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Analysis of Spatiotemporal Dynamics and Driving Factors of China's Nationally Important Agricultural Heritage Systems

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Abstract: China's Nationally Important Agricultural Heritage Systems (China-NIAHS) are agricultural systems with deep historical and cultural roots that exhibit temporal continuity and spatial heterogeneity in their formation and distribution. As modern and industrialized agriculture have developed, traditional agricultural systems are facing unprecedented challenges and pressures. This study investigates the spatiotemporal distribution and influencing factors of 196 China-NIAHS sites, categorized into five categories. Using spatial analysis techniques and Geographical Detectors, this study identifies key natural, socioeconomic, and cultural drivers shaping their distribution. The results reveal a predominantly clustered spatial distribution of China-NIAHS, centered around the Yangtze River Basin, with significant influences from population density, tourism development, and industrialization. Historical analysis highlights a west-to-east and northward migration of agricultural activity, driven by political stability and technological advancements. Further findings indicate that the spatial distribution of China-NIAHS is primarily determined by population density, tourism development, and river network density. Population density plays a pivotal role in heritage preservation, tourism development generates economic benefits and facilitates cultural dissemination, and river network density supports the formation and sustainability of heritage sites. Conversely, urbanization and economic development have limited influence, emphasizing the need to prioritize socioeconomic and natural factors in conservation strategies. This study provides a comprehensive understanding of the spatial and temporal dynamics of China-NIAHS, offering valuable insights for sustainable heritage conservation and the strategic integration of natural and socioeconomic factors into modern agricultural policies. These findings deepen the understanding of China-NIAHS, highlighting their role in ecological and cultural sustainability while supporting value assessment, region-specific protection, and sustainable utilization strategies.

Keywords: China's Nationally Important Agricultural Heritage Systems; Globally Important Agricultural Heritage Systems; spatiotemporal distribution; Geodetector; influencing factors

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1. Introduction

Agriculture is one of the earliest production activities engaged in by human society. An agricultural system is a special ecosystem, established through farming activities within a certain natural ecosystem, with specific structures and functions aimed at obtaining targeted products [1]. China is one of the earliest regions in the world to engage in agricultural production that possesses a rich legacy of agricultural cultural heritage. This heritage not only chronicles the historical development of Chinese agriculture over thousands of years but also embodies valuable information on agricultural history and cultural significance. Against the backdrop of modern agriculture, which emphasizes mass production and efficiency, replacing traditional agriculture, the preservation of Chinese agricultural cultural heritage has become increasingly urgent.

The increase in large-scale production and efficiency not only altered traditional agricultural land use patterns and exacerbated environmental degradation but also led to a significant rural-to-urban migration, disrupting traditional rural social structures. Family farming has gradually been replaced by large-scale, intensive agricultural models. At the same time, the decline in traditional agricultural practices has caused many related cultural customs and knowledge to fade away, resulting in the dilution of agricultural festivals and lifestyles, posing severe challenges to the preservation of traditional cultural heritage.

Since the 1950s, research on Chinese agricultural cultural heritage has focused on compiling historical materials and conducting archaeological studies on the agricultural origins. In 1955, Nanjing Agricultural College established the Research Office of China's Agricultural Heritage, and in 1958, it launched the first specialized series on agricultural history, *Selected Collection of Chinese Agricultural Heritage* [2], preserving key historical records. Research then shifted towards archaeological and anthropological methods, particularly the study of agricultural remains at cultural sites. Based on plant remains from the Yangtze and Yellow River basins, Ran Guangyu suggested that China was one of the earliest rice-producing regions, with the origin of agriculture shifting from mountains to river valleys [3]. Huang Qixu from an environmental archaeology perspective, assumed that animal and plant remains, soil analysis, dating methods, and tree rings reveal the emergence and fluctuations of agrarian economies during settlement development [4]. Yan Wenming through analyzing the spatial distribution of cultivated and wild rice remains, concluded that rice agriculture likely originated in the lower Yangtze River region and gradually spread to Yunnan, Shandong, Liaodong, Korea, and Japan [5].

After the 1990s, traditional agricultural production models were incorporated into cultural landscape heritage within world heritage protection. To ensure the proper identification, protection, conservation, and presentation of the world's heritage, UNESCO adopted the *Convention Concerning the Protection of the World Cultural and Natural Heritage* in 1972 [6], emphasizing the role of natural and cultural heritage in sustainable development [7]. Zhou Xin classified and named ancient agricultural tools, and considered them to be the primary basis for examining the level of agricultural development [8]. Shi Xingbang, based on the periodization of agricultural origins, assumed that the cultivation of millet originated on the terraces or slopes at the edge of the mountains in the Loess Plateau [9].

In 2002, the FAO launched the 'Conservation and Adaptive Management of Globally Important Agricultural Heritage Systems' (GIAHS) program, establishing criteria for selecting agricultural heritage projects. GIAHS are defined as remarkable land use systems and landscapes, rich in biodiversity, that are co-adapted to meet the needs of local communities and support sustainable development [10]. The GIAHS program was introduced to China in 2004, marking the beginning of the Chinese Agricultural Cultural Heritage Conservation Project. In 2005, the Rice–Fish Co-culture System in Qingtian, Zhejiang, was designated as one of the first GIAHS sites, known as 'Rice Fish Culture, China' [11]. From a biodiversity perspective, Lu Jianbo emphasized the importance of the Chinese government's involvement in protecting rice–fish farming systems by integrating eco-tourism to enhance economic value [12]. This marked the foundation of research into agricultural cultural heritage [13]. Subsequently, GIAHS was recognized by Chinese scholars as a new type of cultural heritage [14], focusing on its protection, and demonstrating of its value. Daugstad et al. argued that active agricultural production is positively correlated with the preservation of agricultural cultural heritage [15]. Sun Yehong et al. through suggested transforming agricultural landscapes, such as the rice-fish systems, could be transformed into sustainable cultural tourism destinations [16].

In 2012, China launched the China-NIAHS project [17], defining these sites as unique agricultural systems shaped by long-term human–environment interactions. These systems are characterized by rich agricultural biodiversity, traditional knowledge, and distinctive ecological and cultural landscapes. In 2013, the Ministry of Agriculture added 19 new sites to the China-NIAHS list. By 2016, a preliminary GIAHS list was established, completing the China-NIAHS system. Research on China-NIAHS has since focused on heritage identification, landscape preservation, ecological balance, and resource assessment. To ensure the effective protection and continuation of ecological and cultural functions, Min Qingwen proposed a multi-stakeholder approach involving government, scientists, social organizations, communities, businesses, and farmers [18]. Through research on labor productivity in the Hani terraced fields, Zhang Yongxun found that small-scale agriculture in Chinese mountainous regions yields higher labor returns, and that the conservation efforts positively impact farmer incomes [19]. He Lulu's evaluation of the chestnut planting system in Kuancheng, Hebei, highlighted the importance of favorable social and cultural factors positively that influence the economic sustainability of heritage sites [20].

Recent research has primarily examined factors influencing the formation and sustainable development of agricultural cultural heritage, including natural, economic, social, and tourism aspects. However, research on the spatial distribution and influencing factors of China-NIAHS from a macro historical geography perspective remains limited. GIS offers mature spatial analysis and visualization capabilities [21], which can intuitively reflect the spatial distribution and diffusion of geographical elements. Applied to the study of Chinese agricultural cultural heritage, GIS facilitates the analysis of site distribution characteristics, regional differences, and their underlying causes. Current research on the spatial analysis of Chinese agricultural cultural heritage mainly focuses on the current spatial distribution of agricultural sites and the analysis of single influencing factors.

The spatial distribution of agricultural heritage systems is shaped by geographical, environmental, and socioeconomic factors. Ge Beichen et al. suggested that favorable geographical conditions in southeastern China, combined with historical migrations and typological variations, drive the concentration of heritage sites in this region [22]. Supporting this view, Chang Li et al. hypothesized that culture, population, soil, and elevation are the most critical factors driving the spatial clustering of Chinese Agricultural Heritage Sites [23]. Similarly, Guo Xuan et al. emphasized heritage identification and elevation as critical factors promoting the expansion of agricultural heritage [24]. Building on these geographical insights, the spatial and temporal evolution of agricultural heritage systems has also been a focus of research. Xu Xian and Zhang Jianguo observed cohesive spatial patterns of agricultural cultural heritage, advocating for targeted preservation strategies for regionally and historically significant sites [25]. Additionally, Mou Ya and Yu Jing also highlighted that the clustered patterns of China-NIAHS reflect the distinct characteristics of different heritage categories [26].

Socioeconomic factors also significantly influence the spatial distribution of agricultural heritage systems. By analyzing the spatial relationships between sites and influencing factors, Liu Guilin argued that high-quality agricultural products and agritourism can enable agricultural heritage systems to fulfill comprehensive economic, social, and ecological functions, underscoring the importance of socioeconomic integration [27]. Expanding on this, Li Zhidong et al. used Geographical Detectors to examine income disparities in the Ar Horqin Grassland Nomadic System, identifying primary industry type and secondary–tertiary industry development as key economic drivers [28]. To address the management of agricultural heritage systems, Guo Xuan et al. integrated multi-source data and spatial analysis to propose differentiated management strategies for the four distinct clustering zones of China-NIAHS, highlighting tailored approaches to ensure sustainable preservation and development [29].

However, existing research has primarily examined the interplay of natural conditions, historical trajectories, socioeconomic dynamics, and regional strategies in shaping the spatial distribution and preservation of China-NIAHS. However, these studies often focus on the protection and inheritance of China-NIAHS as a whole or through individual projects, rarely employing advanced spatial analysis methods, such as Geographical Detectors, to systematically analyze the factors influencing site distribution or to treat the historical and spatial stages of heritage genesis and development as distinct yet complementary dimensions. This study addresses these gaps by defining its objectives as follows: to analyze the spatial distribution patterns of China-NIAHS across different historical periods, to systematically identify the natural, social, economic, and cultural factors influencing their current distribution, and to provide a quantitative basis for heritage conservation strategies. Additionally, it evaluates the authenticity and integrity of these systems by considering the historical and spatial stages of their genesis and development as distinct but complementary aspects.

2. Materials and Methods

2.1. Data Sources

This study systematically analyzes the spatial and temporal distribution of China-NIAHS sites using a combination of geospatial tools and historical data. The data for this study come from the official website of the Ministry of Agriculture and Rural Affairs, which has published 7 batches of China-NIAHS, totaling 189 sites as of the latest update (Table 1). These sites are distributed across 31 provincial-level administrative regions in China, excluding Hong Kong, Macao, and Taiwan. Since some projects are joint applications across multiple regions, when retrieving latitude and longitude data through the Amap API, these joint sites were counted separately. This process resulted in a total of 196 research sites for this study.

Table 1. Batches and time of China-NIAHS.

Batch	Time	China-NIAHS Quantity
1	9 May 2013	19
2	29 May 2014	20
4	28 June 2017	29
5	19 January 2020	27
6	12 November 2021	21
7	15 September 2023	50

A spatial attribute database was established based on the GS (2022) No. 1873 standard map, with additional layers such as administrative boundaries, elevation, and river networks sourced from the Resource and Environmental Science Data Platform (https://www.resdc.cn/ (accessed on 21 July 2024)). The indicator data for the factors were obtained from the National Bureau of Statistics, the official portals of provincial statistical bureaus, and the official website of the Ministry of Transport.

China-NIAHS sites first appeared during the Neolithic period and have continued through to the Qing dynasty. This study divides the sites into ten historical periods based on their appearance and number: Neolithic, Pre-Qin, Qin, Han, Wei, Jin, and Southern and Northern dynasties (WJNS), Sui, Tang, and the Five dynasties, Song, Yuan, Ming, and Qing dynasty. The total number of sites and the number of provinces with site distributions for each period are shown below in Figure 1.

This study classifies the 196 sites of China's Important Agricultural Cultural Heritage according to the current status of existing heritage, the structure of traditional Chinese agricultural systems, the 2011 FAO classification of GIAHS, and the classification system of Chinese agricultural cultural heritage. The traditional Chinese agricultural systems are divided into agriculture, livestock, forestry, fishing and hunting, and sericulture, with combinations of different categories of agricultural systems referred to as complex agricultural systems [1]. In 2011, experts from the United Nations Food and Agriculture Organization divided typical GIAHS into 10 categories [30]. In Agricultural Heritage Studies, Chinese agricultural cultural heritage is classified into 10 categories [31]. Combining the Chinese agricultural product classification standards [32] and the categorization of engineering agricultural cultural heritage [31], and to simplify the analysis and highlight core characteristics, this study classifies the FAO-GIAHS and Chinese agricultural heritage into five main categories (Figure 2, Table 2). These categories include planting system, composite ecosystem, breeding system, agricultural engineering system, and fishing and hunting system. This categorization approach simplifies the structure and enhances the clarity and operability of the analysis.

Table 2. The quantity and proportion of the 5 main categories.

Category	Quantity	Proportion	Characteristics	Example
Planting System	109	56.10%	Focused on crop cultivation, including systems like rice terraces and polyculture farming.	Wannia Traditional Rice Culture; Urban Agricultural Heritage-Xuanhua Grape Garden
Composite Ecosystem	59	30.10%	Integrates multiple practices such as agroforestry and multi-layered home gardens.	Qingyuan Forest-Mushroom Co-culture System; Dong's Rice-Fish-Duck System
Breeding System	17	8.67%	Dominated by livestock practices, including nomadic and semi-nomadic pastoral systems.	Ningxia Yanchi Tan Sheep Breeding System; Zhejiang Kaihua Mountain Spring Flowing Water Fish Breeding System
Agricultural Engineering System	10	5.10%	Related to infrastructure, including ancient irrigation and soil–water management systems.	Ningxia Plain Yellow River Irrigation System; Turpan Karez Agricultural System
Fishing and Hunting System	1	0.51%	Includes hunting-gathering systems and traditional fishing practices.	Fuyuan Hezhe Fishing Culture System

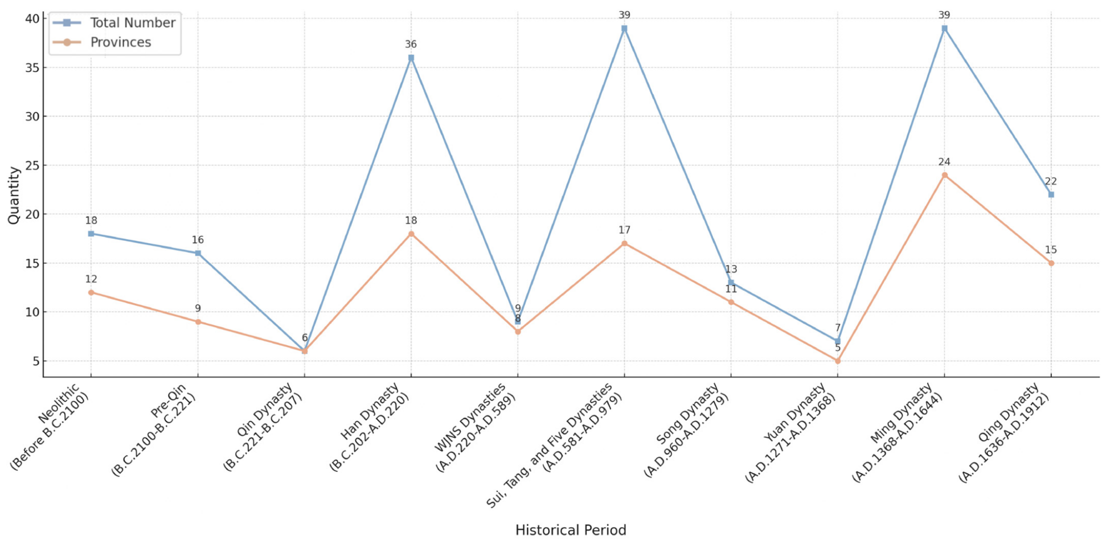


Figure 1. Total number of China-NIAHS sites and number of provinces with site distributions in 10 historical periods.

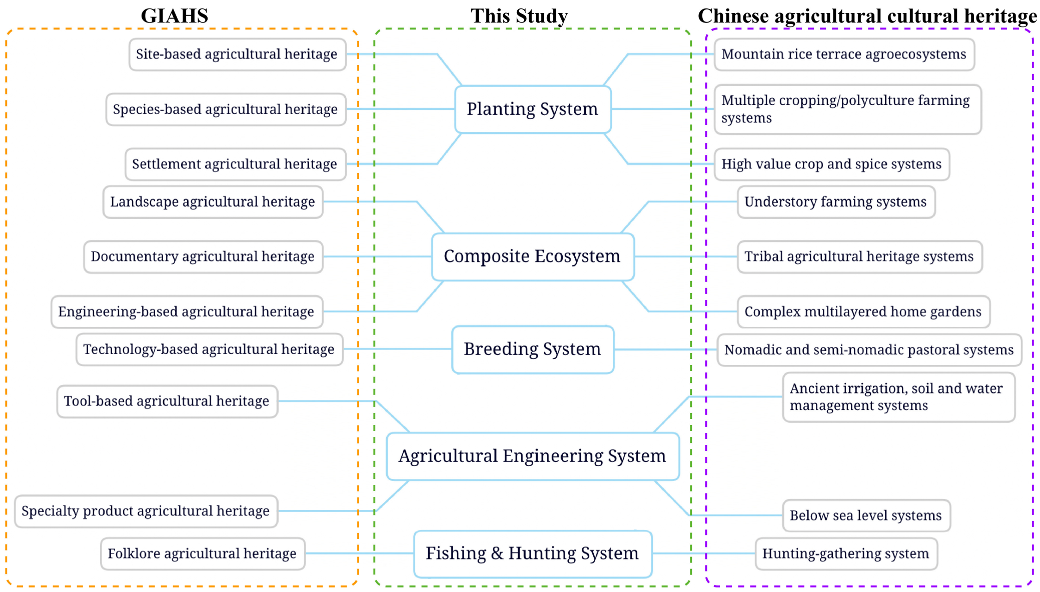


Figure 2. Comparison of GIAHS and Chinese agricultural cultural heritage categories and their simplification into 5 categories in this study.

2.2. Research Methods

The geographical coordinates and administrative information of the sites were retrieved using Python 3.9 to call the Amap API, then converted the sites into point geographic features for spatial analysis in ArcGIS 10.2. Temporal trends were identified by categorizing sites into historical stages based on documented timeline category-based and spatiotemporal patterns that were analyzed using statistical tools. The factor detection module of Geodetector was used to identify the factors driving spatial distribution variations in the sites, while the interaction detection module was employed to assess how various factors interact with the dependent variable. Concurrently, the sites were overlaid with a Digital Elevation Model (DEM) to extract topographical information and analyze relationships between site distribution and elevation. This comprehensive approach highlights the characteristics, clustering tendencies, and influencing factors of the 196 sites (Figure 3).

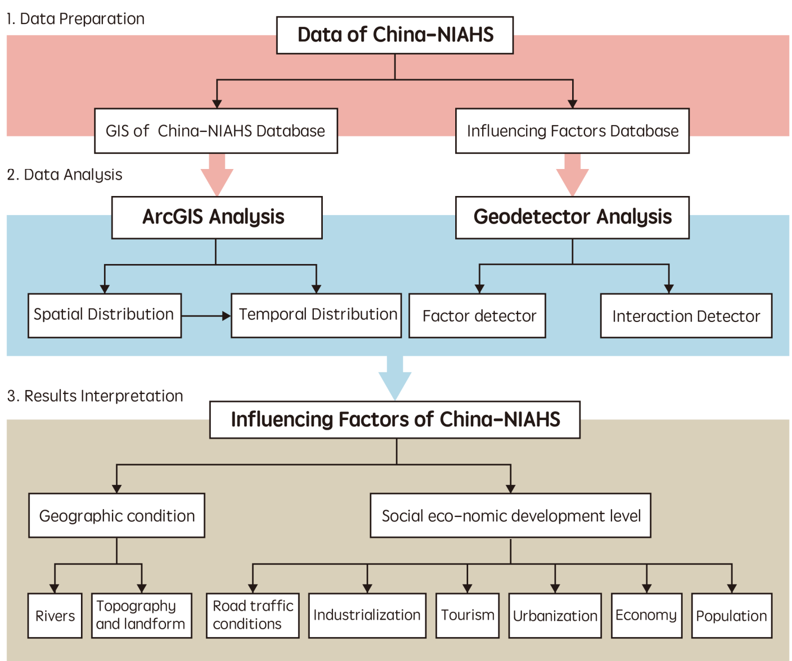


Figure 3. Analysis framework.

2.2.1. Kernel Density Estimation Method

Kernel Density Estimation is a commonly used non-parametric estimation method in spatial point pattern analysis and is a way to visualize point distribution patterns. It can be used to examine the spatial variation in point density within a region and study the distribution characteristics of points. Centered on the position of each site point i (x, y), the density contribution value of each site point within a circular grid cell of specified radius h is calculated using the kernel function K ( ). The calculation formula is expressed as follows:

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

In the formula, n is the number of China-NIAHS sites, d is the dimension, and $x - x_i$ represents the distance from the estimated point X to the sample point x_i.

2.2.2. The Average Nearest-Neighbor Index Method

The average nearest-neighbor index is an important spatial geography metric used to quantify the spatial relationships among China-NIAHS sites. It measures the straight-line distance (Euclidean distance) between each site and its nearest neighbor, providing a representation of spatial clustering or dispersion patterns [33]. By calculating the average of these distances, the ANN index reveals the clustering tendencies and spatial distribution characteristics of China-NIAHS sites as point features. The calculation formula is expressed as follows:

$$ANN = \frac{\overline{D}_O}{\overline{D}_E} \quad (2)$$

$$\overline{D}_O = \frac{\sum_{i=1}^{n} d_i}{n} \quad (3)$$

$$\overline{D}_E = \frac{0.5}{\sqrt{n^2/A}} \quad (4)$$

In the formula, $\overline{D}_O$ is the average distance between each observed feature and its nearest neighbor, $\overline{D}_E$ is the expected average distance for features given a random pattern. d_i represents the distance between the feature i and its nearest-neighboring feature, n corresponds to the total number of features, and A is the area of the minimum bounding rectangle around all features. The z-score value of the statistical average nearest-neighbor index is calculated as follows:

$$z = \frac{\overline{D}_O - \overline{D}_E}{SE} \quad (5)$$

$$SE = \frac{0.26136}{\sqrt{n^2/A}} \quad (6)$$

In the results returned by the average nearest neighbor tool in spatial statistics, the ANN value and z-score need to be combined to determine the degree of clustering or dispersion of feature points in the spatial distribution of China-NIAHS sites. Specifically, when $0 < ANN$ value < 1, a smaller value indicates that the features are more clustered in space. The z-score is a measure of standard deviation and is associated with the standard normal distribution. It measures statistical significance as follows: when the Critical Value (z-score) < -2.58, the point distribution is significantly clustered; when the Critical Value (z-score) is between -1.65 and 1.65, the distribution is significantly random; when the Critical Value (z-score) > 2.58, the point distribution is significantly dispersed.

2.2.3. Standard Deviation Ellipse Method

The standard deviation ellipse method is a commonly used approach for analyzing the dispersion characteristics of a dataset. It calculates the centroid based on the spatial distribution of point data and then constructs the major and minor axes of the ellipse. The major axis of the standard deviation ellipse indicates the primary direction of the site points' distribution, while the minor axis represents the direction of minimal dispersion. The area of the ellipse is used to determine the degree of dispersion of the site points. The calculation formula is as follows:

$$SD_a = \sqrt{\left[\sum_{i=1}^{n} (\Delta a_i \cos\theta - \Delta b_i \sin\theta)^2\right] / n} \quad (7)$$

$$SD_b = \sqrt{\left[\sum_{i=1}^{n} (\Delta b_i \cos\theta - \Delta a_i \sin\theta)^2\right] / n} \quad (8)$$

$$\tan\theta = \frac{\left[\sum_{i=1}^{n}\left(\Delta a_i^2 - \sum_{i=1}^{n}\Delta b_i^2\right) + \sqrt{\left(\sum_{i=1}^{n}\Delta a_i^2 - \sum_{i=1}^{n}\Delta b_i^2\right) + 4\left(\sum_{i=1}^{n}\Delta a_i \Delta b_i\right)^2}\right]}{\left[2\sum_{i=1}^{n}\Delta a_i \Delta b_i\right]} \quad (9)$$

In the formulas, a represents the major axis, b represents the minor axis, SD_a and SD_b represent the standard deviations of the major and minor axes. Δa_i and Δb_i represent the deviations of the a and b coordinates of China-NIAHS sites from their mean center. θ is the rotation angle of the ellipse. n is the number of sites. The smaller the area of the standard deviation ellipse, the more clustered the distribution, and the closer it is to the centroid.

2.2.4. Centroid Analysis Method

Centroid analysis is primarily used to determine the direction and distance of the movement of the centroid distribution of China-NIAHS sites over different periods. The formula is expressed as follows:

$$X = \frac{\sum_{i=1}^{n} M_i X_i}{\sum_{i=1}^{n} M_i}, Y = \frac{\sum_{i=1}^{n} M_i Y_i}{\sum_{i=1}^{n} M_i} \quad (10)$$

In the formula, X and Y represent the longitude and latitude values of the centroid of China's Important Agricultural Heritage sites within a certain time period. X_i and Y_i represent the longitude and latitude values of the sites within a certain time period. M_i represents the magnitude of the sites within a certain time period. i represents a specific time period.

2.2.5. Voronoi Analysis Method

Thiessen polygons is a planar subdivision technique obtained from Voronoi triangulation. This method ensures that any point within a convex polygon is closer to the control point of that convex polygon than to any other control points. The formula is expressed as follows:

$$CV = \left(\frac{Std}{Ave}\right) \times 100\% \quad (11)$$

In the formula, CV is the coefficient of variation in the Voronoi polygons, which is the ratio of the standard deviation to the mean of the polygon areas. Std and Ave are the standard deviation and mean of the Voronoi polygon areas, respectively. When the CV value is between 33% and 64%, the China-NIAHS site point set exhibits a 'random' distribution; when the CV value is greater than 64%, the point set exhibits a 'clustered' distribution; when the CV value is less than 33%, the point set exhibits a 'regular' distribution [34].

2.2.6. Geodetector

The Geodetector method (GDM) can identify spatial differentiation in China-NIAHS sites within the Yangtze River Economic Belt [35] and analyze the factors influencing their spatial distribution [22], including the interactions among these factors. The extent to which the influencing factors accounted for the variation in China-NIAHS sites was measured using the q-statistic of the factor detector. The calculation formula is presented as follows:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N_\sigma^2} \tag{12}$$

In the formula, h $(1 \ldots L)$ denotes the number of categories of the influencing factors; Nh represents the number of samples in subregion h; N is the total number of spatial units within the study area; σ and σ_h represent the total variance and sample variance within subregion h, respectively [36]. The q-statistic ranges from 0 to 1, with a higher q-statistic indicating a stronger explanatory power of the influencing factor on the variation in China-NIAHS sites.

The Interaction Detector module was employed to analyze whether the interaction between any two influencing factors would alter the explanatory power of the spatial distribution variation in China-NIAHS sites [37–39]. Interaction was denoted by ∩ in this study [22]. The criterion of interaction relationship is shown as follows in Table 3.

Table 3. Type of interaction of dual independent variables on dependent variables.

Interaction	Criterion
Nonlinear–weaken: Impacts of single variables are nonlinearly weakened by the interaction of two variables.	$q(x1 \cap x2) < Min(q(x1), q(x2))$
Uni-variable weaken: Impacts of single variables are uni-variable weakened by the interaction.	$Min(q(x1), q(x2)) < q(x1 \cap x2) < Max(q(x1), q(x2))$
Bi-variable enhance: Impact of single variables are bi-variable enhanced by the interaction.	$q(x1 \cap x2) > Max(q(x1), q(x2))$
Independent: Impacts of variables are independent.	$q(x1 \cap x2) = q(x1) + q(x2)$
Nonlinear–enhance: Impacts of variables are nonlinearly enhanced.	$q(x1 \cap x2) > q(x1) + q(x2)$

In addition, this study categorizes the results of the Interaction Detector analysis into three levels: high, medium, and low, using the Natural Breaks (Jenks) method, which defines the split points based on observed percentile thresholds [40].

3. Results

3.1. The Spatial Distribution Characteristics of China-NIAHS

Using the average nearest-neighbor index (ANN) method, the analysis revealed an ANN value of 0.546888 (<1), indicating a clustered distribution pattern. The z-score of −12.857255 (below −2.58), and a p-value of 0.000 further confirm the statistical significance of this clustering. The spatial distribution of China-NIAHS sites was also analyzed in relation to the Hu Line [41], a demographic boundary extending from Heihe in Heilongjiang Province (northeast) to Tengchong in Yunnan Province (southwest) (Figure 4). This line divides the densely populated and economically developed eastern region from the sparsely populated and environmentally challenging western region. The results show that the majority of China-NIAHS sites are located on the eastern side of the Hu Line, where population density and economic activity are higher. This clustered distribution, supported by the ANN value, reflects the influence of historical and geographical factors, including favorable environmental conditions and proximity to centers of human activity.

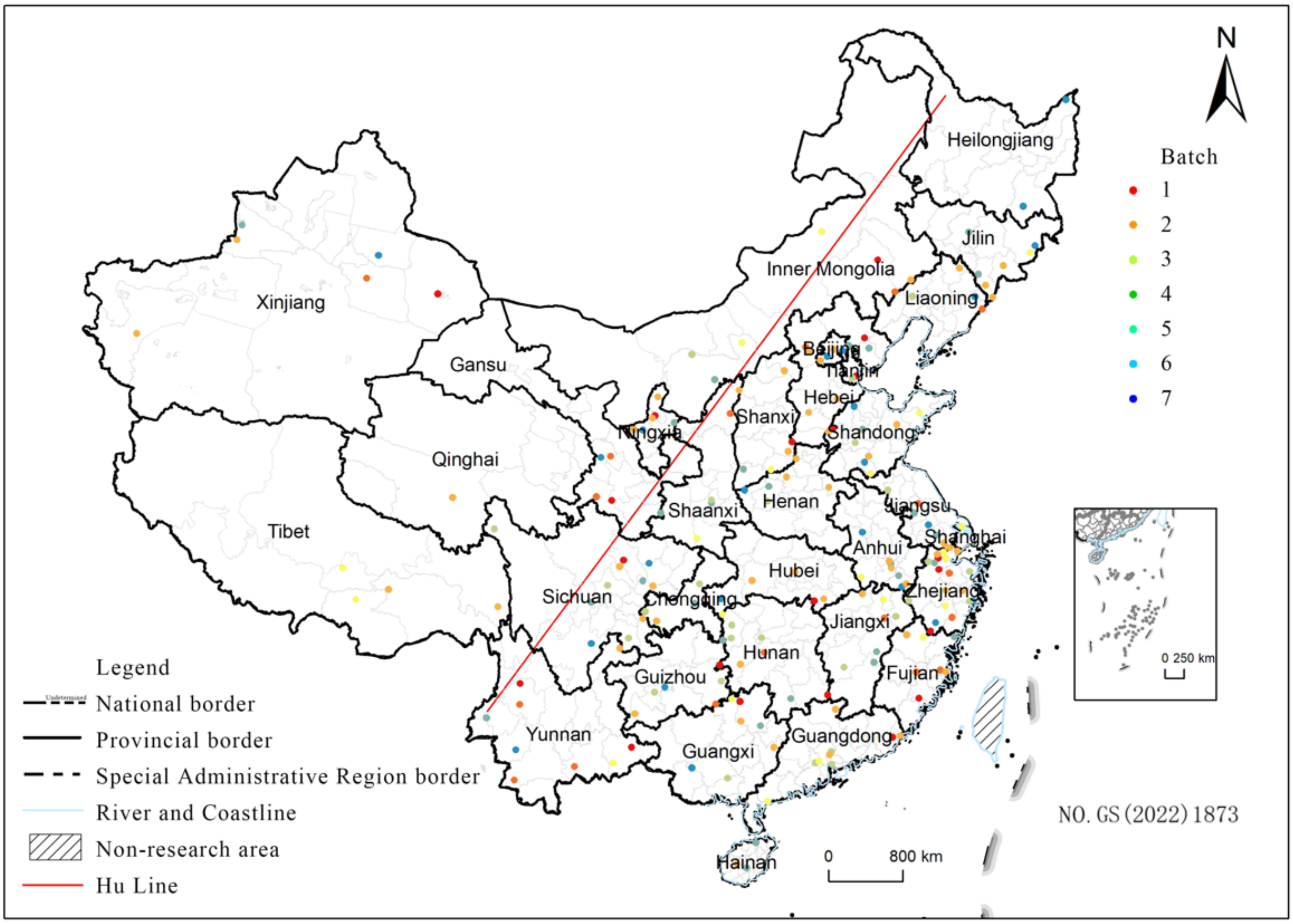


Figure 4. Spatial distribution of map of the 7 batches of China-NIAHS published by the ministry of agriculture and rural affairs.

3.1.1. Regional Concentration and Imbalance in the Distribution of Sites Across Provincial-Level Administrative Regions

From the kernel density distribution of China-NIAHS sites across provincial administrative regions, it can be observed (Figure 5) that China-NIAHS and GIAHS sites exhibit a certain degree of regional concentration and spatial distribution imbalance. The overall sites show characteristics of greater concentration in the eastern coastal areas, notable presence in the southern regions, relatively fewer sites in the central and western regions, and a clear single-core distribution trend along the lower Yangtze River and eastern coastal areas.

Combining the statistical results of the currently announced China-NIAHS and GIAHS site numbers (Figure 6), provinces with a higher number of China-NIAHS sites, such as Zhejiang, Jiangsu, Shandong, and Guangdong Province, are mainly distributed in the eastern coastal regions of China.

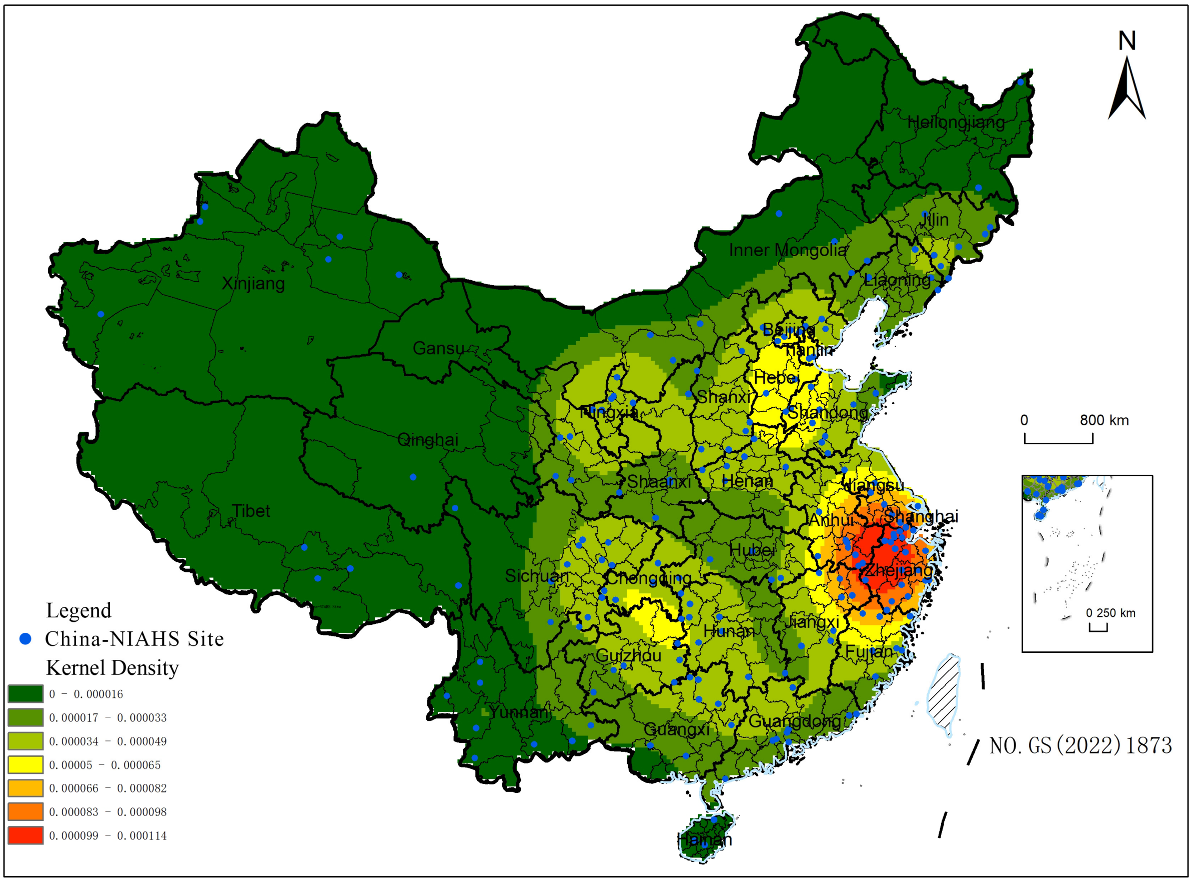


Figure 5. Kernel density distribution map of China-NIAHS sites.

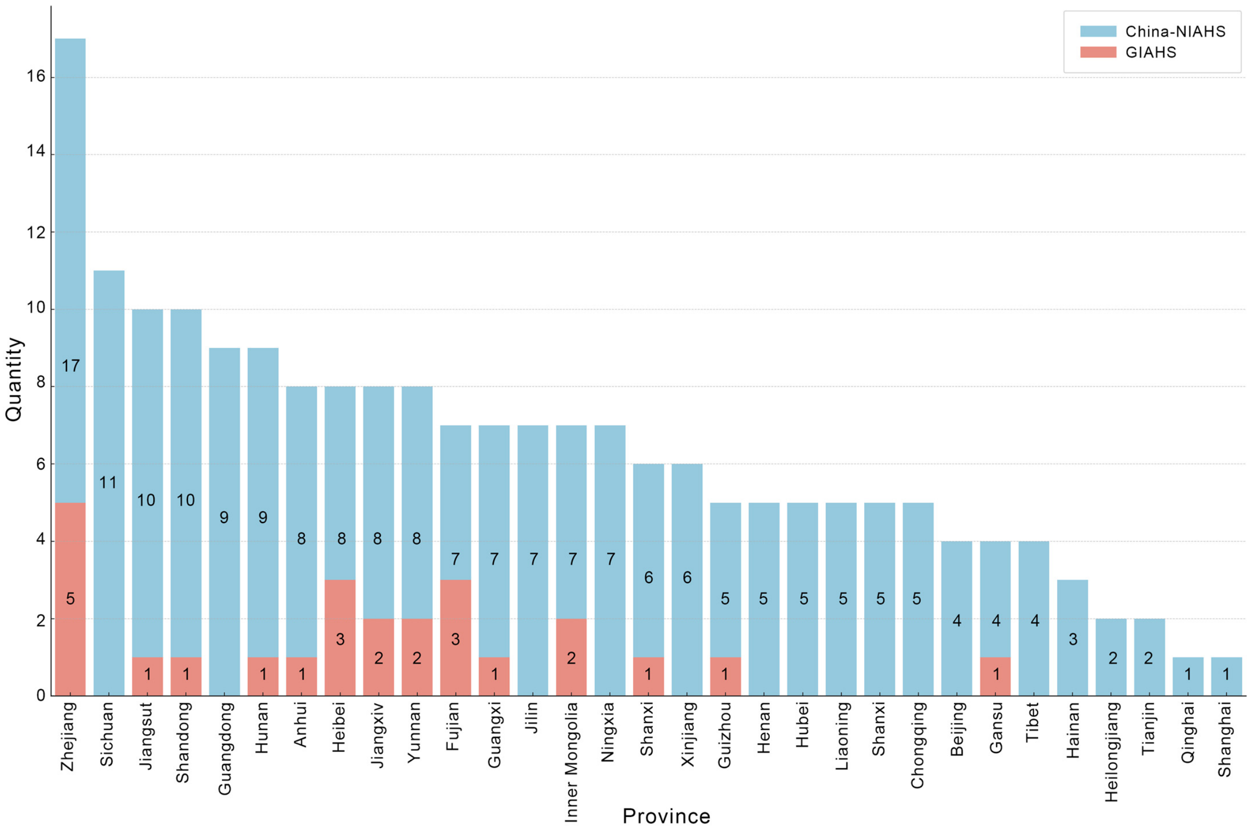


Figure 6. Statistics on the number of China-NIAHS and GIAHS in different provinces.

Southern provinces, such as Zhejiang, Yunnan, and Fujian, exhibit a high concentration of China-NIAHS and GIAHS sites, reflecting the rich biodiversity and unique agricultural ecosystems of the southern regions. These include terraces and rice–fish co-culture systems, which possess significant ecological value. Additionally, the coexistence of multiple ethnic groups has fostered the blending of diverse farming cultures, contributing to a unique agricultural heritage. In contrast, the central and western provinces have fewer sites, largely due to harsher natural conditions, such as arid climates and high plateaus, which constrain agricultural development. Slower economic growth in these regions has also led to limited investment in the protection and inheritance of agricultural heritage. Nonetheless, the distinct nomadic and highland agricultural cultures of these areas are still reflected in their agricultural heritage.

3.1.2. Spatial Distribution Characteristics of the Five Categories of Agricultural Systems

Combining the spatial distribution and number of China-NIAHS sites across the five categories of agricultural systems (Figure 7), it is evident that the overall pattern is dominated by planting systems, followed by composite ecosystem and breeding systems, with agricultural engineering and fishing and hunting systems being relatively fewer. Among these, planting system, composite ecosystem, and fishing and hunting system are predominantly distributed on the eastern side of the Hu Line, and agricultural engineering systems are mostly found on the western side of the Hu Line, while breeding systems are more evenly distributed on both sides. The fishing and hunting system, having only one site, is not included in the statistics.

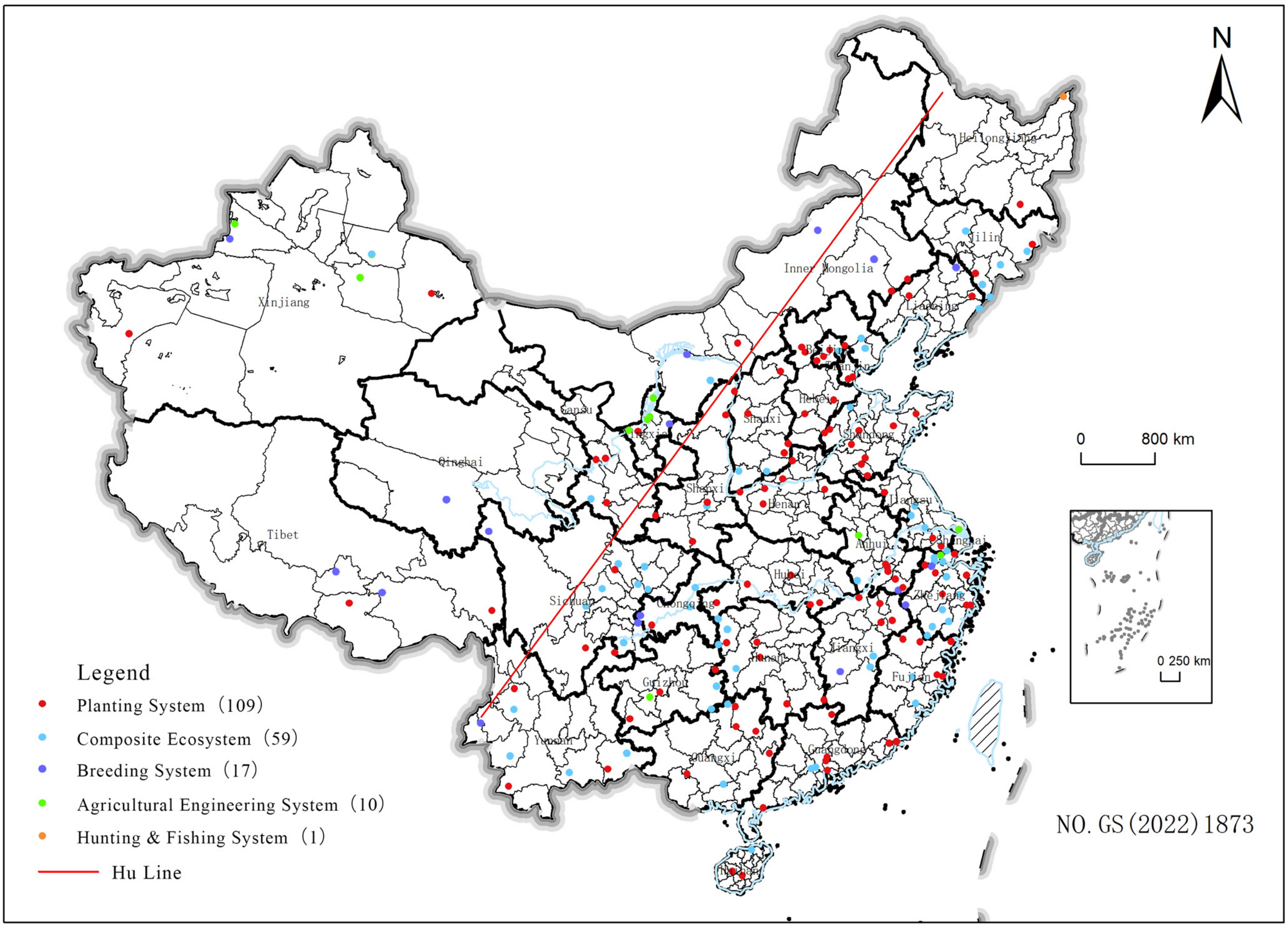


Figure 7. Spatial distribution of sites considering the 5 categories of agricultural systems.

From the spatial distribution centroid and direction of the sites (Table 4 and Figure 8), the overall centroid of China-NIAHS sites is located at the southern end of the North China Plain, between the middle reaches of the Yellow River and the Yangtze River. This region is the central area of early agricultural and cultural development in China. The lengths of the major and minor axes of the ellipse are similar; no particular directionality is detected, thus suggesting that the direction of the overall distribution of the sites with respect to the centroid is relatively dispersed.

Table 4. Standard deviation ellipse parameters of China-NIAHS sites.

Category	Major Axis (Meters)	Minor Axis (Meters)	θ (°)
Total	970,633.9094	1,102,053.568	61.04247138
Planting System	903,173.3508	1,001,326.302	36.59615409
Composite Ecosystem	679,150.1082	1,142,306.965	43.11226936
Breeding System	1,024,505.412	1,485,344.478	82.59283542
Agricultural Engineering System	1,528,828.053	496,547.3745	120.3876212

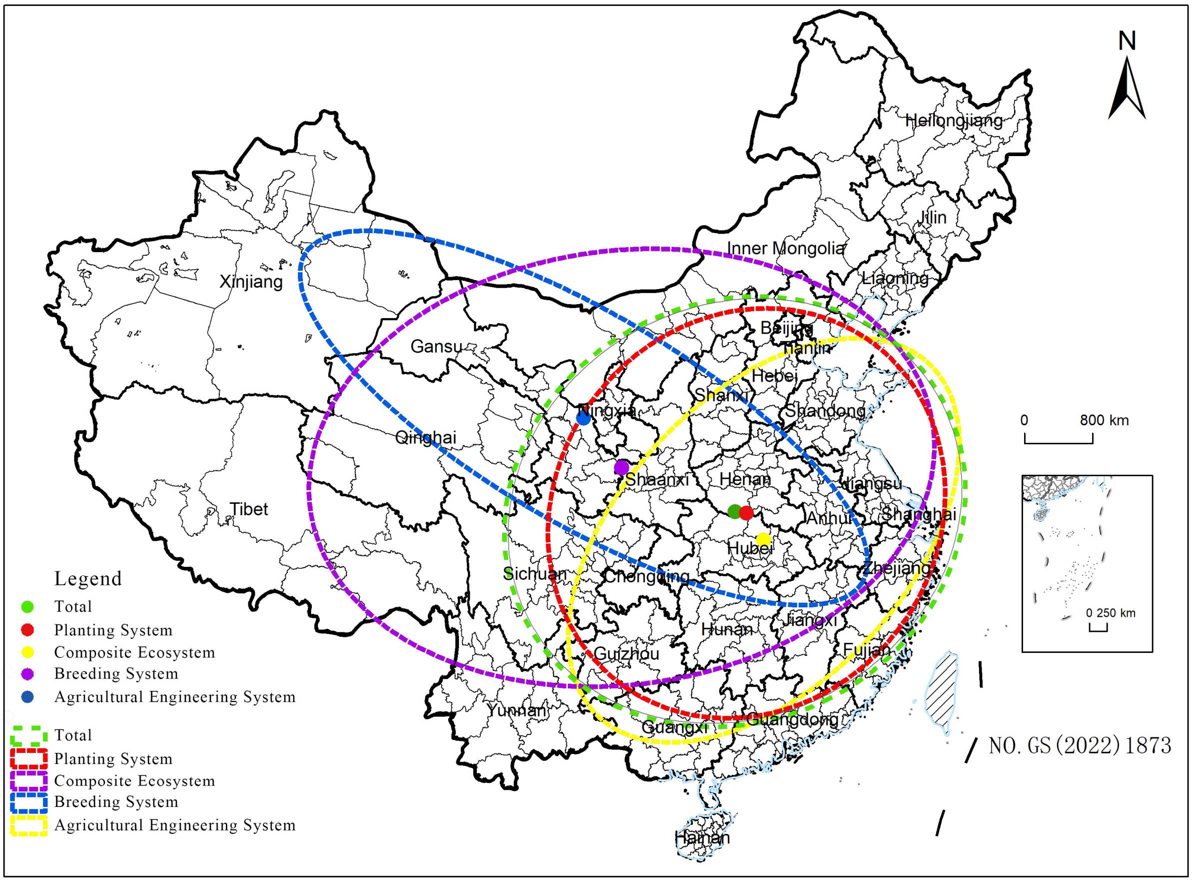


Figure 8. Centroid and direction of the spatial distribution of China-NIAHS sites.

From the average nearest-neighbor index (Table 5), the spatial distribution of sites across different categories of agricultural systems exhibits three distinct characteristics. The planting system and composite ecosystem, consistent with the overall clustered pattern, show a clustering trend. The breeding system and agricultural engineering system exhibit a random distribution pattern.

Table 5. The average nearest-neighbor index of China-NIAHS sites: overall and by category.

Category	Observed Mean Distance/Meters	Expected Mean Distance/Meters	ANN	Z-Score	*p*-Value	Distribution Pattern
Total	71,158.0343	130,114.5704	0.546888	−12.857255	0	Clustered
Planting	125,749.7214	164,216.5510	0.765755	−4.763647	0.000002	Clustered
Composite Ecosystem	120,598.4795	150,648.5190	0.800529	−2.931143	0.003377	Clustered
Breeding	339,457.3881	334,812.1808	1.013874	0.109436	0.912857	Random
Agricultural Engineering	381,774.6679	347,807.3572	1.097661	0.560499	0.575139	Random

The kernel density distribution maps of different agricultural systems (Figure 9) reveal a highly uneven spatial distribution. The planting system sites exhibit a 'dual-core and dual sub-core' pattern, with primary core areas in Hebei, centered around Beijing, and at the junction of Anhui and Zhejiang in the lower Yangtze River region. Sub-core areas are located in western Shandong and western Ningxia. The composite ecosystem sites exhibit a distinct 'single-core' distribution, with the core area located in the lower Yangtze River, particularly in Shanghai and northern Zhejiang. The breeding system sites exhibit a 'single main core and single secondary core' distribution, with the main core at the junction of Anhui, Zhejiang, and Jiangxi and the secondary core in Chongqing and eastern Sichuan.

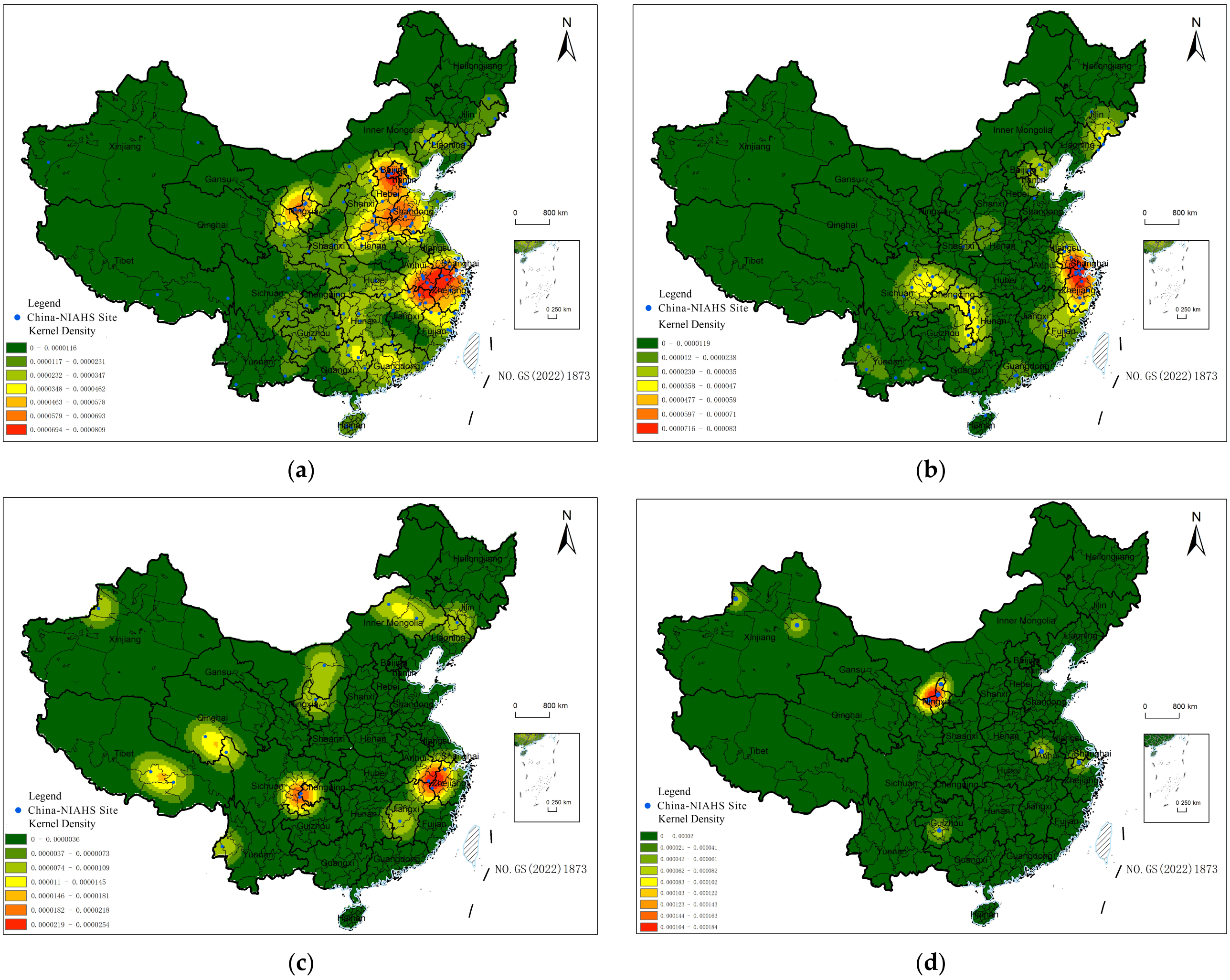


Figure 9. Kernel density distribution maps of 4 categories of agricultural system sites: (**a**) planting system sites; (**b**) composite ecosystem sites; (**c**) breeding system sites; (**d**) agricultural engineering system sites.

Overall, the planting system as the dominant form of traditional Chinese agriculture, exhibits a wide spatial distribution, with its centroid located in the East China region, between the Yellow River and Yangtze River basins. These areas are historically key agricultural regions, characterized by favorable soil, water, and climate conditions. The northeast–southwest orientation of the major axis of the distribution ellipse reflects the spread of farming culture from the Central Plains towards the northeast and southwest, with expansion into the fertile middle and lower reaches of the river basins. The composite ecosystem incorporates diverse farming practices. Its centroid is located in the Jianghan Plain in central eastern China, a major grain-producing region known for its fertile land and temperate climate. The northeast–southwest axis reflects the diffusion of these systems along the Yangtze River basin, with higher concentrations in Zhejiang, Sichuan, and Jiangsu, which are regions that have been historically focused on ecological balance and integrated agricultural practices.

The development of the breeding system met the self-sufficiency needs in rural China, has its centroid in northeastern China, a region historically known for livestock production. The southwest–northeast axis of its distribution reflects the spread from the northern grasslands to agricultural regions in both eastern and western China. The agricultural engineering system is located in the northwest of China, at the border of Qinghai and Gansu, an arid region that depends on irrigation for stability. The northwest-southeast axis of the ellipse reflects the crucial role of irrigation from the Yellow River in the northwest, alongside the significant agricultural engineering developments in the Yangtze River basin, particularly in rice-growing areas.

The fishing and hunting system is typically influenced by water and fishery resources. However, modern fishing techniques and environmental concerns have led to the decline of traditional systems, with the Hezhe Fishing Culture in Heilongjiang being the last remaining example, reflecting reflects its unique historical and cultural significance.

3.2. The Temporal Variation Characteristics of China-NIAHS

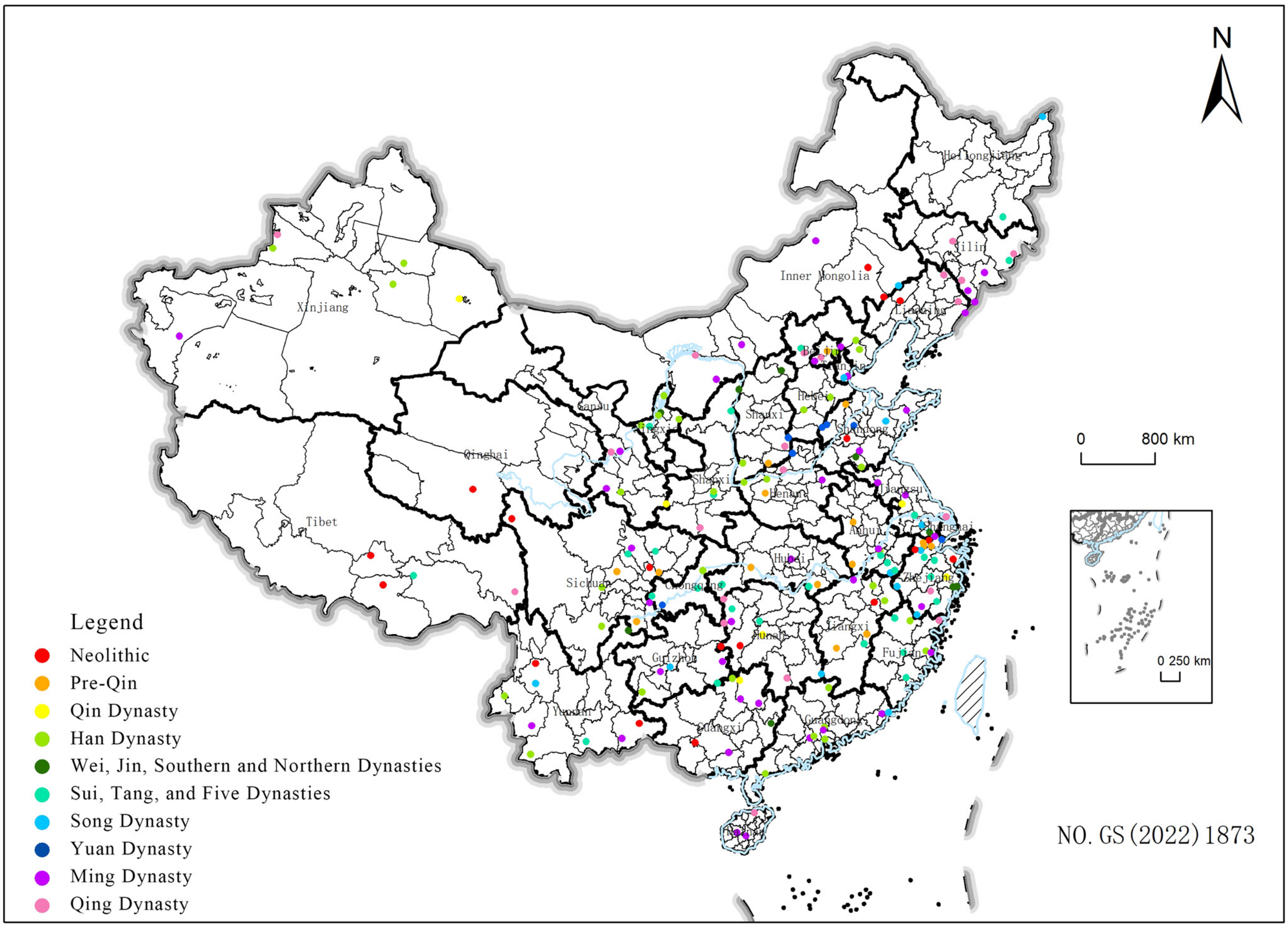
From the average nearest neighbor index (Table 6), the spatial distribution of China-NIAHS sites across different historical periods exhibits three distinct characteristics. Only the Han dynasty shows a clustered distribution pattern, while the Qin, Wei, Jin, Southern and Northern dynasties, and Yuan dynasty exhibit dispersed distribution patterns. The remaining dynasties show random distribution patterns.

Table 6. Nearest neighbor index of China-NIAHS sites in different historical periods.

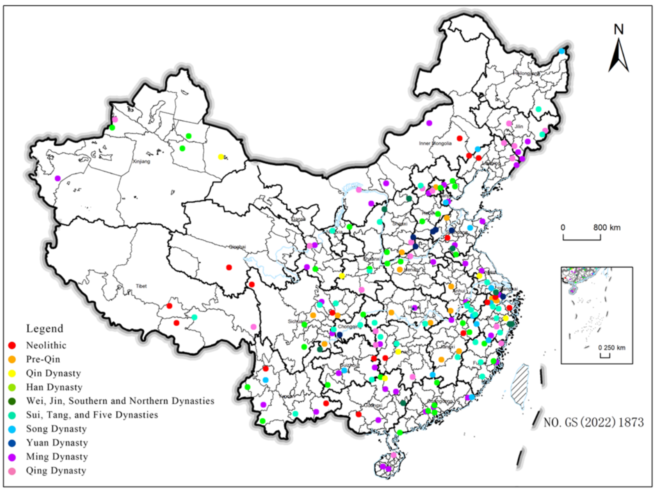
Construction Period	Observed Mean Distance/Meters	Expected Mean Distance/Meters	ANN	Z-Score	*p*-Value	Distribution Pattern
Neolithic	243,575.2201	261,087.2757	0.932926	−0.544401	0.586166	Random
Pre-Qin	182,799.8454	169,812.6188	1.076480	0.585244	0.558383	Random
Qin	608,535.4776	356,581.2447	1.706583	3.311080	0.000929	Dispersed
Han	182,357.1455	240,040.8978	0.759692	−2.758356	0.005809	Clustered
WJNS	383,780.7233	257,841.8182	1.488435	2.803230	0.005059	Dispersed
STF	233,242.3471	224,402.5644	1.039393	0.412767	0.679777	Random
Song	383,841.2071	323,050.7585	1.188176	1.297977	0.194295	Random
Yuan	297,641.9141	189,208.6594	1.573088	2.900690	0.003723	Dispersed
Ming	259,351.8663	274,643.9553	0.944320	−0.665212	0.505915	Random
Qing	361,228.0909	356,308.0229	1.013808	0.121056	0.903647	Random

WJNS: Wei, Jin, Southern, and Northern dynasties; STF: Sui, Tang, and Five dynasties.

Combining the spatiotemporal distribution map of the sites (Figure 10), the growth in the number of China-NIAHS sites in different historical periods is closely related to political, economic, and social changes. During periods of unified and stable dynasties, such as the Han, Sui, Tang, and Ming dynasties, agricultural development flourished, and the number of new sites and the provinces where they were distributed increased correspondingly. In contrast, during periods of division and turmoil, such as the Qin, Wei, Jin, Southern and Northern dynasties, and Yuan dynasty, agricultural development was impacted to some extent, resulting in fewer new sites and a reduced number of provinces covered.



(**a**)



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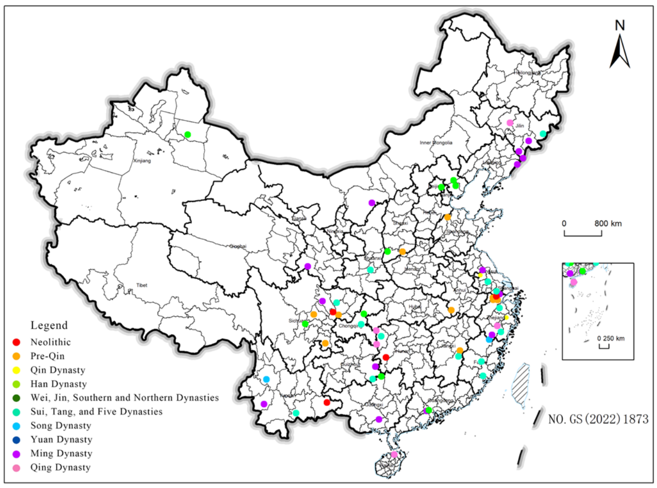
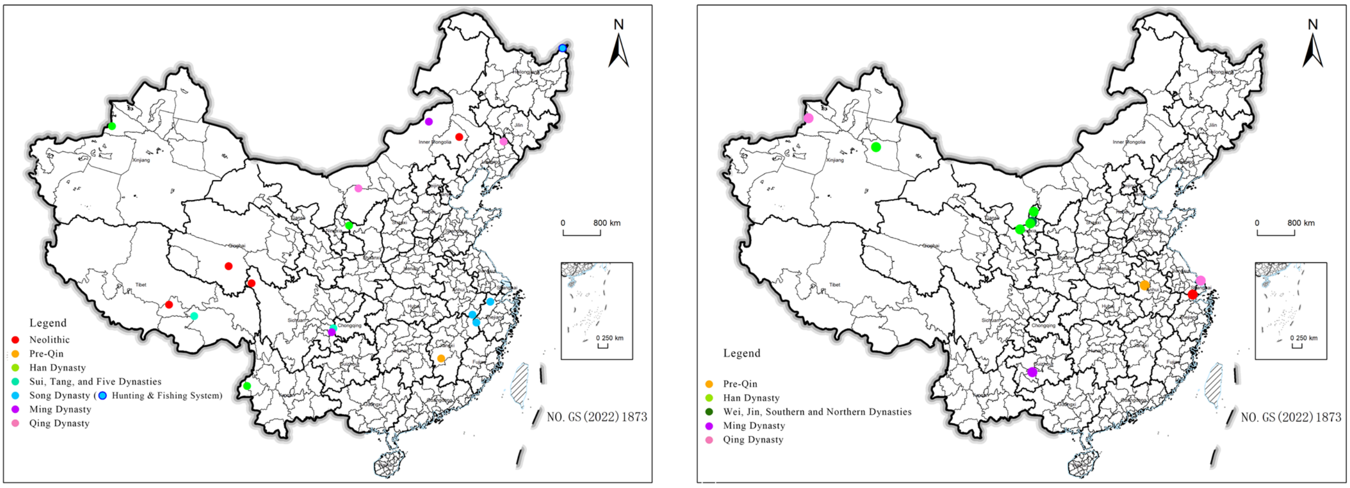


(**c**)

Figure 10. *Cont.*



(**d**) (**e**)

Figure 10. Spatiotemporal distribution of China-NIAHS sites by Chinese historical periods: (**a**) spatiotemporal distribution of overall sites; (**b**) spatiotemporal distribution of planting system sites; (**c**) spatiotemporal distribution of composite ecosystem sites; (**d**) spatiotemporal distribution of breeding (including fishing and hunting system sites); (**e**) spatiotemporal distribution of agricultural engineering system sites.

3.2.1. Staged of Spatiotemporal Distribution of China-NIAHS Sites

To better analyze the temporal variation characteristics of China's Important Agricultural Heritage sites, the centroid migration and distribution direction of sites across different historical stages were analyzed using the Mean Center and Standard Deviation Ellipse tools (Table 7, Figure 11). From the changes in the centroid positions, it can be seen that the overall trend of centroid migration is from west to east and then northward, which can be divided into four distinct directional stages.

Table 7. Standard deviation ellipse parameters of China-NIAHS sites in different historical periods.

Construction Period	Major Axis (Meters)	Minor Axis (Meters)	θ
Neolithic	840,397.7442	1,418,447.332	67.204702
Pre-Qin	528,295.3891	696,439.5863	72.23652
Qin	1,308,542.079	587,254.6929	123.310189
Han	1,239,175.712	883,967.6125	132.146089
WJNS	883,409.8404	747,393.3161	131.242251
STF	733,466.1197	1,041,585.955	63.043793
Song	641,392.7541	1,335,258.689	29.874495
Yuan	396,614.537	605,159.0238	57.813304
Ming	993,319.9414	1,248,642.688	31.833974
Qing	1,104,810.113	1,266,840.489	59.728054

In the first stage, from the Neolithic to the Pre-Qin period, the mean center of China-NIAHS sites shifted eastward, from the junction of southern Shaanxi and Chongqing to northern Hubei Province. In the second stage, from the Qin to the Han dynasty, the mean center shifted northwest, moving from the Han River basin in northern Hubei to southern Shaanxi. During the third stage, from the Wei, Jin, and Southern and Northern dynasties to the Song dynasty, the migration direction reversed, shifting from west to east, moving from southern Henan in the Huai River basin to northern Hubei, and then to western Anhui. In the fourth stage, from the Yuan to the Qing dynasty, the mean center shifted again from east to northwest, moving from northeastern Henan in the lower Yellow River to northern Hubei, and then to northern Henan in the middle Yellow River.

The Voronoi analysis, show that the CV value for the overall sites in all four stages is greater than 64%, indicating a 'clustered' distribution pattern (Table 8 and Figure 12). In the first stage, a clear 'clustered' distribution is observed in the middle and lower reaches of the Yellow and Yangtze Rivers. In the second stage, clustering is evident the middle reaches of the Yellow River in Ningxia, Shanxi, and Henan, as well as in several provinces in the lower Yangtze River. During the third stage, a strong 'clustered' pattern emerges in the lower Yangtze River, with secondary clustering in Sichuan, Chongqing, and Hunan. In the fourth stage, clustering is prominent in the Beijing, Tianjin, Hebei, and Shanxi regions, and along the eastern coastal areas, with secondary clusters in the middle Yangtze River, Guangxi, and Guizhou. The patterns indicate that the middle Yellow River and the middle and lower Yangtze River regions are key centers of agricultural civilization heritage. As social development and productivity increased, agricultural development spread to the eastern coastal and southwestern regions.

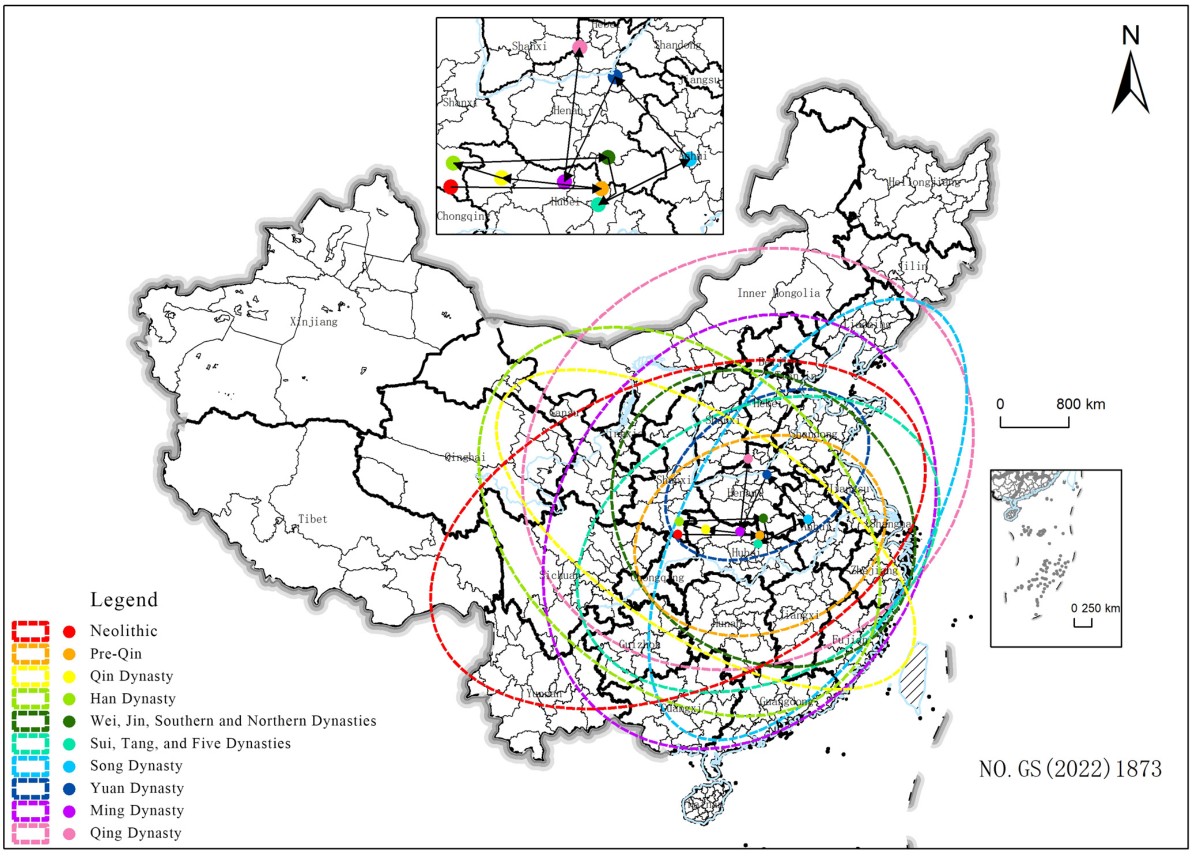


Figure 11. Movement trend of the mean center and distribution direction of China-NIAHS sites in different periods.

Table 8. CV values from Voronoi analysis of different categories of sites in different stages.

Category	First Stage	Second Stage	Third Stage	Fourth Stage
Total	1.3231	1.3458	1.4720	1.5271
Planting	1.1827	1.6173	1.6141	1.5700
Composite Ecosystem	1.5857	1.2634	1.2362	1.5680
Breeding	0.1000	0.4228	1.0000	0.6621
Agricultural Engineering	1.0000	0.3697	0.6435	0.3700

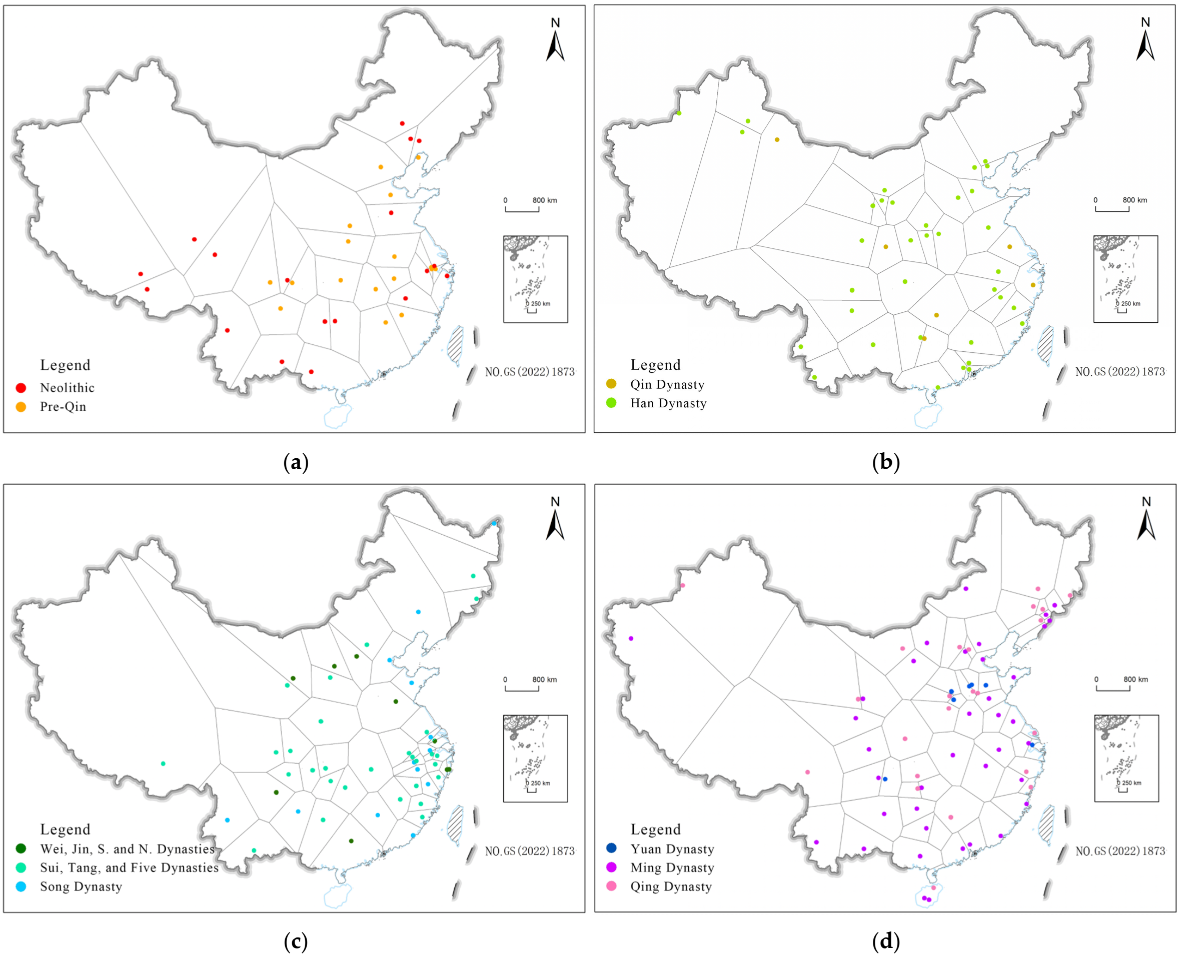


Figure 12. Voronoi analysis diagram of China-NIAHS sites in different historical stages: (**a**) first stage; (**b**) second stage; (**c**) third stage; (**d**) fourth stage.

3.2.2. Staged of Spatiotemporal Distribution Characteristics of the Five Categories of Agricultural Systems

The trend graph of the number of sites for the five agricultural systems (Figure 13) reveals significant temporal variations in the distribution of China-NIAHS sites. The total number of sites is relatively high during the Han, Sui, Tang, and Five dynasties, as well as Ming periods, indicating more developed and diversified agricultural systems. The planting system, a core component of agricultural culture throughout most historical period, consistently had a high number of sites compared to other system categories, especially during the Han and Ming periods. The composite system, emerging in the Neolithic period, fostered more integrated agricultural practices in subsequent periods. The breeding system played a supplementary role, had fewer sites, and exhibited little variation across periods. The agricultural engineering system, which appeared during the Han dynasty, evolved with advancements in agricultural technology and state-led efforts to modify the agricultural environment. The fishing and hunting system, with only one example from the Song dynasty, reflects its limited presence, confined to specific ecological regions or social groups, and largely replaced by modern fisheries in contemporary agricultural systems.

Based on Voronoi analysis diagrams and CV values (Table 8 and Figure 14), the spatial distribution of China-NIAHS sites follows a generally clustered pattern. Specifically, the planting and composite ecosystem sites exhibit a ‘clustered’ distribution across all four stages, concentrated in the middle and lower reaches of the Yellow and Yangtze Rivers. The breeding system sites show a ‘regular’ distribution pattern in the first stage, a ‘random’ distribution in the second stage, no sites in the third stage, and a ‘clustered’ distribution in the fourth stage. The agricultural engineering system has no sites in the first stage, a 'random' distribution in the second, a less distinct 'clustered' distribution in the third, and again a 'random' distribution in the fourth. This indicates that the planting and composite ecosystem sites consistently exhibited clustering trend, while the breeding system evolved from a dispersed to a clustered distribution. Due to the limited number of sites, the agricultural engineering system showed a more dispersed distribution overall.

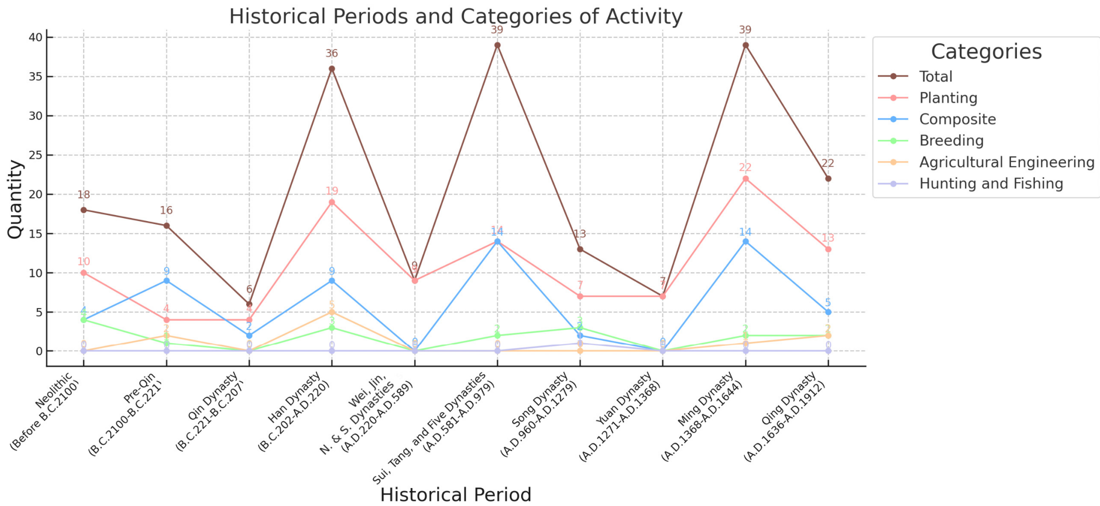


Figure 13. Time trend of the number of sites for the 5 categories of agricultural systems in different historical periods.

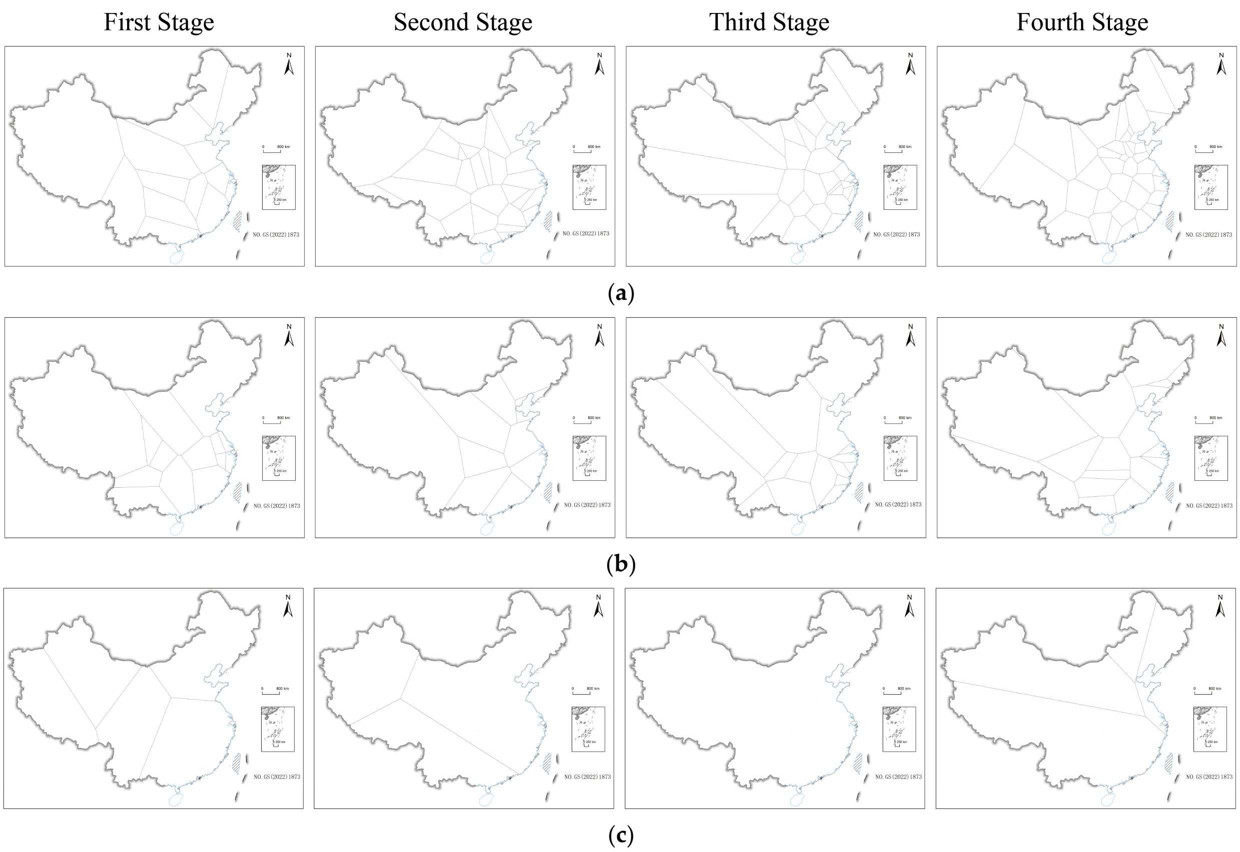


Figure 14. Voronoi analysis diagrams of 3 categories of agricultural system sites in 4 different historical stages: (**a**) planting system sites; (**b**) composite ecosystem sites; (**c**) breeding system sites.

3.3. Factors Influencing the Spatial Clustering of China-NIAHS

3.3.1. General Pattern of China-NIAHS Concentration Determinants

Through a review of relevant studies on the spatial distribution of China-NIAHS and its influencing factors, it is concluded that the spatial distribution of China-NIAHS is primarily determined by geographical factors such as rivers, topography, and landforms [42–44]. These indicators reflect the natural and environmental conditions that support the development of agricultural systems, such as water availability, terrain suitability, and ecological adaptability. On the other hand, the social–economic development-level factors that support the development of agricultural systems may include road traffic conditions, industrialization, tourism, population, urbanization, and the level of economic development [45–48]. These factors emphasize the role of human and economic dimensions in shaping the spatial distribution of agricultural heritage sites. Road traffic conditions indicate regional accessibility and connectivity, crucial for tourism and heritage preservation. Tourism contributes both economic benefits and cultural promotion for heritage conservation. Population density plays a pivotal role in the continuation of agricultural traditions, while urbanization and economic development level highlight the tension between modernization and heritage conservation.

The results of the geographic detection analysis indicate that the influence of each factor on the spatial distribution of China-NIAHS sites varies (Table 9). Each influencing factor demonstrated a significant effect on the distribution changes of China-NIAHS sites ($p < 0.05$). The factors are ranked in terms of influence magnitude as follows: population (q = 0.406) > tourism (q = 0.311) > industrialization (q = 0.166) > road traffic conditions (q = 0.164) > topography and landforms (q = 0.139) > urbanization (q = 0.135) > rivers (q = 0.073) > economic development level (q = 0.052).

Table 9. Factors influencing spatial distribution of China-NIAHS sites and their explanatory power.

Dimension	Factor	Index	Indicator Code	q Statistic		*p*-Value
Geographic condition	Rivers	River network density	X1	0.035	0.073	0.000
		The length of the river system	X2	0.085		0.000
	Topography and landform	Elevation	X3	0.139		0.000
Social–economic development level	Road traffic conditions	Railway operational length	X4	0.097	0.164	0.000
		Length of expressways	X5	0.283		0.000
		First-class highways	X6	0.387		0.000
		Second-class highways	X7	0.160		0.000
	Industrialization	Industrialization index	X8	0.166		0.000
	Tourism	Total tourism revenue	X9	0.311		0.000
	Urbanization	Urbanization rate	X10	0.135		0.000
	Economic development level	Real GDP per capita	X11	0.052		0.000
	Population	Total population size	X12	0.406		0.000

The spatial distribution of China-NIAHS sites is primarily influenced by socioeconomic factors, with population density and tourism being the most significant determinants. Industrialization and road traffic conditions play a secondary role. While geographical factors such as rivers, topography, and landforms are important, their explanatory power is weaker compared to socioeconomic influences. Economic development, with the lowest q-value, exerts minimal influence on the distribution of these agricultural heritage sites. Consequently, China-NIAHS sites are most concentrated in areas with high population density, tourism potential, and well-developed infrastructure, while their distribution is less influenced by natural geographic factors and economic development.

3.3.2. Influence of Geographical Factors

Geographic conditions, including rivers, topography, and landforms, are fundamental to the spatial distribution of China-NIAHS sites, providing essential context for the development, sustainability, and preservation of agricultural heritage. However, their explanatory power in determining site distribution is limited, especially when compared to socioeconomic factors such as population density, tourism, and infrastructure.

River systems have played a crucial role in the formation and development of China's ancient agricultural civilization, not only providing the material foundation for agricultural production but also influencing crop cultivation patterns and strengthening regional connections. Together with the socioeconomic structures they supported, these river systems have shaped China's long agricultural history and the distribution of its rich China-NIAHS sites.

According to the geographic detection analysis, rivers ($q = 0.073$) show a relatively weak explanatory power in terms of spatial distribution. Despite this, rivers still contribute to the accessibility of certain agricultural heritage sites, especially in areas with historically important river systems like the Yellow River and Yangtze River. Based on the distribution of river buffer zones with sites of medium-importance agricultural cultural heritage (Table 10, Figure 15), it was found that the distribution pattern of the sites exhibits a coarse, banded settlement pattern along the river system.

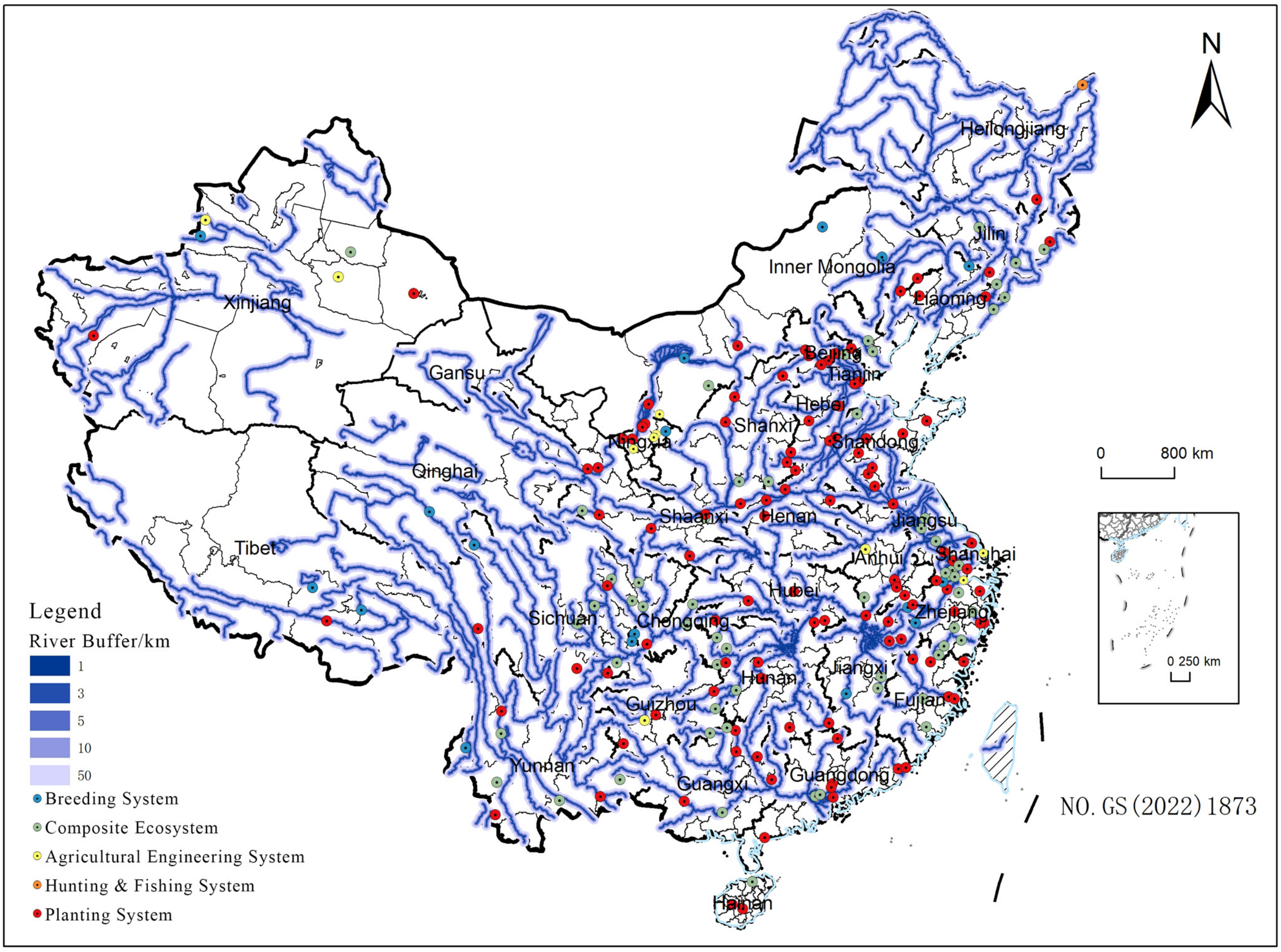


Figure 15. Distribution map of China-NIAHS sites with respect to river buffer zones.

Table 10. Number of China-NIAHS sites within buffer zones of increasing distance from rivers.

Buffer Range/km	Planting System	Composite Ecosystem	Breeding System	Agricultural Engineering System	Fishing and Hunting System
0–1	62	40	10	7	1
1–3	5	10	0	0	0
3–5	0	1	1	1	0
5–10	0	0	1	0	0
10–20	1	0	0	0	0
>20	41	8	5	1	0

The distribution of sites within different river buffer ranges exhibited distinct patterns. Moreover, 61% of the sites are within 1 km, and 70% of the sites are within 5 km of rivers. Within 20 km, the number of sites decreases with distance, although a certain number of sites are unexpectedly found beyond this range. This suggests that, while the sites exhibit some hydrophilicity characteristics in their distribution, the influence of large rivers and their tributaries on site distribution is relatively limited. Since the Song dynasty, irrigation technologies powered by human labor, animal power, water, and wind energy have gradually become widespread, allowing sites to thrive even in regions with underdeveloped water systems or small and micro-sized rivers.

Topography and landforms are basic elements of the natural environment, and elevation is the most important natural attribute of topography. Due to the high dependence of human beings on the natural environment, it is prompted that the scope of human activities is closely related to the spatial distribution of China-NIAHS sites. Therefore, elevation is an important factor influencing the distribution pattern of the sites. Although the q-value for topography and landforms ($q = 0.139$) is higher than that for rivers, it still indicates relatively low explanatory power compared to other socioeconomic factors. While topography is not the dominant factor, it remains an important contextual element influencing site distribution. By overlaying the coordinate points of China-NIAHS with the DEM (Table 11 and Figure 16), it can be observed that China-NIAHS sites are primarily concentrated in low-altitude regions below 500 m. As elevation increases, the number of sites gradually decreases, with only a small number of sites distributed above 2000 m. This pattern highlights the strong dependence of agricultural activities on favorable topographical conditions and their adaptability to varying elevations.

The spatial distribution of China-NIAHS sites is strongly influenced by topography and landforms, reflecting the relationship between agriculture and terrain. Plains and depressions, with fertile soil and abundant water, support large-scale cultivation, especially of water-intensive crops like rice, and facilitate agricultural engineering. These areas, often densely populated, also promote the diffusion of agricultural techniques. In contrast, hilly regions with diverse terrain support practices such as fruit tree cultivation and terraced farming but are less suited for large-scale planting. Mountainous areas, particularly at lower elevations, host diverse agricultural systems, including composite ecosystems and breeding systems, adapted to more complex conditions. As elevation increases, agricultural challenges intensify, with high-altitude areas favoring specialized practices like breeding systems and composite ecosystems. In plateau regions, agricultural sites are sparse due to harsh conditions, but fertile basins still support both planting and breeding systems. Overall, these patterns reflect the diversity of China's agricultural heritage, shaped by both natural environments and human adaptation, from large-scale farming in plains to specialized systems in mountainous and plateau areas.

The analysis of geographic conditions reveals a complex relationship between natural features and the spatial distribution of China-NIAHS sites. Rivers, while historically crucial for agricultural irrigation, are less influential in the current distribution compared to socioeconomic factors such as population density and tourism. Although topography and landforms influence the type of farming systems, their explanatory power in determining the precise location of China-NIAHS sites is relatively limited.

Table 11. Number of China-NIAHS sites at different elevations.

Altitude/m	Planting System	Composite Ecosystem	Breeding System	Agricultural Engineering System	Fishing and Hunting System	Total	%
−268–200	59	5	4	26	1	95	48
200–500	23	3	0	19	0	45	23
500–1000	9	1	1	5	0	16	8
1000–2000	18	4	5	7	0	34	17
2000–4000	0	1	0	1	0	2	1
4000–7524	0	3	0	1	0	4	2

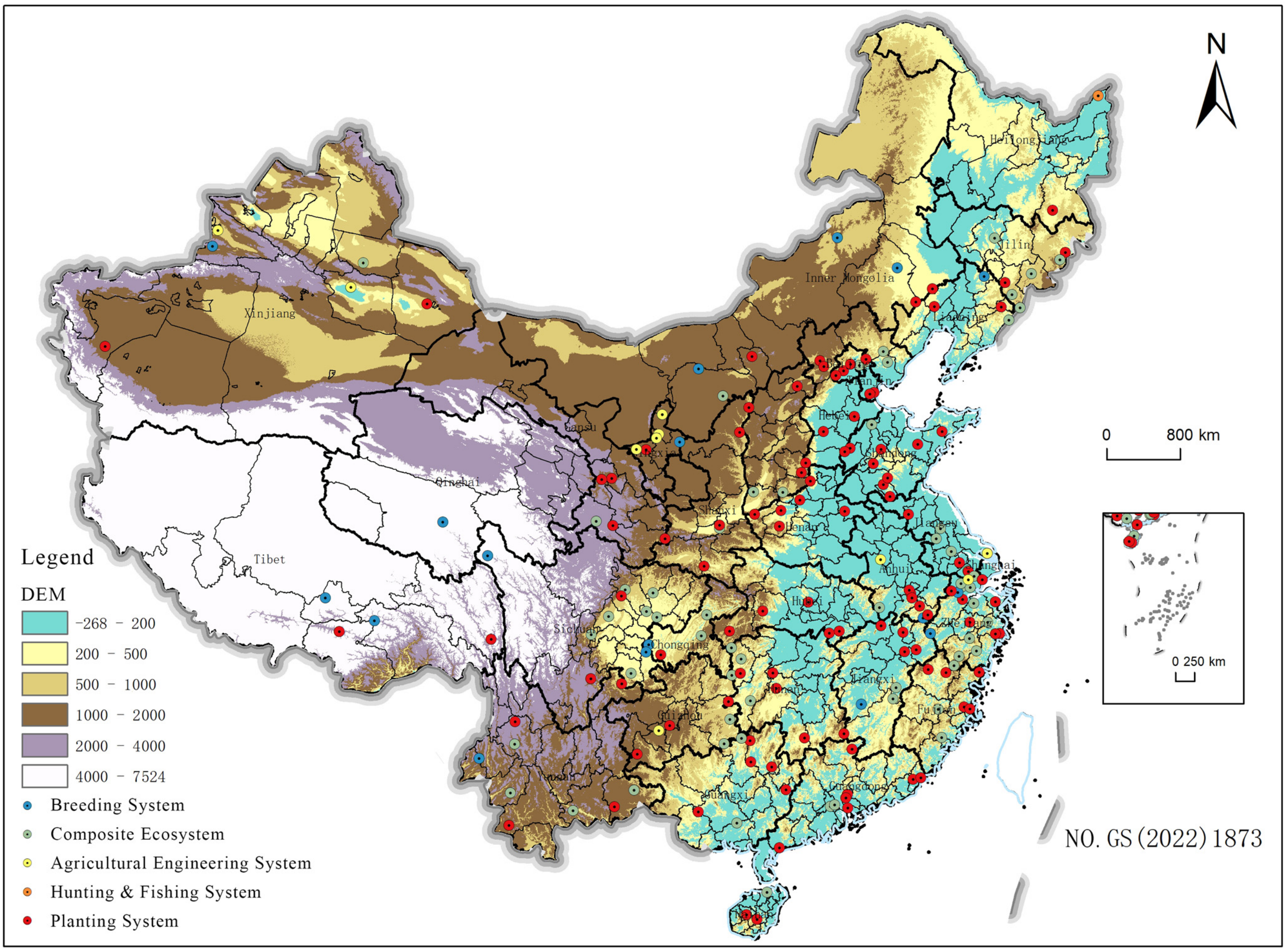


Figure 16. Elevation distribution of China-NIAHS sites.

3.3.3. Influence of Socioeconomic Factors

The social and economic development level is a key factor affecting the spatial distribution of China-NIAHS sites, encompassing six factors: road traffic conditions, industrialization, tourism, urbanization, economic development level, and population. These factors collectively reflect the influence of socioeconomic development on the spatial distribution of China-NIAHS sites, with significant differences in their explanatory power. Population (q = 0.406) is the most influential factor, followed by tourism (q = 0.311), both having the strongest explanatory power for the spatial distribution of the sites. Road traffic conditions (q = 0.164), industrialization (q = 0.166), and urbanization (q = 0.135) have weaker influences, though they remain statistically significant. Economic development level (q = 0.052) exhibits the weakest explanatory power, suggesting its relatively weak influence on the spatial differentiation of the sites.

Population density is a key factor influencing the spatial distribution of China-NIAHS sites, as regions with higher population concentrations are better positioned to protect agricultural cultural heritage. Densely populated areas typically benefit from greater human capital and more active cultural exchange, which facilitates the spread of agricultural technologies and knowledge, thereby supporting the preservation and development of agricultural heritage. This results in a concentration of heritage sites in such regions. According to the top ten provinces by 2024 population ranking (Figure 17a), most provinces with high population numbers, except for Henan and Hubei, also have a significant number of China-NIAHS sites. This underscores the correlation between population size and the number of agricultural heritage sites, highlighting that densely populated areas offer favorable conditions for the growth and preservation of agricultural heritage, driven by abundant human resources, cultural vitality, and infrastructure.

Tourism significantly influences the spatial distribution of China-NIAHS sites, driving the development and preservation of agricultural cultural heritage. The economic benefits generated by tourism often prompt local governments and institutions to invest more in site protection. Additionally, tourism helps disseminate and promote traditional agricultural culture, increasing public awareness and appreciation. Regions with strong tourism industries tend to have better heritage protection environments, facilitating more effective preservation and transmission of agricultural heritage. Analysis of the top ten provinces by tourism revenue in 2024 (Figure 17b) shows that, except for Hunan and Guangxi, most of these provinces also rank highly in the number of China-NIAHS sites. This reinforces the connection between tourism development and the distribution of agricultural heritage sites. Notably, Zhejiang, which has the highest number of China-NIAHS sites, also ranks among the top three in total tourism revenue, indicating that robust tourism industries contribute to both economic growth and a favorable environment for heritage site protection.

Industrialization has a limited impact on the spatial distribution of China-NIAHS sites. Among the top ten provinces ranked by industrialization index in 2024 (Figure 17c), most show a moderate number of China-NIAHS sites. In contrast, Qinghai, ranked eighth in industrialization, has only one site. This suggests that, while industrialization may be associated with a moderate number of heritage sites in some regions, its overall effect is more complex and not directly proportional to the number of agricultural heritage sites. Industrialization often brings environmental changes and altered land use patterns, which can threaten traditional agricultural heritage. In highly industrialized regions, the preservation of agricultural heritage faces greater challenges due to competition for land and resources, as well as environmental degradation.

Road traffic conditions have a limited impact on the spatial distribution of China-NIAHS sites, suggesting that transportation infrastructure plays a minor role in promoting or restricting their spread. Among the road-related indicators, first-class highways (q = 0.387) have the strongest explanatory power, followed by expressways (q = 0.283), second-class highways (q = 0.160), and railway length (q = 0.097). This indicates that primary highways have the most significant influence on site distribution. Analysis of the top ten provinces ranked by the length of first-class highways in 2024 (Figure 17d) shows that while seven of these provinces have large numbers of China-NIAHS sites, three exhibit medium-sized counts. This suggests that the number of heritage sites does not always correlate with the extent of first-class highways. Although better transportation can support heritage site protection and dissemination, it may also have dual effects. In remote areas, limited road access can shield sites from urbanization, industrialization, and mass tourism, offering a more controlled preservation environment.

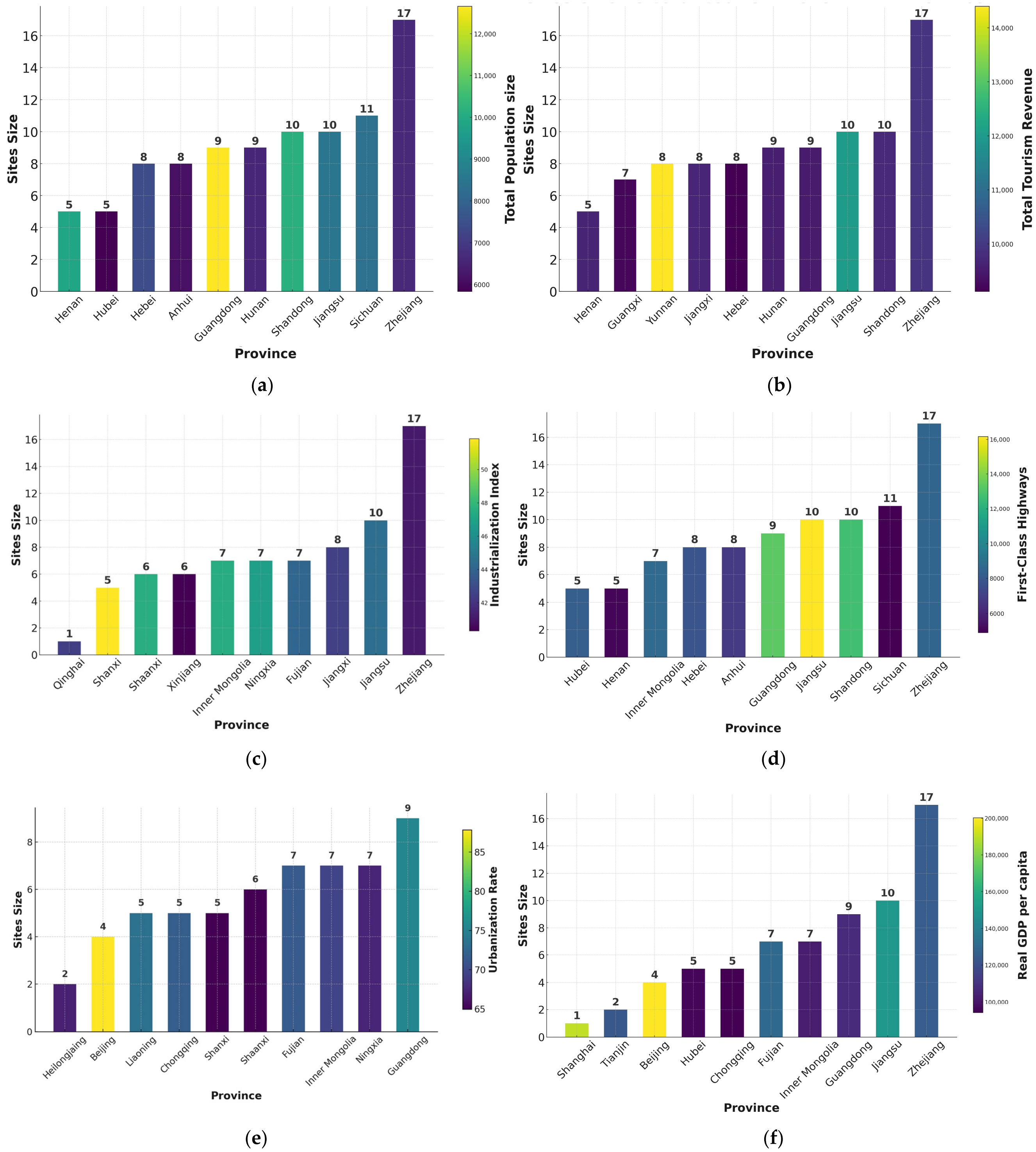


Figure 17. Comparison of China-NIAHS sites and socioeconomic development factors across the top 10 provinces: (**a**) population size; (**b**) total tourism revenue; (**c**) industrialization index; (**d**) road traffic conditions; (**e**) urbanization; (**f**) real GDP per capita.

Urbanization has a limited impact on the spatial distribution of China-NIAHS sites, suggesting that urban growth does not significantly shape the locations of these heritage sites. While urbanization has enhanced regional productivity and industrial development, excessive urban expansion poses a threat to agricultural heritage sites. According to the 2024 rankings of the top ten provinces by urbanization rate (Figure 17e), only Guangdong has a large number of China-NIAHS sites, while the other provinces show medium or fewer sites. This indicates that urbanization does not necessarily lead to more heritage sites, and in some cases, urban expansion may limit their preservation. In rapidly urbanizing areas, agricultural heritage sites are at greater risk due to land development, infrastructure expansion, and increased competition for space.

Economic development has minimal impact on the spatial distribution of China-NIAHS sites. Analysis of provinces ranked by real GDP per capita in 2024 reveals that despite high economic levels (Figure 17f), Beijing (ranked first) has relatively few sites, and Shanghai (ranked second) has only one. Additionally, half of the top ten provinces have smaller site numbers. This suggests that while economic development may provide financial support for heritage protection, it does not directly correlate with the number of agricultural heritage sites, with factors such as population density and tourism playing a more significant role.

3.3.4. Interaction Analysis

The interaction detection module was used to calculate the interactions between all factor pairs in relation to the spatial distribution changes in China-NIAHS sites (Figure 18). The results indicate that the interaction q-statistic for paired factors is higher than that for individual factors, suggesting that the interaction of a single factor with others may enhance its explanatory power [22]. A total of 55 pairs of factors exhibited nonlinear amplification, implying that a single factor alone is insufficient to fully explain the spatial distribution of China-NIAHS sites. However, the synergistic effects of multiple factors can reveal more complex distribution patterns. Furthermore, 11 factor pairs showed dual-factor enhancement, meaning that the interaction between these factors significantly improves the explanatory power of site distribution, potentially driving the expansion of agricultural civilization or supporting site protection in certain regions.

The interaction between river network density (X1) and other factors predominantly falls within the high-level range, indicating that regions with dense river networks have a significant influence on the spatial distribution of agricultural heritage sites. These areas often feature fertile plains conducive to agricultural development, which, in turn, promotes the concentration of China-NIAHS sites. Additionally, the interaction between length of the river system (X2) and real GDP per capita (X11) reaches 0.828, highlighting that economically developed regions with abundant river resources experience stronger synergies between economic growth and agricultural civilization, which fosters population concentration. The next most significant interaction is between river network density (X1) and the industrialization index (X8), with a value of 0.816. This suggests that in areas with advanced industrialization, the presence of rich river resources further supports the integration of industry and agriculture, enhancing the distribution of agricultural heritage sites.

First-class highways (X6) and second-class highways (X7) rank in third place with an interaction value of 0.811. This indicates that transportation infrastructure positively influences the distribution of agricultural heritage sites. Improved transportation facilities contribute to the dissemination and preservation of cultural heritage, while also enhancing tourism to agricultural heritage sites and raising public awareness. Furthermore, the interaction between first-class highways (X6) and total tourism revenue (X9) with other factors is also significant, further highlighting the close relationship between an efficient transportation network and a thriving tourism industry, both of which jointly promote the development and protection of the sites.

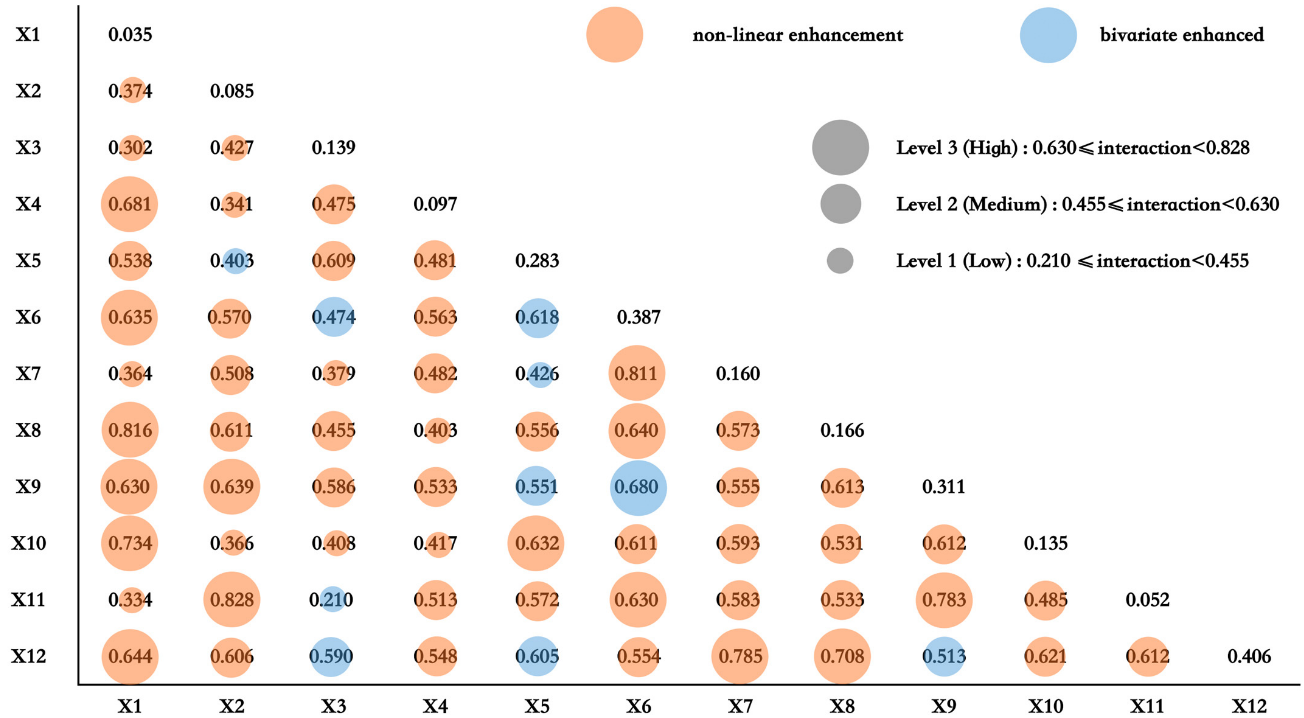


Figure 18. Interactive effects of pairwise factors on the spatial distribution changes of China-NIAHS sites.

Conversely, the interaction between real GDP per capita (X11) and elevation (X3) is the lowest, with a value of only 0.210, indicating a weak relationship between geographic elevation and economic development level. In high-altitude areas, economic development may be constrained by natural conditions, making it difficult to directly correlate with the economic level, which may also affect the distribution of the sites.

Although river network density interacts strongly with other factors in many regions, its interaction with river system length, elevation, second-class highways, and GDP per capita is weak. This suggests that while river network density is influential in some areas, its impact is limited in high-altitude regions where agricultural production is constrained by natural conditions. In remote or economically underdeveloped areas, river resources have a limited effect and do not create strong synergies with factors such as economic development or transportation infrastructure.

4. Discussion

This study examines the spatial distribution, influencing factors, and historical evolution of 196 China-NIAHS sites. The findings show a clustered distribution, mainly in southeastern China, particularly in Zhejiang, Jiangsu, and Fujian. Over time, the distribution transitioned from the western frontier to the central Yellow River Basin and later to the southeastern Yangtze River Basin, shaped by favorable geography and historical migrations. Key factors influencing site distribution include natural conditions like rivers and topography and socioeconomic factors such as population density and tourism. Population density and tourism are identified as the strongest drivers of site concentration. These results enhance understanding of the spatial and temporal dynamics of China-NIAHS, providing valuable insights for their preservation and management.

4.1. Clustered Spatial Distribution and Regional Clustering Zones

This study confirms that China-NIAHS sites predominantly exhibit a single-core distribution trend along the lower reaches of the Yangtze River and the eastern coast. Provinces in the Yangtze River basin and areas south of it, influenced by diverse topography and biodiversity [49], have developed prominent agricultural ecosystems, particularly in Zhejiang Province, which leads in both China-NIAHS and GIAHS numbers. This underscores the significant impact of location and natural environment on conservation efforts. Additionally, the integration of historical spatial analysis reveals how agricultural heritage systems evolved under the interplay of environmental and human factors over time. Furthermore, the identification of four regional clustering zones—northwest, northeast-Hebei–Shandong, Yangtze River Delta, and Hunan–Chongqing–Yunnan–Guizhou—provides a comprehensive framework for understanding the spatial concentration and distribution patterns of China-NIAHS [29].

4.2. Historical Evolution of Distribution Patterns

The historical and spatial distribution of China-NIAHS across different periods reveals the impact of historical events, such as population migrations and political shifts on agricultural centers. These movements are evident in the west-to-east and northward migration trends observed. The center of gravity of the sites is located in the southern North China Plain, between the middle reaches of the Yellow and Yangtze Rivers, with a general southward spread, aligning with the dense population east of the Hu Line and advancing agricultural development [50]. Among the five categories of agricultural systems, the planting system dominates, followed by the composite ecosystem and breeding system, while agricultural engineering system and fishing and hunting system are less represented. This distribution reflects the historical trajectory of Chinese agriculture, transitioning from early crop domestication and dry farming in north to paddy fields agriculture in the south, and eventually sophisticated systems characterized by intensive land use and ecological adaptation [51].

This study further situates China-NIAHS within their historical and developmental contexts by identifying four historical stages of site distribution and tracing their migration patterns using the average nearest neighbor index and standard ellipse deviation. Voronoi analysis diagrams reveal distinct distribution trends during these stages, providing empirical evidence of the progression of Chinese agricultural civilization. The west-to-east migration reflects the movement of agricultural centers from less fertile, resource-constrained areas in the west to the more favorable agricultural conditions of the east, driven by better water resources, fertile plains, and milder climates. This migration also coincides with population growth and the establishment of political and economic hubs in the eastern regions. The subsequent northward migration was likely influenced by the expansion of political centers and the adaptation of agricultural systems to northern climates and terrains. It finds that early site distributions were random and dispersed characteristics, significantly influenced by wars and social unrest. Since the Neolithic period, the center of gravity of sites has shifted from west to east and then north, reflecting changes in agricultural management and political centers. Over time, a 'clustered' trend emerged, with sites spreading from the Yellow River and Yangtze River basins to the eastern coast and southwest regions, consistent with the historical spread of ancient Chinese agricultural [52].

The implications of this migration are multifaceted. On the positive side, the shift allowed for the optimization of natural resource utilization, fostering the development of advanced agricultural systems in regions with better environmental conditions. The migration further highlights the importance of integrating agricultural practices with evolving socioeconomic and environmental contexts to ensure their sustainability in changing conditions. This temporal perspective highlights the dynamic nature of agricultural heritage systems, shaped by historical migration patterns, changing environmental conditions, and socioeconomic development.

4.3. Influencing Factors Shaping China-NIAHS Distribution

The spatial distribution of China-NIAHS is shaped by a complex interaction of natural, socioeconomic, and cultural factors, with population density, tourism development, and river network density being the most influential. Population density directly affects the capacity of regions to protect and transmit agricultural heritage, highlighting the importance of leveraging demographic advantages for conservation and sustainable development [53]. Tourism serves a dual purpose, generating economic benefits while enhancing the cultural value of agricultural heritage. Regions with strong tourism potential should integrate conservation efforts with tourism strategies to foster a mutually beneficial relationship between economic growth and cultural preservation [54]. In contrast, factors like urbanization and economic development have a weaker influence. While urbanization poses risks to heritage preservation in rapidly growing areas [55], its overall impact is less significant than other factors. Sustainable urban planning and a balanced approach to urban growth and heritage protection are essential to mitigate these risks. Although economic development supports conservation funding, population density and tourism have a more substantial effect on site distribution.

Industrialization presents a nuanced influence, with its pressures being more evident in highly industrialized regions. Balancing industrial growth with cultural preservation requires strategies to mitigate its adverse effects on agricultural heritage. Transportation conditions also have a dual impact: better infrastructure can facilitate heritage conservation and cultural dissemination, but excessive development linked to urbanization and tourism can lead to degradation [56]. Conversely, limited accessibility in some regions may help preserve heritage sites by reducing modernization pressures. The interaction analysis further highlights the importance of geographic and infrastructural factors. Strong interactions between river network density, industrialization, and transportation infrastructure indicate that regions with well-developed river systems and transport networks are more conducive to the development and protection of agricultural heritage. By contrast, factors like GDP and elevation have less pronounced interaction effects, underscoring their limited role in shaping spatial patterns.

4.4. Resilience and Sustainability of Traditional Agricultural Systems Amid Globalization

The impact of globalization on traditional agricultural systems has led to the marginalization of small-scale farmers unable to compete with modern industrial agriculture [57]. China-NIAHS initiative addresses these challenges by emphasizing the sustainability and resilience of traditional agriculture, mitigating economic and environmental shocks. Similar efforts are evident in GIAHS projects worldwide, such as Lebanon's Shouf Biosphere Reserve, Italy's Vallecorsa terraced systems, and Tunisia's oasis systems, which showcase innovative adaptations to challenging environments [58–60]. Japan's Nishi-Awa Steep Slope Land Agriculture System demonstrates how traditional farming techniques can adapt to steep terrains, balancing productivity with ecosystem stability [61]. Spain's Historical Irrigation System at the Horta of Valencia, highlights the importance of efficient water management practices for sustaining agricultural activities in semi-arid regions [57]. Peru's Andean Agriculture in the Cusco–Puno Corridor underscores the role of traditional practices in preserving biodiversity and cultural landscapes across diverse altitudes [57].

These systems balance agricultural productivity with ecosystem stability, akin to China's terraced systems in the south. However, European rural landscapes have experienced significant changes, with low-yield traditional farming replaced by intensive agriculture, leading to the loss of traditional knowledge, biodiversity, and cultural landscapes [62,63]. Spain's farmer-managed irrigation practices in the Valencia region illustrate how communal resource management and cooperation enhance agricultural resilience in challenging environments [64]. Despite this, European GIAHS sites highlight the role of cultural biodiversity in creating resilient agricultural ecosystems and preserving cultural landscapes [65]. These examples underscore the importance of biocultural conservation, demonstrating the adaptability and sustainability of traditional agricultural systems amid globalization [66,67]. The GIAHS initiative thus preserves these systems while fostering sustainable innovation through dynamic conservation, ensuring the future of rural areas and communities.

4.5. Limitations and Future Works

However, this study has several limitations. Focusing solely on China-NIAHS provides a necessary lens for understanding spatial and temporal distribution patterns at the national level, as these sites are officially recognized and represent exemplary models of agricultural heritage. Nevertheless, the relatively small number of sites selected based on the China-NIAHS criteria limits the scope of comprehensive spatial analyses across all agricultural system categories. This limitation is particularly evident for under-represented systems, such as fishing and hunting system, where the single national site is available. Additionally, the uneven progress in agricultural heritage protection across provinces complicates the establishment of consistent criteria for identifying provincial and municipal agricultural heritage systems, potentially introducing regional biases. While national-level systems provide a standardized and authoritative dataset, provincial and municipal sites encompass a wider range of agricultural systems and local cultural contexts, offering unique research value.

To address these limitations, future research should focus on expanding the dataset to including more sites and diverse agricultural systems, enabling more robust spatial and temporal analyses. Developing standardized criteria for provincial and municipal sites would improve the consistency and comparability of data across regions. Furthermore, integrating local cultural and historical contexts into agricultural heritage recognition criteria could uncover previously overlooked aspects of agricultural systems, enhancing regional conservation efforts.

5. Conclusions

Since ancient times, China has long been in a stage of agricultural society characterized by farming. The vast land has given rise to a diverse and distinctive agricultural ecosystem with high economic and ecological value. This study provides significant insights into the spatial distribution and historical evolution of China-NIAHS, deepens and develops the previous understanding and quantitative analysis of the importance of their importance, and offers guidance for further exploration of the role and value of China-NIAHS across different historical periods. The findings demonstrate the following:

1. The spatial distribution of China-NIAHS sites shows clear regional differentiation, with more sites in the eastern lower reaches of the Yangtze River and coastal areas, and fewer sites in the west and north. The overall distribution exhibits a 'single-core clustering' pattern, radiating from the Yangtze and Yellow River basins to surrounding regions. Eastern and southeastern China includes Zhejiang, Shanghai, and the southern parts of Jiangsu and Anhui, historically economic and cultural centers, hosts the majority of heritage sites due to dense populations, well-developed river systems, and robust tourism economies. The distribution of different agricultural systems is uneven, with the planting system showing a 'dual-core and dual sub-core' clustering distribution, while the composite ecosystem sites exhibit a clear 'single-core' clustering distribution. Breeding and agricultural engineering systems show a random distribution with a single core.

2. The migration of the center of gravity of China-NIAHS sites during historical periods generally aligns with the direction of human civilization origin, population, and political center migration, moving from west to east and then north. The spatial distribution of sites during historical periods mostly shows a random trend, with a clear stage-by-stage growth in the number of sites. Notably, the Han, Sui, Tang, and Ming dynasties were the most significant periods for the development of China-NIAHS.
3. The level of agricultural engineering technology has influenced the water affinity of China-NIAHS site selection. Before the Tang dynasty, with lower agricultural engineering technology levels, water affinity played a decisive role in site selection, with most sites located near major rivers. As irrigation and water lifting technologies and tools developed, sites with stronger drought resistance began to appear more frequently in areas far from major river basins, although water-dependent sites still commonly chose river basins for easy irrigation.
4. The diversity of terrain is a significant factor in the emergence of special sites. Most planting and composite system sites are located in areas with flat and open terrain, while more complex mountainous environments, such as terraced fields, forest–livestock symbiosis, and specialized animal farming, are more likely to emerge in areas with significant elevation differences. Higher altitudes and colder climates have also fostered agricultural adaptation strategies in harsh environments.
5. The spatial clustering of China-NIAHS is shaped by a combination of natural and socioeconomic factors. Population density ($q = 0.406$) and tourism ($q = 0.311$) were found to have the strongest explanatory power for the spatial distribution changes of China-NIAHS sites. Regions with higher population density and tourism development showed a more concentrated distribution of sites, emphasizing the role of human activities in preserving agricultural heritage. Conversely, urbanization ($q = 0.135$) and economic development ($q = 0.052$) had a relatively weaker influence, suggesting the need for balanced growth strategies to mitigate risks to heritage conservation. Geographic factors, such as river network density and elevation ($q = 0.139$), provided essential context but had weaker explanatory power overall. Strong interactions between river systems, industrialization, and transportation infrastructure further underscored the importance of integrated strategies for site preservation.

Overall, this study provides theoretical support for the value assessment, protection, and sustainable use of China-NIAHS, contributing to the systematic exploration and preservation of China's agricultural heritage while positively impacting global agricultural heritage conservation. The findings have practical implications for managers and policymakers. First, the spatial distribution of China-NIAHS sites reveals regional imbalances, with higher concentrations in eastern and coastal areas. This suggests a need for targeted strategies to enhance site identification and protection in underrepresented regions. Second, the influence of agricultural technology on site selection highlights the importance of ongoing technological innovation. Policymakers should support advancements in water management and drought-resistant technologies, particularly in water-scarce resources, to sustain agricultural heritage. Additionally, the correlation between population growth and site concentration highlights the need to manage urbanization and development pressures carefully [57]. Policies should balance heritage conservation with urban and economic growth to prevent the loss of important agricultural sites.

To address these challenges effectively, the following specific policy recommendations are proposed:

1. Enhance Regional Protection: Implement targeted policies to bolster efforts in regions with fewer China-NIAHS sites [68]. This includes improving site identification and protection mechanisms to ensure comprehensive coverage across the country.

2. Promote Integration with Geographical Indication Products: Foster the integration of agricultural heritage systems with geographical indication products to enhance economic viability [69,70]. Focus on leveraging local advantages, highlighting ecological and cultural values, and aligning industries with regional strengths while integrating rural tourism to strengthen heritage conservation and GI branding for greater market competitiveness [71].
3. Facilitate Industrial Integration and Coordination: Support the integrated development of agriculture, culture, and tourism industries in heritage regions [72]. Promote policies that align stakeholders, including governments, communities, and businesses, to create cohesive strategies and diversified economic models that balance conservation and sustainable development.
4. Support Technological Advancement: Invest in and promote innovation in agricultural technologies, particularly in regions that face water scarcity. By enhancing drought resistance and water management practices, the sustainability of agricultural heritage systems can be better maintained.
5. Balanced Development: Formulate policies that integrate agricultural heritage conservation with urban and economic planning [73]. This approach will help mitigate the impact of rapid development on heritage sites, ensuring their preservation for future generations.
6. Expand GIAHS Designation: Based on the analysis of factors influencing the spatial distribution of China-NIAHS sites, prioritize the inclusion of regions with unique and underrepresented agricultural systems into the GIAHS framework. This approach will not only enhance global recognition of diverse agricultural practices but also provide a robust platform for preserving the cultural and ecological values of China-NIAHS. Aligning GIAHS designation with the preservation of China-NIAHS can foster sustainable development, promote traditional agricultural practices, and strengthen community involvement.

Future research will also involve a more detailed and microscopic study of the spatial distribution and influencing factors of historical agricultural systems at multiple levels. Building on this study's national-level findings, Zhejiang Province—home to the largest number of China-NIAHS sites—will serve as the focus area for exploring all provincial and municipal Agricultural Heritage Systems within its boundaries. This will allow for a more holistic understanding of spatial distribution patterns and influencing factors, incorporating diverse agricultural systems beyond national-level sites. Additionally, the research will be expanded to encompass the entire Yangtze River Basin, comparing the spatial distribution and influencing factors of AHS across the upper, middle, and lower reaches of the basin, covering 11 provinces. This comparative study aims to uncover regional differences and shared characteristics, offering insights into the dynamics of agricultural heritage across a broader geographical and cultural landscape.

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gov.cn/nybgb/2014/dliuq/201712/t20171219_6111693.htm; http://www.moa.gov.cn/nybgb/2015/shiyiqi/201712/t20171219_6104092.htm; http://www.moa.gov.cn/govpublic/XZQYJ/201706/t20170630_5732250.htm; http://www.moa.gov.cn/nybgb/2020/202003/202004/t20200416_6341679.htm; http://www.moa.gov.cn/nybgb/2021/202112/202201/t20220104_6386254.htm; http://www.moa.gov.cn/govpublic/ncshsycjs/202309/t20230921_6436984.htm, accessed on 28 December 2023.

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