issue.

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