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An investigation into the spatial distribution patterns and influencing factors of fortresses in Tianshui, Gansu Province, China

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The interaction between globalization and localization profoundly influences the evolution of cultural landscapes, and the protection of local traditional culture serves as the foundation for cultural diversity and confidence. Tianshui fortresses, as typical folk defensive settlements, embody unique landscape and geographical features, reflecting distinct local cultural characteristics. This research adopts various methods, including field investigations and geographic information technologies, to explore the spatial distribution patterns of the fortresses in Tianshui and the mechanisms influencing them. It is discovered that the fortresses, as folk defensive architecture/settlements, exhibit unique geographical distribution patterns compared to state defensive buildings/settlements, characterized by relatively homogeneous specifications, formations, and distribution patterns without hierarchical differences in importance. The study finds that the reasons for fortress construction, settlement distributions, and terrain are the main factors influencing the spatial distribution of fortresses. The force transmission chain, “natural conditions—land grain productivity—land population carrying capacity—population distribution—settlement distribution—fortress distribution,” is identified as the primary mechanism affecting the spatial distribution of Tianshui fortresses. This study analyzes the distribution patterns of Tianshui fortresses, filling the gap in the specialized database on these settlements. It further deepens the theoretical understanding of the evolutionary patterns of special cultural landscapes and provides targeted reference materials for the protection of local traditional culture, heritage tourism development, and related practical applications.

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Introduction

As one of the main research subjects in geography, cultural landscapes have a strong sense of locality and reflect how the dual cultural phenomena of globalization and localization manifest as material entities on the Earth's surface (Wei et al. 2024). Utilizing geographical concepts and methods, combined with spatial data mining to analyze the characteristics, types, and spatiotemporal distributions of cultural landscapes, helps clarify the formation and evolution mechanisms of these landscapes, discuss their positioning and value at various regional scales, and lay a solid foundation for promoting the protection of cultural landscapes, as well as the in-depth development and utilization of excellent cultural resources (Hu and Wu, 2024). Under the significant impact of globalization and urbanization, China's rural and urban cultural landscapes are facing the dangers of fragmentation, mutation, and even extinction. Beyond the traditional scales of single sites, blocks, and towns, the protection of cultural landscapes needs to seek breakthroughs from regional and inter-regional perspectives, in order to further enhance integrated and regional protection concepts (Wang et al. 2017).

The essence of Chinese cultural landscapes lies in the countryside, where diverse cultural landscapes are largely preserved. These landscapes serve as significant bases for ethnic identifiability and identity, as well as the quintessence for achieving differentiation and maintaining individuality (Wu, 2016; Ma et al. 2023b). With traditional settlements at the core, protecting the tangible and intangible cultural landscapes of characteristic villages is crucial for safeguarding historical and cultural contexts, inheriting local memories, and "keeping hometowns in memory" (Long and Tu, 2017). In recent years, the concept of cultural landscapes has garnered significant attention, with more emphasis placed on the coordination of cultural heritage across space, time, and cultural elements. This approach not only facilitates a comprehensive reimagining of the historical development of human societies but also endows cultural heritage with deeper humanistic significance, broadening and enhancing the protection and utilization value of cultural heritage.

Fortresses are a unique type of cultural landscape and a material remnant built by humans on the Earth's surface, once widely distributed across the land. Although many have disappeared today, a significant number still remain. Generally, these fortresses are considered physical cultural heritage and are often included in the research fields of architectural heritage, local heritage, local landscapes, and traditional regional cultural landscapes (Wang et al. 2009). They serve as essential carriers of local characteristics and significant representations of local traditional culture. Currently, research on cultural heritage and cultural landscapes has largely focused on renowned examples with outstanding universal value, while ordinary, folk cultural heritage and cultural landscapes have been largely overlooked. This type of heritage reflects unique human-environment interactions and retains a sense of local character in the context of globalization. As a common heritage, it exhibits greater potential for adaptive reuse, yet it also faces the risk of being neglected and rapidly disappearing amid globalized urbanization. Fortresses are a typical example of this kind of cultural heritage. They are characterized by their scale and unity, reflecting both macro-level geographical patterns and micro-level landscape features. Consequently, they possess unique research significance and value—not only enriching theories about the formation mechanisms of cultural landscapes but also providing new perspectives and bases for the preservation of such cultural heritage. As a type of folk defensive architecture or settlement, the fortresses in Tianshui are also an important part of the regional residential culture of humankind. Their site selection, layout, style, structure, and materials are the result of long-term coordination with the

geographical environment of the region. In today's world, which re-examines cultural globalization, the relationship between architecture and specific regions is a concrete issue (Wang, 2017a). From this perspective, studying fortresses from a geographical angle is significant not only for promoting tourism and preserving heritage but also for cherishing regional characteristics and protecting the essence of ethnic culture.

Geographic information systems (GIS) have a strong advantage in geographic data processing and play an indispensable role in urban sustainable development planning, natural resource sustainability monitoring, natural disaster risk management, and other fields (Li et al. 2023). Methods such as mathematical statistical analysis, spatial analysis, geographical detection, and spatial optimization are increasingly being used in various studies (Wang et al. 2023), and the study of space-time causality is continually evolving (Gao et al. 2022), providing scientific and rational methods for the further study of cultural heritage, such as fortresses. Conducting research on fortress cultural landscapes using GIS technology holds significant value for advancing cultural heritage studies. An in-depth analysis of the formation and evolution of fortress locality helps to understand the underlying mechanisms driving profound changes in rural cultural landscapes within the context of global localization, thereby guiding the practice of cultural landscape conservation and utilization. Through field investigations and geographic information technology, this study systematically reveals the spatial distribution patterns of Tianshui fortresses and the underlying influencing mechanisms. It aims to provide valuable references for research in the field of special cultural landscapes and local practical applications. Additionally, a Tianshui Fortress Cultural Landscape Database has been established, comprising four sub-databases: the Tianshui Fortress Entity Database, the Tianshui Fortress Surrounding Environment Database, the Tianshui Current Geographic Database, and the Tianshui Historical Geographic Database. As there is currently no systematic, specialized database for fortresses, this study plays a crucial role in filling this research gap. Based on this, it serves as an important reference for fortress data collection efforts in other regions.

Related work

Research on fortresses in China. Fortresses are small defensive structures or settlements surrounded by walls. This concept encompasses various types of buildings or settlements and can generally refer to small defensive structures or communities. Early research on fortresses in China was scattered across studies related to ancient architecture, ancient villages, and traditional dwellings. For example, Liu Dunzhen's (1957) research and "The Record of Chinese Architecture" compiled by Liang Sicheng, based on earlier research, both included content related to fortress architecture (Liu, 1957; Liang, 2012). Early studies pioneered fortress research; however, due to the limitations of research methods and difficulties in obtaining data at the time, most studies mentioning fortresses remained superficial and descriptive, lacking systematic and in-depth analysis.

Starting from 1996, scholars, primarily those focused on architecture, began conducting more systematic research on fortresses. For instance, researchers like Zhang discovered that the ancient city of Pingyao still preserves a closed residential form known as "bao," which closely resembles early neighborhoods and native villages (Zhang and Song, 1996). Subsequent research expanded the spatial dimension of fortress studies by integrating them with ancient urban residential patterns. Subsequently, with the rising enthusiasm for the World Heritage nomination of Fujian Tulou, Yang, Dai, and Cao focused their fortress research

on the architectural characteristics of Fujian earthen fortresses and their comparative study with Fujian Tulou (Yang, 1997; Dai, 1999; Cao, 2000). Yang and Zhang, respectively, focused on the fortresses in the Qin River Basin in Hubei and Shanxi (Yang, 2001; Zhang, 2001). In 2003, Wang began a systematic study of fortresses, using traditional fortresses in Shanxi as examples and approaching them from the perspective of defensive settlements. He established a framework for the “traditional defensive settlement” type, revealing the essential defensive characteristics of fortresses, primarily characterized by linear fortifications along the periphery of the settlement. Additionally, he summarized the development and composition of the defensive structures surrounding fortresses from the perspective of architectural technology (Wang, 2003). Zhang and others selected the fortresses in the Yulin region of northern Shaanxi as their research subject, based on the regional division of the Nine Frontiers and Eleven Garrison Towns of the Ming Dynasty. They elucidated the formation, development process, and historical significance of the military defense system by analyzing the site selection, layout, relationships between fortresses, and the connection between fortresses and the Great Wall in this region (Zhang and Li, 2005). Tan focused on the impact and constraints of economic and technological factors such as population, cultivated land, funds, and city construction techniques on the traditional morphology of fortress settlements (Tan, 2011). Some studies introduced economic and technological perspectives, yet they fell short in examining the complex and dynamic influences of these factors over different historical periods. Gao traced the evolution of fortresses in the Hexi Corridor from military to civilian use during the Ming and Qing Dynasties (Gao, 2016). Ma and Sun identified three types of evolution for fortress settlements: maintaining the settlement's size with population growth, expanding the settlement's boundaries, and abandoning or relocating the settlement (Ma and Sun, 2017). Zhou utilized GIS, mathematics, and statistical methods to analyze the layout, defense systems, and the impact of trade markets on three towns and the northern desert area (Zhou, 2017).

Zhang's team conducted research on the historical geographic information system architecture of military settlements along the Ming Great Wall, establishing a database to support the recognition and study of the Ming Great Wall's cultural heritage. The study, from a spatial and humanistic perspective, utilized spatiotemporal GIS technology, providing comprehensive and accurate data for the recognition and research of the Ming Great Wall cultural heritage, as well as efficient technical support (Zhang et al. 2019). Additionally, Feng and others used the Ming Great Wall in Datong as a case study, combining existing cultural heritage classification methods with spatial information technology and different heritage value assessment systems to evaluate and analyze the spatial distribution patterns of multi-level heritage sites (Feng and Chen, 2019). Xie and others explored the spatial characteristics of military settlements in the Zijingguan defense area using GIS-based elevation analysis, proximity analysis, density analysis, surface cost analysis, and shortest path analysis. This aimed to reveal the spatial structure, geographical site selection, and influencing factors of Zijingguan (Xie et al. 2020). Lin, Ma, and others focused on the morphological layout, emphasizing the relationships between fortresses and geographical elements such as terrain, water systems, and villages in their site selection and layout (Lin, 2021; Ma and Zhang, 2020). In recent years, with the development of GIS technology, “3S,” unmanned aerial surveys, and other information technologies, more spatial pattern research methods can be further applied to the study of Baozhai, such as self-organizing simulations of spatial structures (Zhang, 2021; Bano, 2023), spatial syntax (Wei et al. 2021; Ma et al. 2023a), spatial decision analysis (Liang et al.

2024), deep mapping (Zhong, 2022) and other methods. Additionally, the increasing volume of spatiotemporal big data has given rise to advancements in geographical spatiotemporal big data analysis and efficient collaborative computing technology (Lu et al. 2020; Lu and Zhang, 2014; Luo et al. 2016). The integration of these more modern and intelligent geographic information systems technologies with Baozhai research can bring more systematic and scientific results to the study of Baozhai (Wang and Fu, 2023).

In China, fortress research has primarily focused on architecture, historical geography, and cultural heritage preservation. However, most studies rely on traditional surveys and literature reviews, lacking large-scale quantitative analysis and systematic modeling support. Additionally, research has been concentrated in regions such as Shanxi, northern Shaanxi, and Fujian, while quantitative studies specifically targeting fortress-rich areas like Tianshui, Gansu, remain scarce. In light of this, existing research faces issues such as an incomplete conceptual framework of fortresses and a lack of studies from a human geography perspective.

Research on fortresses in the international context. In 1925, American cultural geographer Carl Sauer first introduced the concept of “cultural landscape” from the German academic tradition into English, profoundly shaping the development of geography in the United States and beyond (Martin Geoffrey et al. 2008). Drawing from German cultural landscape theories, he proposed “cultural determinism,” arguing that culture does not passively emerge from nature but, rather, that culture and nature together shape the environment in which we live. Sauer conducted extensive field investigations on rural landscapes in the US and Mexico, studying cultural traditions and technological practices formed through the interaction between humans and nature, which led to the establishment of the Berkeley School (Deng, 2003). In his influential 1925 paper, *The Morphology of Landscape*, Sauer defined cultural landscapes as the result of a cultural group shaping the natural landscape, where culture acts as the driving force, nature serves as the medium, and the cultural landscape emerges as the outcome. His ideas have had a lasting impact, and his concept of “cultural landscape” remains central to cultural geography research (Sauer, 2008). During the 1970s and 1980s, the rise of new cultural geography, led by scholars such as Peter Jackson and Denis Cosgrove, further advanced the field (Cosgrove and Jackson, 1987). Over decades of development, Western cultural geography has matured significantly. In this context, culture is no longer seen merely as an abstract system of symbols but as a complex social process materialized through geographical environments such as urban layouts and rural landscapes (Jackson, 2012). As a unique type of cultural landscape, fortresses are widely distributed across rural China, serving as vital carriers of local identity and symbols of traditional culture. From an international cultural geography perspective, fortress studies differ from China's traditional focus on architecture, historical geography, and heritage conservation. The incorporation of quantitative analysis from international research could inject new perspectives into the study of fortresses.

Research on fortresses in other countries mainly focuses on castles (Creighton, 1998), including fortresses or forts (Ettel, 2014; Forcael et al. 2017), and fortification architecture (Pishchulina and Argun, 2019). The study directions vary widely, encompassing history, emotions, heritage, and tourism, benefiting from the significance and abundance of castle culture overseas. For example, King systematically discussed medieval castles in England and Wales, covering their origins, development, and subsequent influences (King, 1988). Although systematic studies

on fortresses in certain regions have provided detailed accounts of castle development, they are often based on specific cultural and regional contexts, limiting their applicability to other areas. El-Hakim designed a complete set of 3D modeling processes for the restoration of castle heritage and applied it to multiple castles in northern Italy to create high-precision models suitable for interactive visualization (El-Hakim et al. 2007). Creighton et al. conducted a survey of the surrounding environments of medieval castles in the UK, studying castles from a “landscape” perspective. This approach allows for more comprehensive utilization of the rich data around castle sites and deeper research into the embedded landscapes within castles (Creighton, 2012).

Oppio et al. used a multi-criteria spatial decision support system (MC-SDSS) to systematically assist in the management of castle heritage in the mountainous region of northern Italy, comprised of thirteen castles (Oppio et al. 2015). Pluskowski explored the connection between castles and landscapes from an archeological and heritage perspective (Pluskowski et al. 2019). Jamieson investigated the impact of landscapes on the site selection of medieval castles in Sussex, southern England (Jamieson, 2019). Bachagha et al. conducted archeological reconstruction, combining remote sensing data with on-site surveys to reconstruct parts of the linear defense systems from the Roman period, including fortifications. This provided new methods for military site archeology (Bachagha et al. 2020). Storozum et al. referred to the wall system built between the 10th and 13th centuries along the Sino-Mongolian border as the “Medieval Wall System.” They identified 525 fortress sites along the wall using historical maps and remote sensing imagery, characterizing the size and form of these fortresses based on the perimeter of the walls, revealing spatial distribution patterns (Storozum et al. 2021). Millán-Millán et al. conducted historical reconstruction research on the Beas de Segura castle in Spain. They utilized modern technologies, including unmanned aerial photography, and combined them with relevant historical documents to reconstruct the historical morphology of the castle, providing essential foundations for its conservation and utilization (Millán-Millán and Fernández-Cuadros, 2021). Jamieson, using medieval castles in Holderness on the eastern plains of Yorkshire as an example, studied the natural and cultural landscapes in the region, including castles, churches, topography,

and vegetation. The research focused on exploring the mechanisms by which natural and cultural landscapes in the region influenced the architectural form and site selection of Norman medieval castles in England (Jamieson, 2021). Valle Abad et al. virtually reconstructed medieval castle sites in Spain, ensuring the rigor and scientific nature of the reconstruction by extracting castle functions and architectural forms and considering the landscape features of the site (Valle Abad et al. 2022).

International fortress research is diverse and comprehensive, covering areas such as heritage conservation, tourism management, historical landscapes, and spatial analysis. Advanced research methods, including 3D modeling, multi-criteria spatial decision support systems (MC-SDSS), and remote sensing data integration, have been widely applied. However, international research is predominantly centered on European castle culture, largely shaped by Western academic discourse. Castles and fortresses in these studies are often associated with elite ruling classes such as states, nobility, and military powers, neglecting the unique geographical and historical conditions of China. As a result, they overlook the existence of folk defensive settlements—fortresses built, inhabited, and defended by ordinary people for protection. Thus, Western fortress studies cannot be directly applied to China’s research needs.

Given the research gaps in perspective, cultural differences, and regional focus, this study employs multi-source geographic data analysis to quantitatively explore the spatial distribution patterns and driving factors of fortresses. Specifically, it investigates the geographic distribution characteristics and underlying mechanisms of Tianshui fortresses, revealing their unique spatial patterns as folk defensive settlements. Unlike state (military) fortifications, Tianshui fortresses exhibit homogeneous forms and distributions, lacking hierarchical distinctions in scale and importance. This study fills a gap in the Tianshui Fortress Database, deepens the theoretical understanding of special cultural landscape evolution, and provides targeted references for local cultural heritage conservation and heritage tourism development.

Methods

Study area. In the city of Tianshui and its surrounding areas in Gansu Province, the distribution of fortresses is relatively concentrated (as shown in Fig. 1). For example, Tongwei County, a

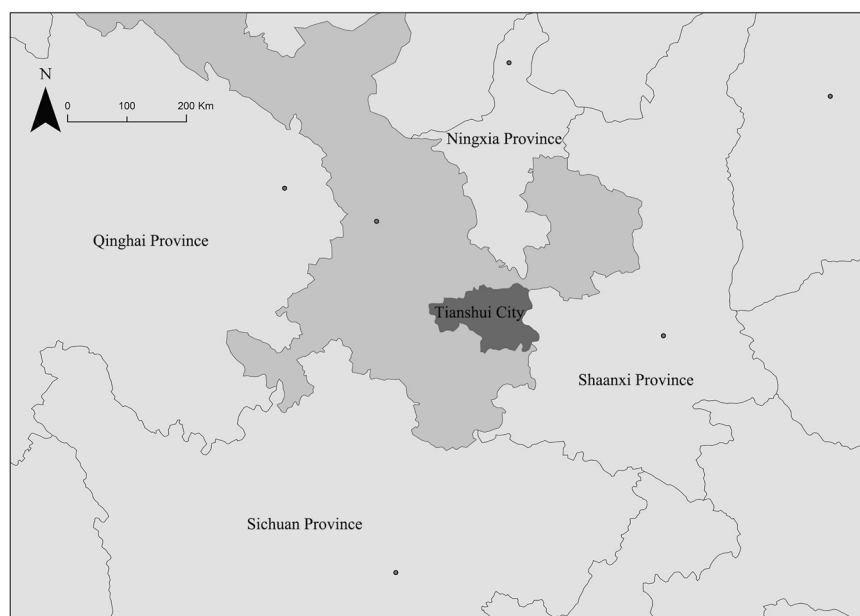


Fig. 1 Relationship between Tianshui city and Gansu Province. This figure illustrates the relationship between Tianshui City and Gansu Province.

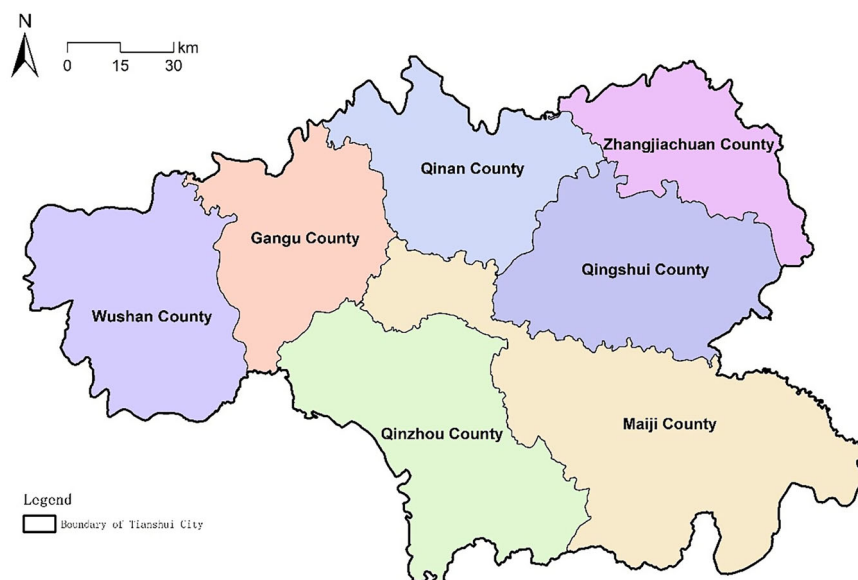


Fig. 2 Administrative divisions of Tianshui City. This figure illustrates the administrative divisions of Tianshui City, highlighting its various districts and counties.

small county in the Longzhong region, is known as the “Land of a Thousand Fortresses.” In the <3000 square kilometers of Tongwei, more than 1500 fortresses are scattered across the hills, mountains, and villages. Considering that the entire Tongwei County has fewer than 400 administrative villages, we find that, on average, each village is home to about four ancient fortresses (Bo, 2008; Ye, 2014). Zhujizu conducted relevant field visits to various fortress sites in Zhuanglang County, focusing on the Zhuanglang River and Shuiluo River basins. By combining data from historical county records of Zhuanglang, he verified and documented over 70 existing fortress sites within the county (Zhu, 2021).

The spatial distribution pattern of fortresses in Tianshui City exhibits wide coverage and high density, with diverse topography, making it a region of significant research value and an exemplary area for empirical studies. Tianshui City is located at the intersection of Shaanxi, Gansu, and Sichuan provinces, with geographical coordinates ranging from 104°35' to 106°44' east longitude and 34°05' to 35°10' north latitude. Covering a total area of 14,325 square kilometers, the city is divided by the western Qinling Mountains into a northern region of 11,673 square kilometers, accounting for 81.49% of the total area, and a southern region of 2,652 square kilometers, constituting 18.51% of the total area.

As illustrated in Fig. 2, as of October 2015, Tianshui City is administratively divided into two districts: Qinzhou District and Maiji District, as well as five counties: Ganghe County, Wushan County, Qin'an County, Qingshui County, and Zhangjiachuan Hui Autonomous County. The city encompasses 78 towns, 35 townships, and 10 streets.

Data source. This study obtained a comprehensive and accurate dataset of existing Tianshui fortresses, including their names, locations, and historical information, through an integrated approach involving remote sensing image interpretation, on-site inspections, questionnaire surveys, and reference to historical records. After collecting the data, standardized processing was applied to integrate information from gazetteer verification, literature research, historical records, basic geographical spatial data, remote sensing imagery, drone data, and other sources. By

the end of 2019, a total of 718 existing Tianshui fortresses were identified.

Manual interpretation of remote sensing images. The primary data source for fortress identification is the latest 2-m resolution Google satellite imagery after 2019, supplemented by virtual Earth images from Bing, imagery from Amap, ESRI, and other sources. Tianshui City is divided into different zones using a 10-km grid, and each zone is further divided into 100 operational units using a 1-km grid, with each operational unit covering an area of 1 square kilometer. In total, Tianshui City has more than 14,500 operational units (as shown in Fig. 3). The identification process is carried out zone by zone and digitized accordingly. During the digitization and editing process, fortress walls are used to outline fortress boundaries, creating fortress polygon datasets. Additionally, fortress geometric centers are used to generate fortress point datasets.

Field survey and research. Multiple on-site investigations were conducted in the research area, covering all districts and counties of Tianshui City, as well as all townships and administrative areas in Wushan County. The investigation revealed that fortresses accounted for over 40% of the area, with image records of fortresses exceeding 25%, and drone aerial records capturing fortresses exceeding 7% (as shown in Figs. 4 and 5).

Questionnaire distribution for the survey. Due to logistical constraints, it was not possible to survey all fortresses in Tianshui City. Additionally, the locations and current conditions of many fortresses are best known by local residents. Therefore, survey questionnaires were utilized to collect data on Tianshui City's fortresses. With the support of various levels of administrative departments in Tianshui City and specific guidance from township-level administrative departments, a questionnaire survey on ancient fortress resources in Tianshui City was conducted in 2019. A total of 446 completed questionnaires were collected, accounting for 62% of the total distributed.

Reference to historical records and literature. The spatial data obtained through the above steps represent the spatial information of fortresses. However, a significant amount of fortress

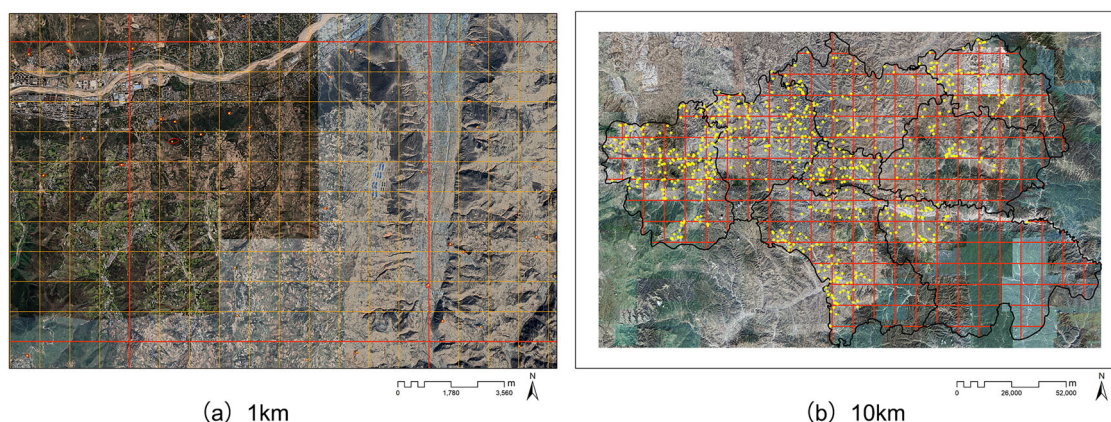


Fig. 3 Tianshui remote sensing image zoning. **a** The red grid represents a 10 km grid, and the dark yellow grid represents a 1 km grid. **b** The red grid represents a 10 km grid.



Fig. 4 Examples of Tianshui fortresses with image records. This figure showcases various fortresses in Tianshui, accompanied by photographic records that document their structures.

names and historical information remains unclear. Therefore, it is necessary to cross-reference this data with existing historical records and literature to obtain more reliable and correlated information about Tianshui fortresses. The literature and historical records primarily include local chronicles, military records, toponymic records, statistical yearbooks, government official archival materials, and specialized heritage research survey reports related to the Tianshui region.

Research framework. The study obtained initial fortress point data, including the quantity and coordinates of fortresses in Tianshui City, by utilizing methods such as manual interpretation of remote sensing images, on-site investigations, questionnaire distribution, and referencing literature records. After digitizing the data using GIS software, the required vector data for fortresses were generated. This dataset was then integrated with terrain, road, water system, and settlement data. Spatial analysis methods, including landscape shape index, average nearest neighbor analysis, kernel density analysis, overlay analysis, and geodetector analysis, were employed to investigate the morphological characteristics, dispersion patterns, clustering characteristics, and

associations with environmental factors. These analyses were used to calculate the overall spatial and temporal characteristics of fortresses in Tianshui City, including quantity and area. Further analysis revealed spatial distribution patterns such as density and proximity relationships for Tianshui fortresses. The study aimed to uncover the intrinsic relationships among various influencing factors and their correlation with fortress distribution. The framework of the research is illustrated in Fig. 6.

Research methods

Kernel density analysis. Density estimation is a common problem in geographical information data surface estimation (Zhou et al. 2023). In recent years, numerous researchers have utilized the Kernel Density Estimation (KDE) method for data surface estimation (Anderson, 2009; Carlos et al. 2010). Kernel Density Estimation is a non-parametric method that calculates the density estimation of a point dataset using spatial smoothing techniques to process discrete point data. It estimates the density of points in the vicinity of sample points within a unit spatial range and fits this into a smooth surface. For a given set of observed points x_1, x_2, \dots, x_n , the kernel density estimate function $\hat{f}_h(x)$ for a

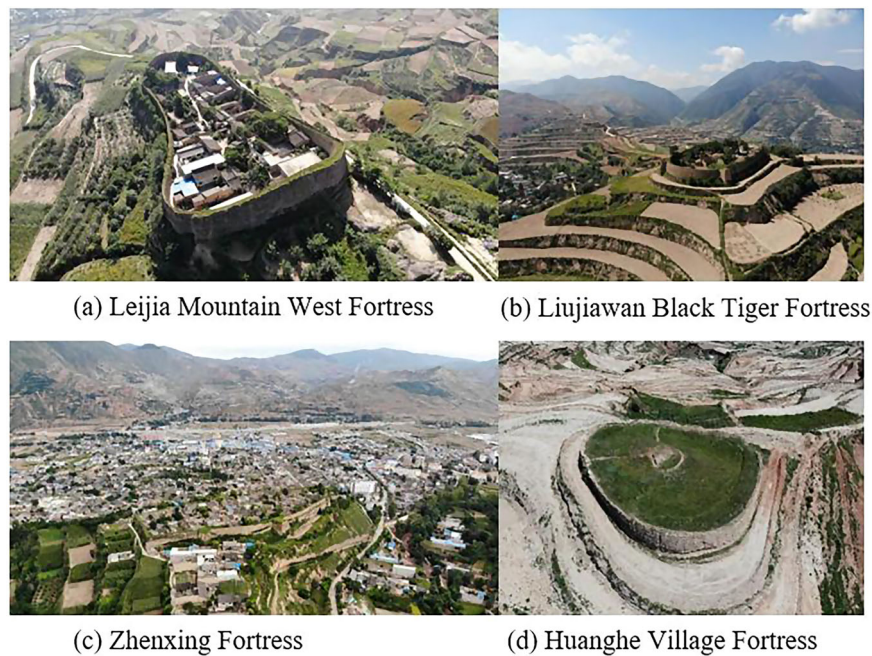


Fig. 5 Examples of Tianshui fortresses with drone aerial records. a-d Four typical fortresses in Tianshui City captured by the author using drone aerial photography.

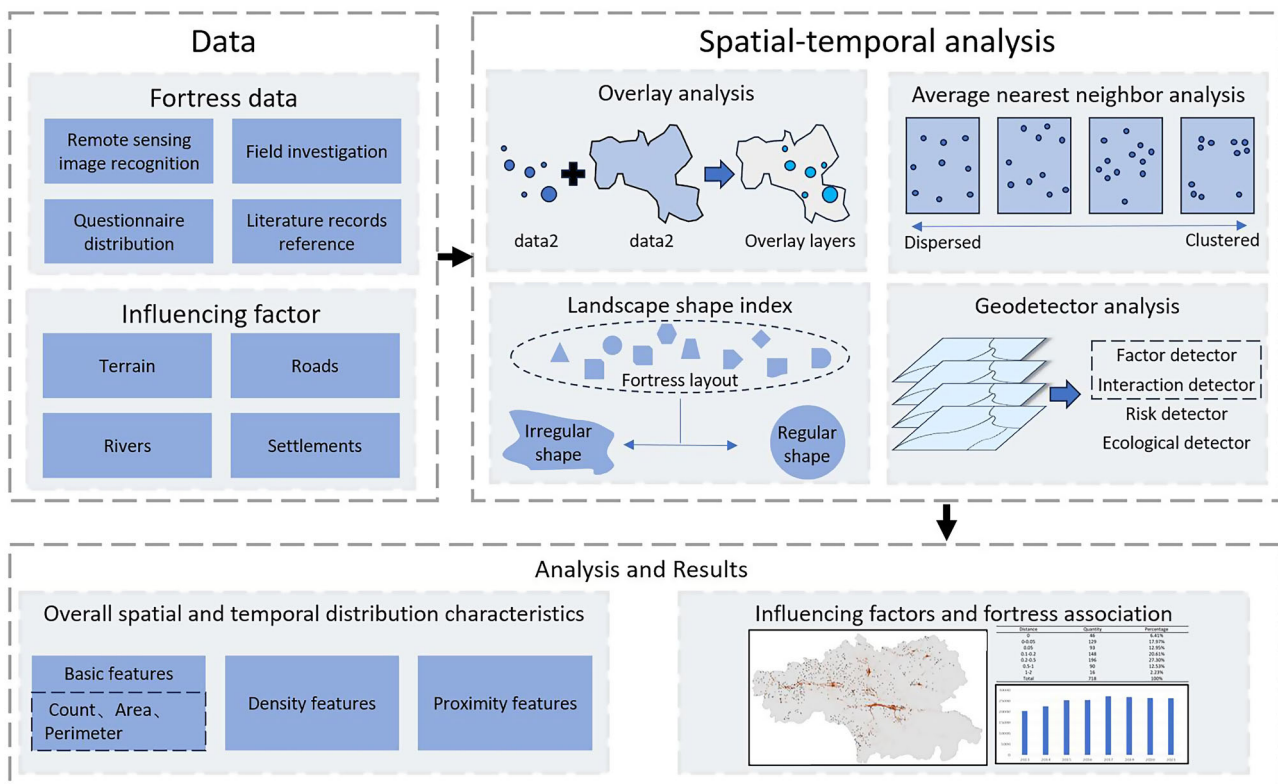


Fig. 6 Framework diagram. This framework diagram outlines the key components and relationships involved in the study of Tianshui fortresses.

grid unit x is calculated using the formula:

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

where x_i is the coordinate value of the i point ($i = 1, 2, \dots, n$), K is a selected kernel density estimation function, and h is the search radius threshold for this kernel function.

Kernel function analysis for point data is fundamentally a weighted method based on the distances between points (Gong et al. 2018). Points that are farther away have a smaller impact on the target grid compared to relatively closer points. Examining the formula of the kernel density estimation function, the factors influencing the kernel function estimation method include the type of kernel function and the search radius for the kernel

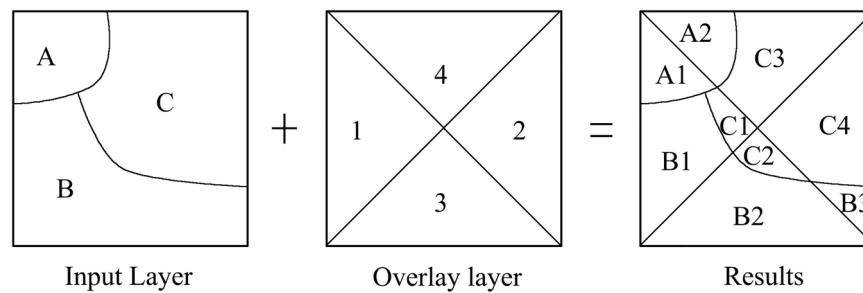


Fig. 7 Schematic diagram of the superposition principle. Illustrating the superposition principles of slope, aspect, and other variables through raster synthesis and classified overlay.

function. There are various types of kernel functions, including Gaussian functions, uniform kernel functions, triangular kernel functions, and gamma kernel functions, with Gaussian functions being a common choice (Zhao et al. 2018). Among the factors influencing the kernel function estimation, the search radius has a more significant impact on the results than the type of kernel function used. Kernel density analysis can effectively reflect the spatial clustering characteristics of fortresses in the study area—the higher the kernel density value for fortresses, the more concentrated their distribution is.

Average nearest neighbor analysis. This study employs the average nearest neighbor (ANN) index to assess whether the spatial distribution of fortresses is a result of random distribution or influenced by clustering effects (Clark and Evans, 1954; Kadri and Nasrallah, 2023). The analysis primarily compares the average distance between the centers of fortress points and their nearest neighboring fortress points with the expected average distance under the assumption of random distribution. The ratio of these two distances gives the Average Nearest Neighbor index. The calculation formula is as follows:

$$R_n = \frac{\bar{D}_o}{\bar{D}_E} = \frac{2\sqrt{\frac{n}{A}} \sum_{i=1}^n d_i}{n} \quad (2)$$

Among them, \bar{D}_o is the average distance between fortress points and their nearest neighboring fortress points, \bar{D}_E is the average distance under the assumption of random distribution of fortress points, n is the number of fortress points, A is the study area's size for fortress point data, and d_i is the distance between the i th fortress point and its nearest neighboring fortress point. If the nearest-neighbor index $R_n < 1$, i.e., $\bar{D}_o < \bar{D}_E$, the distribution pattern of fortress point data is considered clustered. Conversely, if $\bar{D}_o > \bar{D}_E$ and $R_n > 1$, the distribution pattern tends towards dispersion. If $R_n = 1$, meaning $\bar{D}_o = \bar{D}_E$, the fortress point data exhibits a random distribution pattern.

Landscape shape index. The landscape shape index (LSI) refers to the ratio of the perimeter of a fortification to the perimeter of a circle with the same area, indicating the complexity of the landscape shape (Liu et al. 2024; Peng et al. 2023). The formula for calculating the shape index is as follows:

$$LSI = \frac{E}{2\sqrt{\pi A}} \quad (3)$$

where E is the perimeter of the fortification (m), and A is the area of the fortification (m^2). The theoretical range of the shape index is $[1, +\infty)$, with a value of 1 when the fortification is circular; the larger the value, the more complex the shape of the fortification.

Overlay analysis. The principle is shown in the Fig. 7, overlay analysis involves merging two or more layers of features to create

a new feature layer (Kharaghani et al. 2023), including the attribute analysis of the features from the previous layers (Walke et al. 2012). Projection transformation is employed to ensure that the multiple source data for analysis are within a common projection framework (Srinivas et al. 2018). In this study, the positional information of fortresses is overlaid with layers such as the Digital Elevation Model (DEM), slope, aspect, road network, water systems, population, points of interest (POI), and other relevant layers. This overlay is conducted to analyze the spatial distribution of fortresses in relation to various factors such as topography, transportation, and water systems, and to explore the interrelationships among these factors, and to identify different patterns in fortress distribution.

Geodetector analysis. The geodetector analysis method is a set of statistical techniques used to detect spatial variations and explain the driving forces behind them. It employs factor detection tools to analyze the impact of both natural and human factors on the distribution of fortresses (Yin et al. 2025). Factor detection is utilized to assess the extent to which a factor X explains the spatial variation of attribute Y . This method employs the q -value as a measure, expressed by the formula:

$$q = 1 - \frac{\sum_{h=1}^L N_h \sigma_h^2}{N \sigma^2} = 1 - \frac{SSW}{SST} \quad (4)$$

Here, $h = 1, \dots, L$ represents the stratification variables for variable Y or factor X , indicating categories or zones. N_h and N are the number of units in stratum h and the entire region, respectively. σ_h^2 and σ^2 are the variances of variable Y in stratum h and the entire region, respectively. SSW and SST denote the sum of within-stratum variances and the total variance for the entire region. The q value ranges from 0 to 1. A higher q value indicates a more consistent spatial distribution between X and Y , and a stronger explanatory power of the independent variable X on attribute Y . Conversely, a lower q value suggests a weaker relationship.

Results

The overall temporal and spatial distribution characteristics of Tianshui fortress

Basic feature description. Based on the investigation and statistics conducted in this study, there are currently 718 fortresses remaining in Tianshui. The distribution of these fortresses across various counties is depicted in Fig. 8: Wushan County fortress the highest number with 180 fortresses, followed by Gangu County with 146, Qinzhou County with 112, Maiji County with 111, Zhangjiachuan County with 63, Qinan County with 58, and Qingshui County with the fewest at 48. Notably, Wushan County has the most fortresses, while Qingshui County has the least.

The spatial distribution of fortresses in Tianshui varies significantly, with areas ranging from a minimum of 235 m^2 to

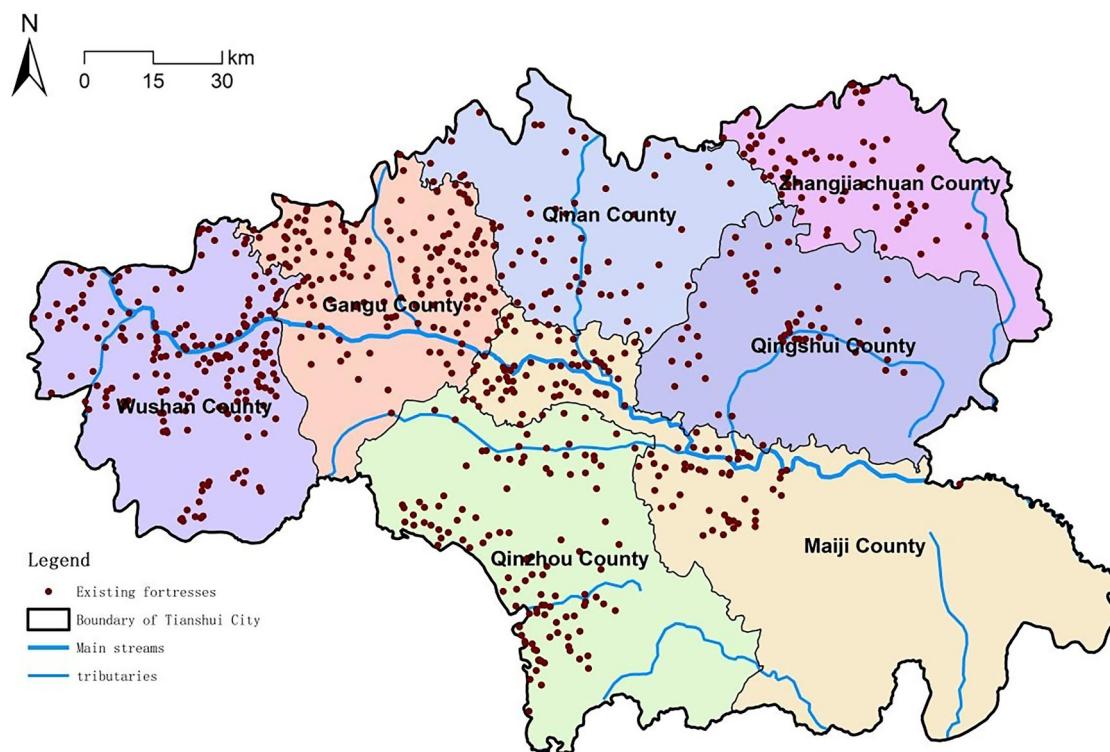


Fig. 8 The spatial distribution of existing fortresses in Tianshui. This figure depicts the spatial distribution of existing fortresses in Tianshui, illustrating their locations across the city.

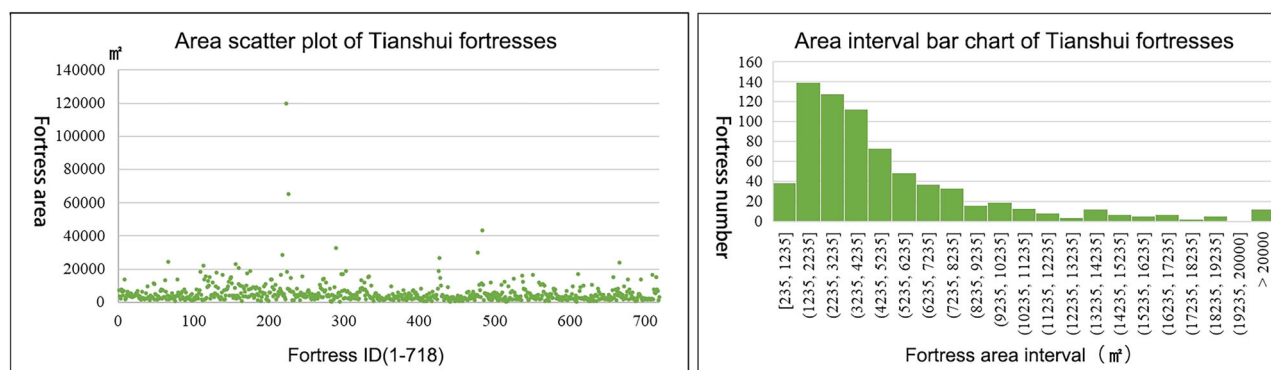


Fig. 9 The statistical results of fortress areas in Tianshui City. This image presents statistical data regarding the areas of fortresses in Tianshui, highlighting size variations.

a maximum of 119,875 m², and an average area of 5338 m². Collectively, these fortresses occupy a total area of 3.83 km² in Tianshui. Notably, only 12 fortresses exceed 20,000 m² in area, while the majority (63.8%) fall within the range of 1000–5000 m². If we consider a typical square fortress in Tianshui, an area of 3600 m² would correspond to a fortress with sides measuring 60 m and a perimeter of 240 m. In summary, the average size of fortresses in Tianshui can be roughly understood as having sides of approximately 60 m, with minimal variation (as illustrated in Figs. 9 and 10).

The perimeter of the fortresses in Tianshui City is measured based on the outer walls surrounding each fortress. There is a correlation between the perimeter and area of the fortresses. The perimeter measurements range from a minimum of 61 m to a maximum of 1671 m, with an average perimeter of 272 m. Collectively, the total perimeter of all fortresses in Tianshui amounts to 195 km (as depicted in Fig. 11).

Clustering characteristics of Tianshui fortress. The results of the kernel density analysis, as illustrated in Fig. 12, reveal a significant clustering characteristic in the spatial distribution of Tianshui's fortress villages. Within an area encompassing hundreds of square kilometers, including Wushan County, Gangu County, and Maiji County in Tianshui City, the highest density of existing fortress villages can reach up to 17 per hundred square kilometers.

Dispersion patterns of Tianshui fortress. The average observed distance in the nearest neighbor calculation for fortress villages in Tianshui City is 2178.48 m, compared to an expected average distance of 2972.57 m. The nearest neighbor index (R) is calculated to be 0.732863, with a Z-score of -13.693923 and a significance level (p) of 0, which is <0.01. These results indicate a statistically significant clustered spatial distribution pattern of fortress villages in Tianshui City (as shown in Fig. 13).

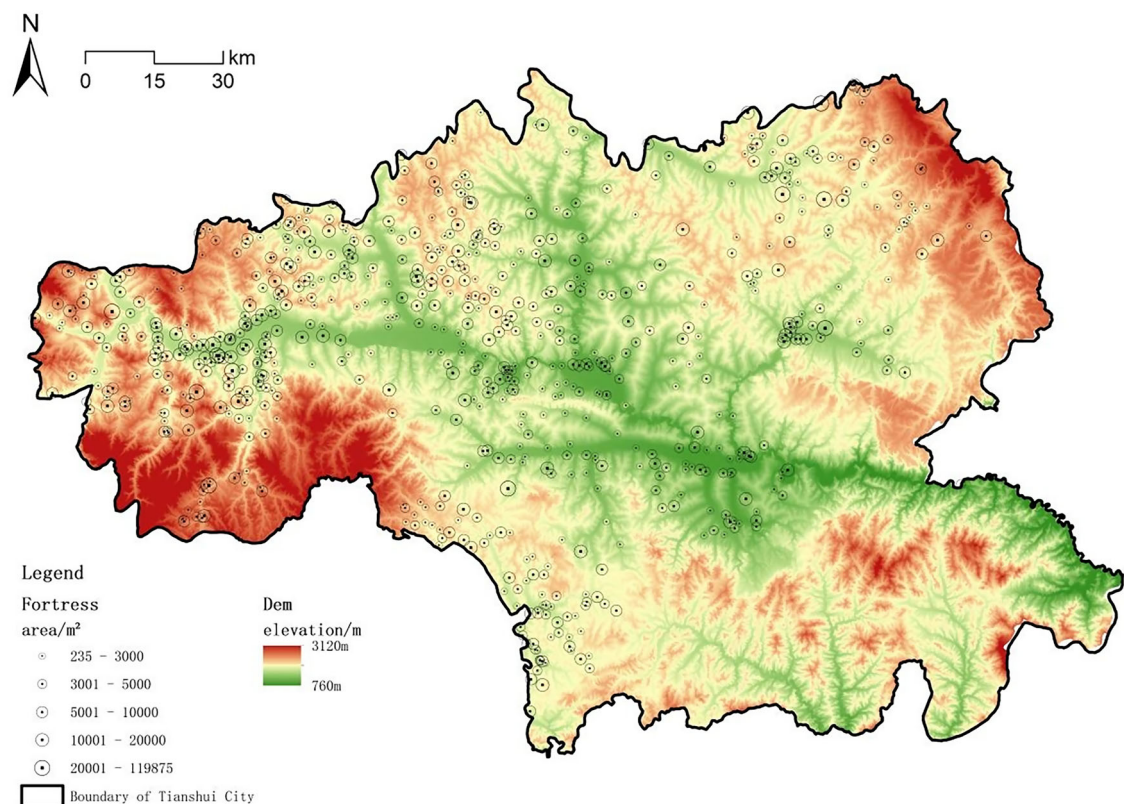


Fig. 10 Distribution of the Baozhai area in Tianshui City. This figure illustrates the distribution of the Baozhai area within Tianshui City, highlighting its geographical features.

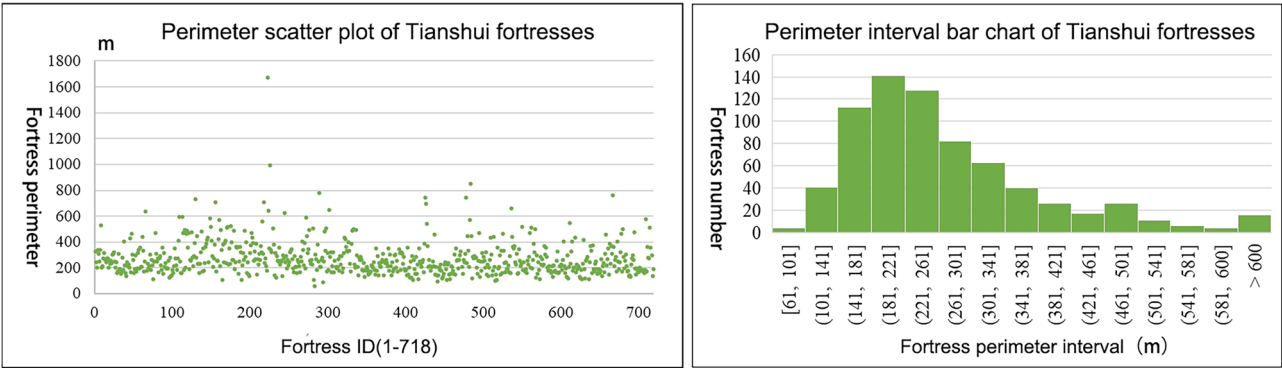


Fig. 11 Distribution interval of perimeter of Baozhai in Tianshui City. This image shows the distribution interval of the perimeter measurements of Baozhai in Tianshui, emphasizing variation in sizes.

Further analysis involves separately calculating the average nearest neighbor characteristics for the two districts and five counties in Tianshui City, with the results presented in Table 1. Previous analyses have shown a clustering effect for fortress villages across the entire region. At the district level, the results reveal clustering effects in Maiji County, Wushan County, and Qinzhou County, while Gangu County, Zhangjiachuan Hui Autonomous County, Qinan County, and Qingshui County exhibit a more random distribution. This variation is attributed to the effects of small-area segmentation.

The average nearest neighbor calculation offers a key insight into the spatial distribution of fortress villages in Tianshui. The average observed distance reflects the typical distance between adjacent fortress villages. Across Tianshui City, the average spacing between fortress villages is 2.28 km, with the highest-density area being Wushan County, where the average spacing is

just 1.71 km. Tianshui City is characterized by many fortress villages, high density, and a distinctly clustered distribution pattern.

The morphological characteristics of Tianshui fortress. The landscape shape index (LSI) describes the shape of the fortresses, allowing for comparisons between different fortresses to understand their morphological differences. By calculating the LSI, one can objectively grasp the morphological characteristics of different fortresses and better comprehend their spatial distribution features. In the research area, the LSI ranges from a minimum of 1.0006 to a maximum of 1.9218, with an average of 1.1354. The majority of fortresses have a shape index of <1.2, constituting over 80% of the total; only two fortresses have a shape index >1.6, with even the highest value being <2. The fortresses primarily exhibit shapes such as circles, ellipses, squares, and polygons, with

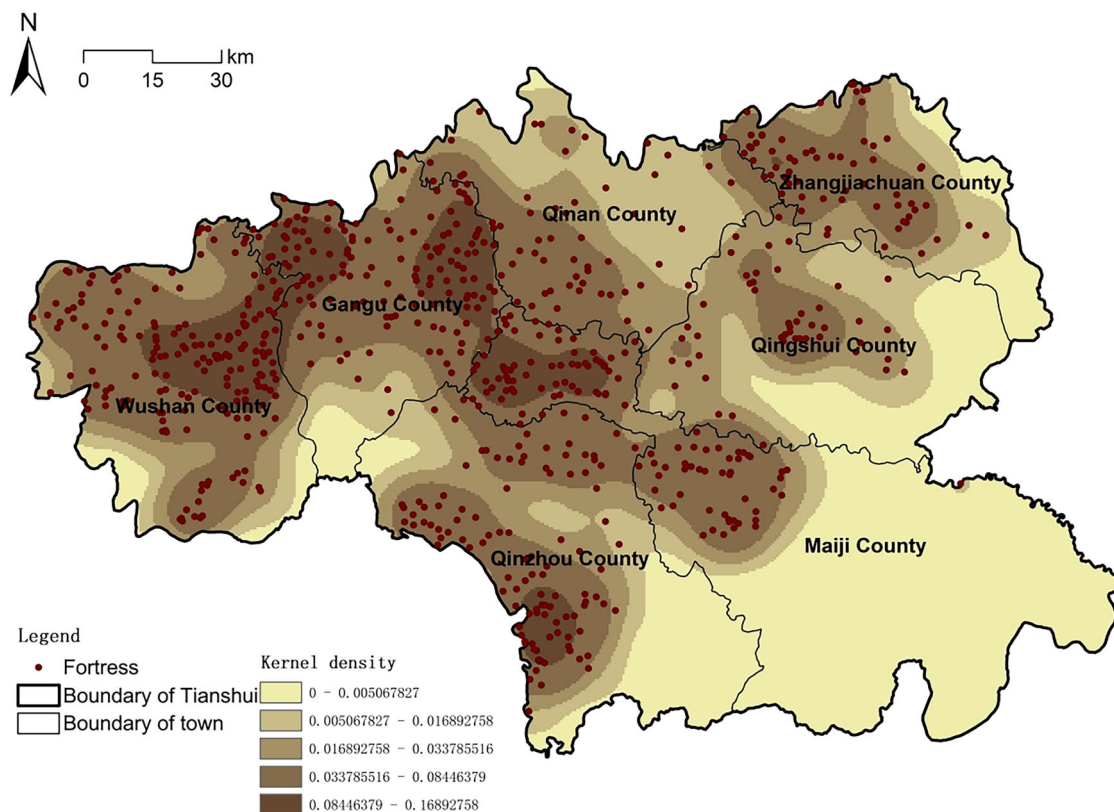


Fig. 12 Results of kernel density analysis in Baozhai, Tianshui City. This figure presents the results of kernel density analysis in the Baozhai area, revealing patterns of fortress concentration.

fewer taking the form of elongated rectangles (as shown in Figs. 14 and 15).

Conducting a spatial distribution analysis based on the planar geometric forms of fortresses, the solid red icons in Fig. 15 represent fortresses with regular geometric shapes, while the hollow icons depict those with irregular geometric forms. It can be observed that the spatial distribution of fortresses exhibits a certain degree of clustering. A closer examination at a finer research scale reveals that the geometric shapes of Tianshui fortresses are influenced by the distinctive local topography.

For defensive purposes and constrained by factors such as population, settlements, and water sources, the site selection of Tianshui fortresses tends to favor relatively elevated areas. Given the ridge-and-hill terrain of the Loess Plateau, these fortresses must intricately integrate with the topography, conforming to the natural contours to form various geometric shapes. Fortresses located on hilltops are typically circular or elliptical, while those situated on prominent edges of ridges may take on elliptical or racetrack-like forms. Fortresses built on rugged mountainous protrusions often have irregular shapes, aligning with the contours of the terrain (as shown in Fig. 16).

The construction of these fortifications incurs substantial expenses, with all necessary resources, both human and material, largely sourced locally. Especially in rural areas, the burden of construction often falls on the local populace. Generally, unless there are specific reasons or requirements, the fortification walls are constructed relatively short and narrow, resulting in confined areas within the city walls. Square-shaped fortresses, serving as the foundational form, align culturally with traditional Chinese architectural patterns. These fortresses are typically constructed in slightly wider areas such as river valley terraces and flat ridges, which are also relatively affluent regions.

In general, the topography significantly influences the siting and morphological layout of Tianshui fortresses. Locations with easily defensible terrain are often chosen for fortress construction, as these sites enhance defensive effectiveness by allowing the erection of structures such as fortress walls. Natural elements like rivers and water sources also play a considerable role in the layout and siting of fortresses. While the interconnected relationship between water systems and topography has been implicitly mentioned in the preceding discussion, a comprehensive explanation of the mechanisms is yet to be provided. The following section will delve deeper into elucidating the impact mechanisms of rivers and water sources on fortress siting.

Correlation analysis between influencing factors and Tianshui fortresses

Relation of terrain and fortress distribution. Elevation. As shown in Fig. 17, the elevation in Tianshui City ranges from a minimum of 760 m to a maximum of 3120 m, with over 99% of Tianshui fortresses distributed between 1000 and 2200 m. Within this range, the distribution follows a basic normal pattern, with the highest concentration of fortresses found between 1600 and 1800 m, accounting for 33.89% of the total. The elevation within Tianshui City varies significantly, exhibiting a high-low-high topographic pattern from west to east.

Slope. As depicted in Fig. 18, the majority of Tianshui fortresses are situated on terrains with slopes ranging from 0° to 30°. Specifically, slopes between 0° and 5° account for 23.12% of the terrain, while those in the 5°–10° range constitute 36.91%. Slopes exceeding 30° are limited, making up only 0.84% of the area, with the maximum slope observed for a fortress reaching ~39°. It is important to note that these slope values are derived

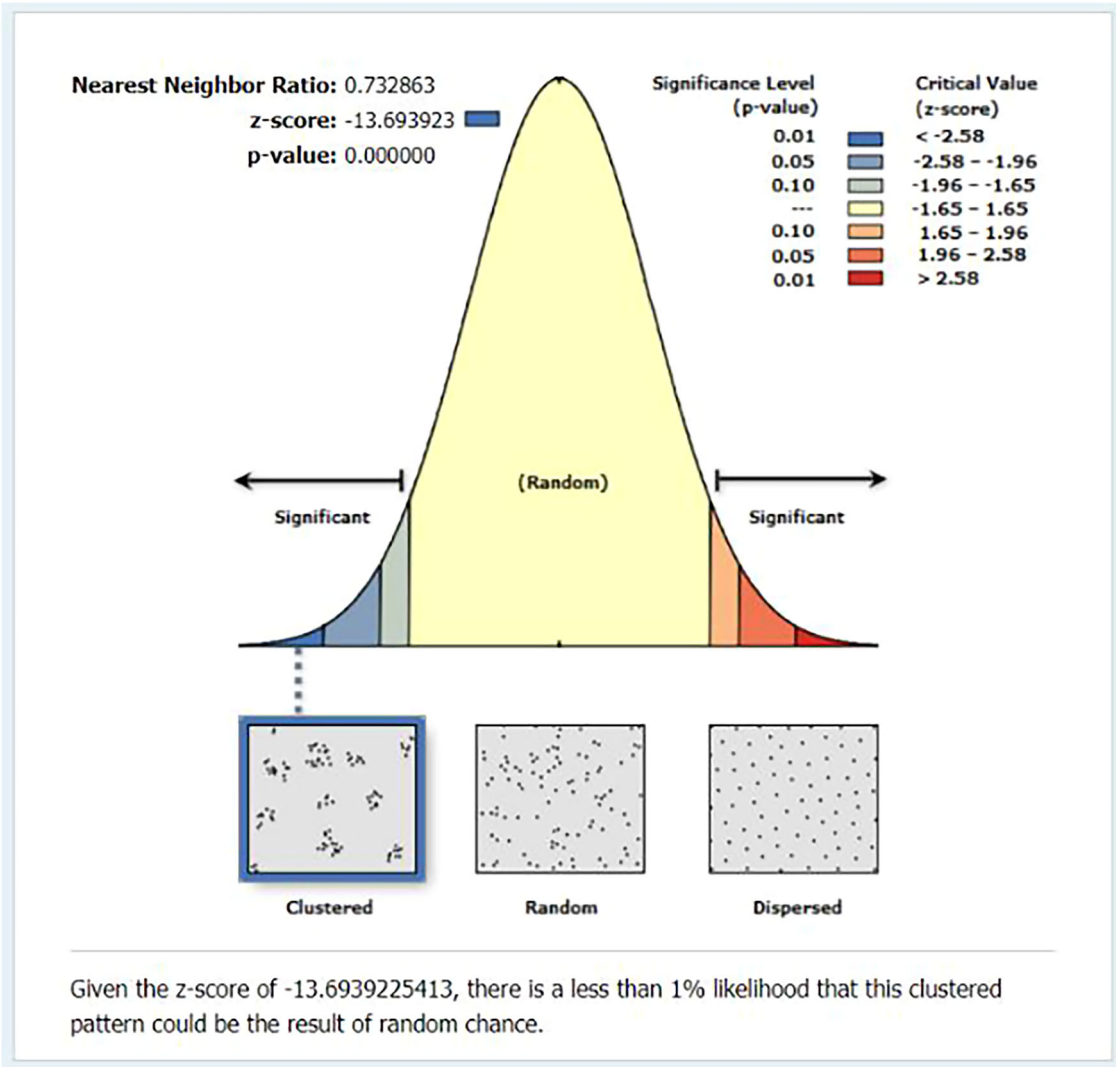


Fig. 13 Results of data spatial proximity calculation of Baozhai points in Tianshui City. This image illustrates the spatial proximity calculations for Baozhai points in Tianshui, showing their relational distances.

Table 1 The average nearest neighbor characteristics of the geographical distribution of counties and villages in Tianshui City.						
County name	Observation mean distance (m)	Expected mean distance (m)	Average nearest neighbor index	Z-score	p-value	Distribution characteristics
Gangu County	2114.77	2079.37	1.017	0.4002	0.689	Random distribution
Zhangjia County	2270.27	2528.65	0.898	-1.5638	0.118	Random distribution
Wushan County	1713.09	2238.47	0.765	-5.9736	0	Concentrated distribution
Qinzhou County	2359.70	2684.20	0.879	-2.4367	0.0148	Concentrated distribution
Qingshui County	3162.44	3324.64	0.951	-0.6398	0.5227	Random distribution
Qin'an County	3789.54	3553.80	1.066	0.9411	0.3466	Random distribution
Maiji County	1755.88	2174.51	0.807	-3.8627	0.0001	Concentrated distribution

from a digital elevation model (DEM) with a spatial resolution of 30 m. Tianshui is located in the hilly region of the Loess Plateau, characterized by rugged topography and steep ravines. The slope values obtained through interpolation methods reasonably reflect the topographical conditions of the areas where the fortresses are located.

The distribution of slope aspects in the local terrain where Tianshui fortresses are located is illustrated in Fig. 19. In this representation, 0° corresponds to true north, 90° to the east,

180° to the south, 270° to the west, and 360° completes the cycle back to true north. Fortresses facing south in the Tianshui region constitute 34.0% of the total, notably surpassing those facing north, which make up 19.4%. Additionally, fortresses oriented towards the east (26.9%) slightly outnumber those facing the west (19.8%). This pattern aligns with the prevalent local architectural preference for south-facing settlements, reflecting cultural traditions passed down during the construction of these fortresses.

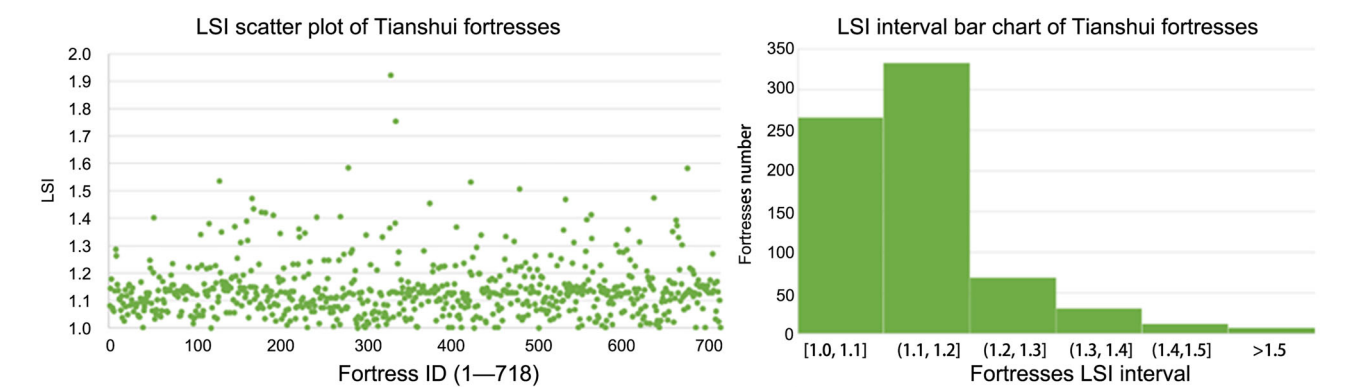


Fig. 14 Statistics of the shape index of fortress in Tianshui City. This figure presents statistics on the shape index of fortresses in Tianshui, providing insight into their geometrical characteristics.

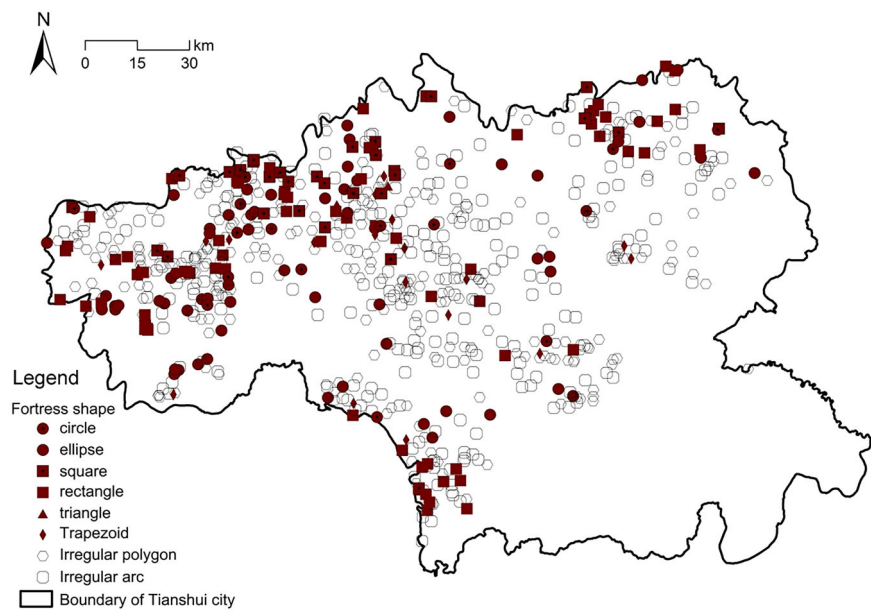


Fig. 15 Geometric types and distribution of Tianshui fortress. This figure categorizes the geometric types of fortresses in Tianshui and illustrates their spatial distribution.

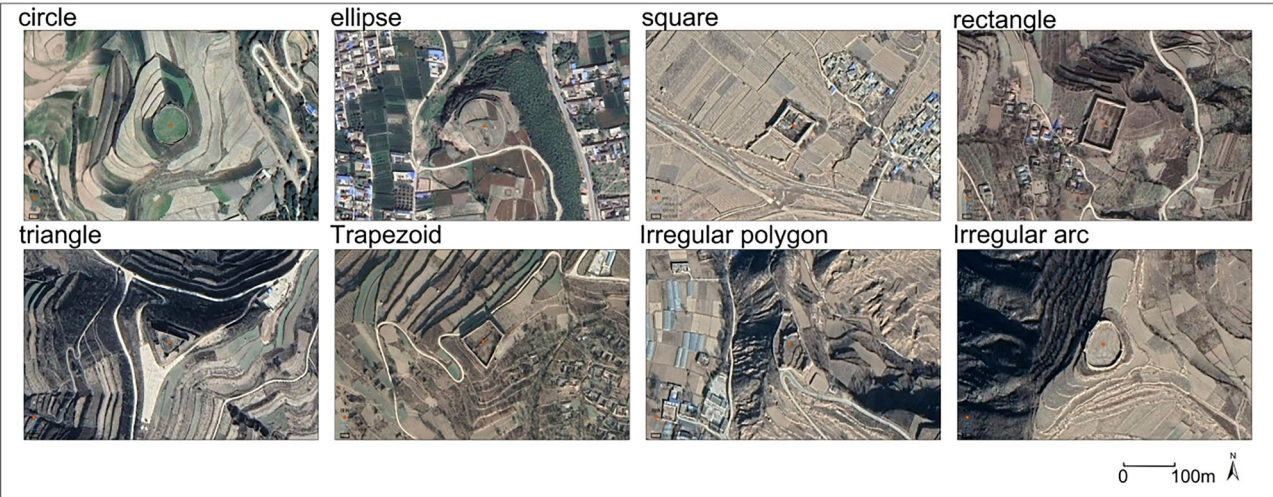


Fig. 16 Examples of the mechanism of the impact of terrain on fortress geometry. This image illustrates examples of how terrain features influence the geometry of fortresses in Tianshui.

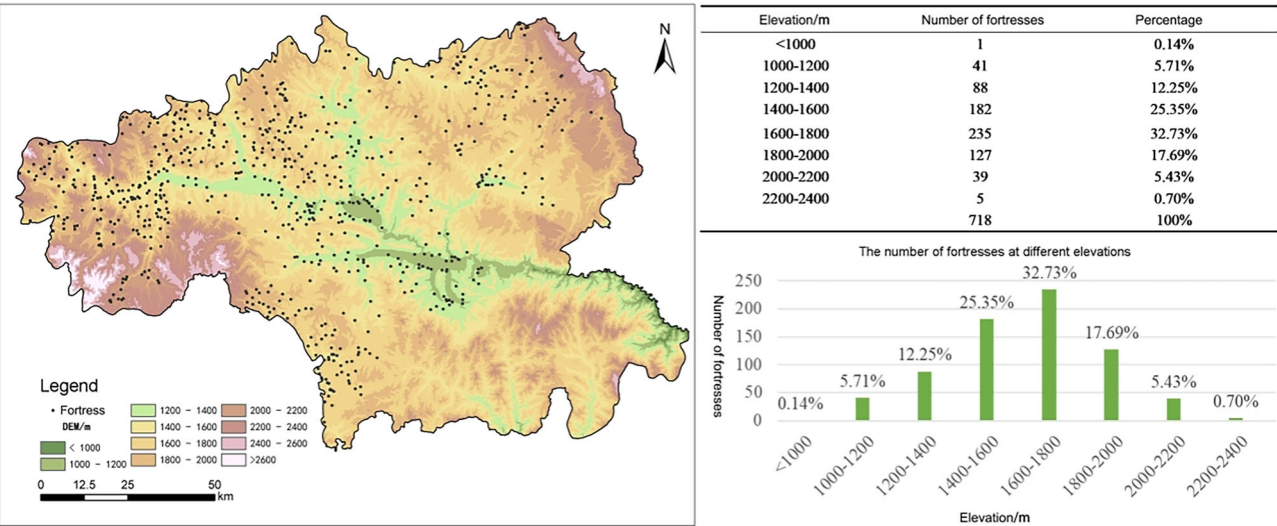


Fig. 17 Relation of elevation and fortress distribution. This figure explores the relationship between elevation levels and the distribution of fortresses in Tianshui.

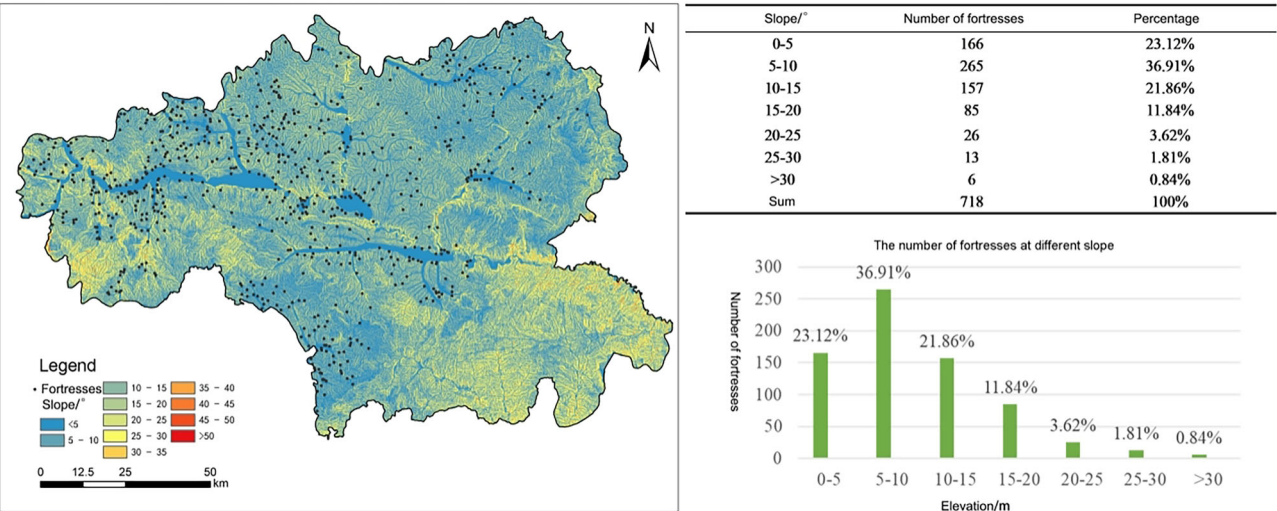


Fig. 18 Relation of slope and fortress distribution. This image examines the correlation between slope angles and fortress distribution in Tianshui.

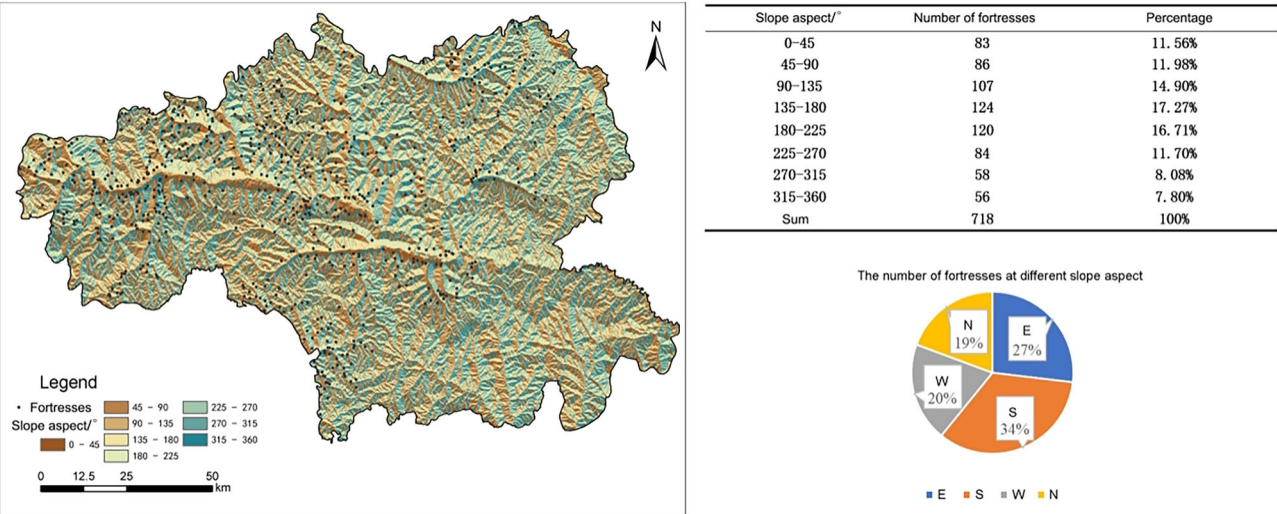


Fig. 19 Relation of aspect and fortress distribution. This figure analyzes the relationship between the aspect (direction) of slopes and the distribution of fortresses in Tianshui.

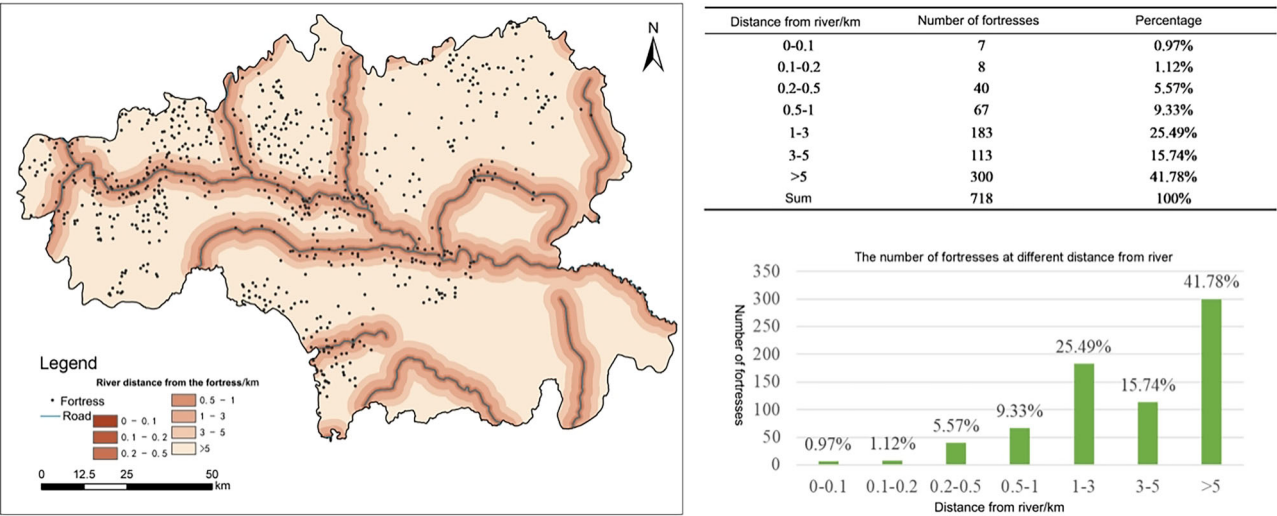


Fig. 20 Relation of rivers and fortress distribution. This image illustrates the relationship between the proximity of rivers and the distribution of fortresses in Tianshui.

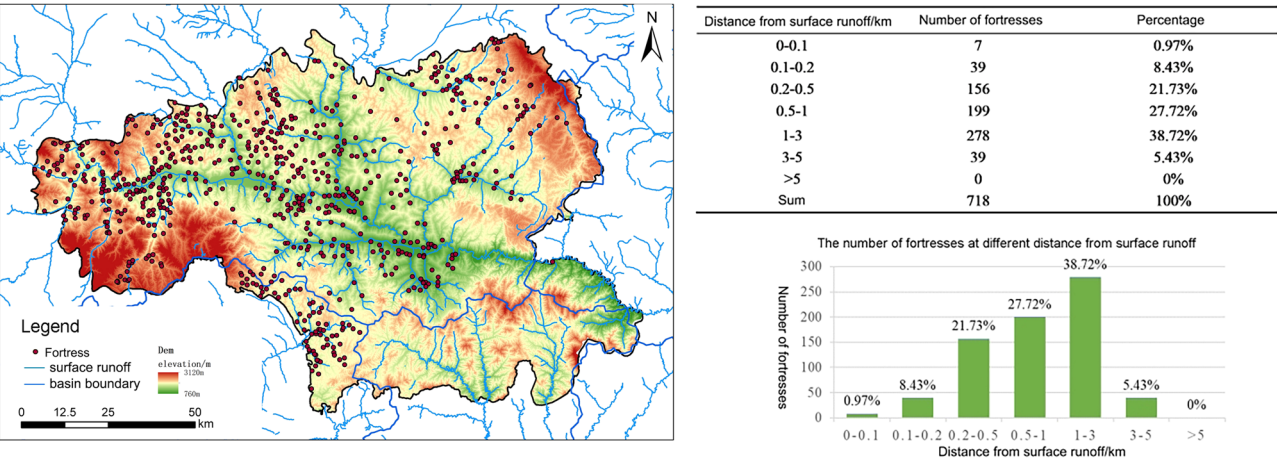


Fig. 21 Relation of water sources and fortress distribution. This figure explores how the availability of water sources impacts the distribution of fortresses in Tianshui.

Relation of the river system and fortress distribution. As depicted in Fig. 20, there is an increase in the number of fortresses as the distance from the river system increases, with over 40% of fortresses located beyond 5 km. This trend diverges significantly from the expected proximity of settlements to water sources. Two factors can help explain this phenomenon: firstly, the river data used pertains to the Wei River and its main tributaries, neglecting many smaller branches and tributaries, which suggests that more comprehensive river system data is needed for a thorough analysis; secondly, Tianshui does exhibit a substantial number of fortresses situated far from the main river. This can be attributed to the loess hilly terrain of Tianshui, where a significant portion of the population resides on mountain ridges and foothills, engaging in terrace cultivation and relying on rainfall for irrigation.

As illustrated in Fig. 21, this study further utilized remote sensing imagery to digitize the minor tributaries within Tianshui City and subsequently analyzed the distances between fortresses and these tributaries. Compared to the main river branches, minor tributaries provide a more accurate depiction of the fortresses' proximity to water sources, facilitating a deeper exploration of the fortresses' affinity to water. Through computational analysis, it was observed that fortresses located

within 1 km of water sources exceeded 50% of the total, while those situated beyond 3 km accounted for only 5.43%. Notably, there were no fortresses located beyond 5 km from water sources.

The above analysis reveals that Tianshui fortresses exhibit a pronounced affinity for water in their geographic distribution. Most fortresses are situated in areas proximate to river sources, as these regions are conducive to irrigation and agriculture, and also serve as focal points for population and settlement concentration. From a micro-landscape perspective, fortresses, compared to settlements, are typically constructed in areas farther away from rivers. For instance, villages located on the second-level terraces of river valleys often place fortresses at the edges of third-level terraces. This pattern arises primarily because the site selection for Tianshui fortresses prioritizes topography and terrain over proximity to river sources. Fortresses, being temporary defensive structures compared to settlements, do not require a continuous long-term water supply and can instead rely on water storage and manual water transport. Additionally, while the fertile second-level terraces between villages and rivers are ideal for irrigation, they are also prone to flooding, making them unsuitable for the construction of rammed-earth fortresses.

In mountainous areas, fortresses also tend to be situated near water sources. On a smaller scale, fortresses are often positioned

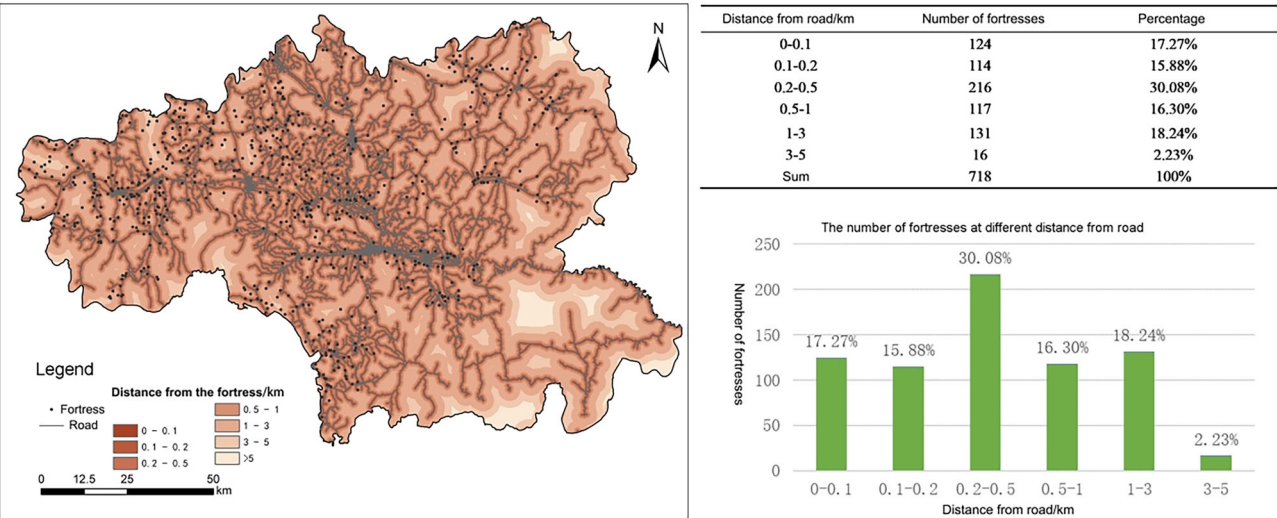


Fig. 22 Relation of road network and fortress distribution. This image analyzes the correlation between road networks and the distribution of fortresses in Tianshui.

on protruding points of ridges, with deep ravines on the periphery. These ravines frequently collect surface and ground-water from rain, mountain floods, or springs, providing both a water source for fortress residents and a natural moat for defense.

Relation of road network and fortress distribution. As illustrated in Fig. 22, the majority of Tianshui fortresses are located within 3 km of accessible roads, with over half situated within 500 m. The construction period of these fortresses predates the development of roads, indicating that there is no direct causation between the two. However, it is evident that the construction of “village-to-village” roads has significantly improved the accessibility of these fortresses. On one hand, this increased accessibility has transformed fortresses into distinctive landmarks visible along routes within Tianshui, contributing to tourism development. On the other hand, large-scale construction projects, such as road development, may involve the dismantling of certain fortresses.

Relation of residential settlement and fortress distribution. Through the analysis, it is observed that although there is a certain correlation and causality between Tianshui fortresses and factors such as topography, water systems, and roads, these patterns alone are insufficient to fully explain the geographic distribution characteristics of Tianshui fortresses. Based on on-site investigations, it is evident that the spatial distribution of Tianshui fortresses is closely tied to their relationship with settlements, due to their unique formation reasons. Tianshui fortresses serve as self-defensive structures for villagers, and are intimately linked with human activities, which are, in turn, constrained by local natural conditions.

Therefore, a preliminary hypothesis suggests the existence of a transmission chain: “natural conditions—land grain productivity—land population carrying capacity—population distribution—settlement distribution—fortress distribution.” As shown in Fig. 23, the study obtained the distribution of natural villages in Tianshui City and further derived their kernel density distribution. By overlaying this with the spatial distribution of Tianshui fortresses, a notable coupling degree was observed, which validates the hypothesis mentioned above.

As depicted in Fig. 24, this study further extracted the distribution of settlements in Tianshui City in 2019 based on publicly available land use data. Computational statistics reveal

Table 2 Results of factor detector of each influencing factor.			
Factor	No.	q-value	Sig.
Elevation	X1	0.07404762	0.00000004561233
Slope	X2	0.01168594	0.53397515476615
Aspect	X3	0.02750467	0.00498293207470
River	X4	0.04427117	0.00130604379138
Road	X5	0.02107802	0.03840001074387
Residential Settlement	X6	0.02812672	0.01679210942083

that over 85% of fortresses are concentrated within a 500-m radius of settlements, with more than 37% within a 100-m radius and over 26% within a 50-m radius. Only 2.23% of fortresses are located 1–2 km away from settlements, and none are situated more than 2 km away. This observation underscores a strong spatial correlation between fortresses and settlements.

Influencing factor analysis for fortress distribution. The above analysis suggests that the geographic distribution of Tianshui fortresses is influenced by a combination of natural and human factors, with topography being the predominant natural factor and proximity to settlements a key human factor. Based on this, the geographical distribution of settlements is closely associated with topography. Therefore, this study employed a geographical detector to conduct a single-factor analysis on six influencing factors: elevation, slope, aspect, rivers, roads, and settlements. The geographical detection results are presented in Table 2. The elevation data is derived from a digital elevation model (DEM), while both the slope and aspect maps are generated from the same DEM data. Additionally, the depicted rivers, roads, and settlements represent the Euclidean distances from the fortifications to these features, thereby reflecting the spatial relationships between the fortifications and these key geographical elements. According to the single-factor detection results, the factors from strongest to weakest influence are elevation, rivers, settlements, aspect, roads, and slope, with elevation being the dominant factor. However, the overall numerical values are relatively low, serving as indicative rather than explanatory. Quantitative analysis has its limitations, and understanding the influencing factors and underlying mechanisms of fortress geographical distribution requires a combination of both quantitative and qualitative analyses.

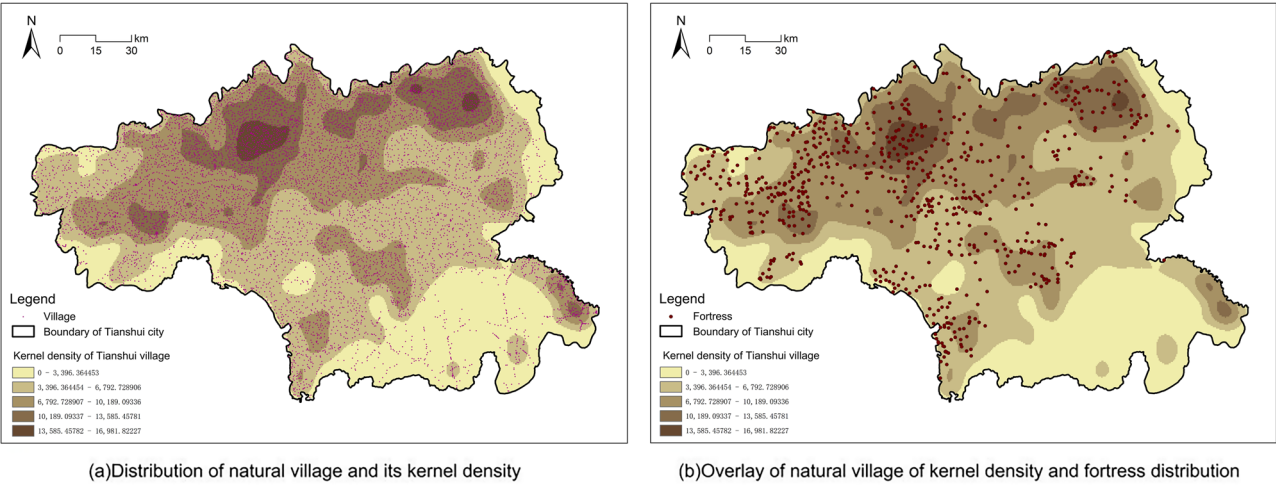


Fig. 23 Comparison of fortress distribution to natural village distribution. Panel 'a' is the distribution map of kernel density based on all village settlements in Tianshui City. Panel 'b' is based on the distribution map of the core density of natural villages in Tianshui City obtained by Panels 'a', and the points of Baozhai villages in Tianshui City are superimposed. It is used to intuitively reflect the degree of correlation between the fortress villages and all villages.

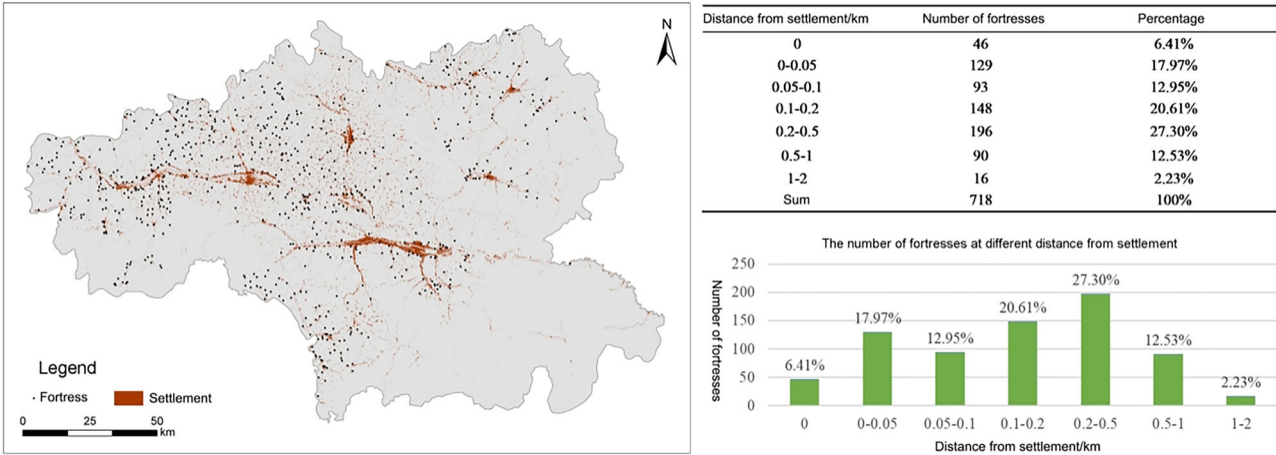


Fig. 24 Relation of residential settlement and fortress distribution. This image examines the relationship between residential settlements and fortress distribution in Tianshui.

Analysis of the localization mechanism of the cultural landscape of Tianshui fortresses

Early cultural deposits of Tianshui fortresses. Tianshui has a long and rich history, serving as one of the cradles of the Chinese nation and Huaxia civilization. It is the birthplace of Fuxi, the first of the Three Sovereigns, and the origin of Fuxi culture. As a national historical and cultural city, Tianshui fortresses over 8000 years of civilization, more than 3000 years of recorded history, and a city-building history of over 2700 years. Known as the “Hometown of Fuxi,” it possesses abundant historical and cultural resources.

The pre-Qin period’s cultural deposits primarily include the Majiayao culture, Qijia culture, Fuxi culture, Qin culture, and the Qin Great Wall culture. During the Han and Three Kingdoms periods, cultural deposits mainly consisted of Silk Road culture and the ancient battlefield culture of the Three Kingdoms. From the Song, Western Xia, Jin, and Yuan dynasties, cultural deposits included the frontier expansion culture of the Central Plains and the Song-Xia war culture. Throughout these historical periods, fortresses or similar defensive settlements were built. However, most of the existing fortresses in Tianshui were constructed

during the late Qing Dynasty, specifically during the Tongzhi era, with a few remnants dating back to the Song and Ming dynasties. As shown in Fig. 25, the majority of fortresses still standing today were built during the Tongzhi period of the Qing Dynasty. Fortresses constructed during the Three Kingdoms period or earlier are mostly known only through historical records or have been rebuilt on their original sites. The influence of early cultures on modern Tianshui is primarily reflected in cultural symbolism.

Large-scale construction of fortresses in Tianshui during the Tongzhi period of the Qing Dynasty. The peak period for fortress construction in Tianshui occurred during the Shaanxi-Gansu Muslim Rebellion. In the first year of Tongzhi (1862), the Hui army from Shaanxi entered the Qinzhou region, prompting local Hui communities to rise in response, leading to a conflict that lasted for eight years. As a result, fortresses were constructed on a large scale throughout Qinzhou, with nearly every village building one. Many of the fortress ruins visible on hilltops today date back to this period. According to the New Gazetteer of Qinzhou Directly Administered Prefecture (Guangxu period), by the 15th year of Guangxu (1889), there were 370 fortresses surrounding

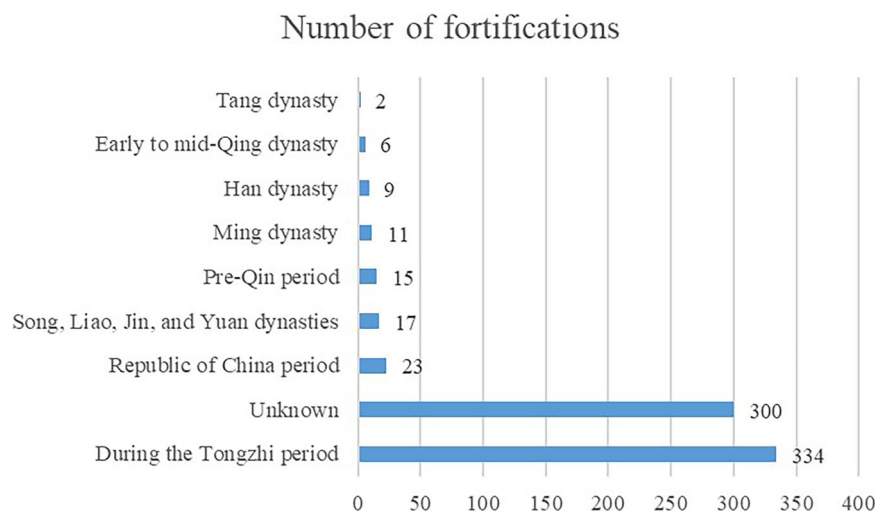


Fig. 25 The founding periods of existing fortresses in Tianshui. This figure presents the initial construction periods and the number of extant fortifications in Tianshui.

Qinzhou: “15 in the eastern township, 83 in the southern township, 105 in the western township, and 167 in the northern township.”

During the decade preceding the Tongzhi Northwest Muslim Rebellion, China was already experiencing internal turmoil, primarily in the southeast but also affecting the northwest. In the first year of Xianfeng (1851), Hong Xiuquan launched the Jintian Uprising, which led to the Taiping Heavenly Kingdom movement that swept across much of China. Although the northwest was not the main battlefield, the Qing court mobilized troops nationwide to suppress the rebellion, with Shaanxi and Gansu serving as key troop recruitment areas. The massive deployment of soldiers from these regions over ten years severely impacted social stability and development in the northwest (Wang, 2017b).

The Tongzhi Northwest War began in the first year of Tongzhi (1862) with the “Holy Mountain Bamboo Cutting” incident in Huazhou and lasted until the autumn of the 12th year of Tongzhi (1873), when the Hui army in Suzhou (Jiuquan) surrendered. Over more than a decade, fortresses were repeatedly captured, prosperous farmlands were turned to ruins, and human settlements were devastated. Reports describe horrifying massacres, where “tens of thousands perished in a single day, blood flowed like rivers, and corpses piled up like mountains, creating a scene of extreme horror (Lu, 2017).” “Zuo Zongtang, while suppressing the Shaanxi-Gansu Muslim Rebellion, emphasized the construction of fortresses. By the 10th year of Tongzhi (1871), numerous fortresses had been built across Gansu province, from Jin County in the east to Pingfan in the west, as well as in areas such as Qinwangchuan, Tumen, Dajing, Tuwowo, Dayugou, and Wudaojian in Beishan. During the rebellion, many fortresses were also built along the new Shaanxi-Gansu postal route, incorporating post stations, relay stations, and command centers within their defenses, with military forces assigned to ensure secure communication. Consequently, fortresses along this route became key strategic points contested by both Qing forces and Hui armies. Many fortresses were destroyed during the conflict. The Xinyou Travel Journal, completed in the Xinyou year of Guangxu (1891), provides detailed accounts of the post-rebellion fortresses along the new Shaanxi-Gansu postal route. For instance, at Gunyuan Wating Post, it records that after the war, “about sixty households remained within the fortress (Fu, 2011).”

Large-scale construction of fortresses by the people of Tianshui during the warlord era of the Republic of China. During the late Qing Dynasty and the early Republic of China, fortresses continued to be built in the Tianshui region. According to the Gazetteer of Tianshui County from the Republican period, there were 541 fortresses surrounding Tianshui, including “103 in the eastern township, 168 in the southern township, 133 in the western township, and 137 in the northern township.”

The issue of banditry was a widespread social problem during the Republic of China, reflecting both the loss of social control and the pathological state of society during this transitional period. Located at the junction of the Sichuan, Gansu, and Shaanxi provinces, the Tianshui and Longnan regions served as critical transportation corridors leading south into Sichuan and east into Shaanxi. This unique geographical location, combined with its extensive mountains and dense forests, provided an ideal environment for bandits to operate and hide. As a result, during the Republican period, the region became a hotspot for bandit activity and a frequent target for roaming marauders. In light of this, after the establishment of the Republic of China, the central government’s authority weakened, and political instability worsened. The Tianshui area and its surroundings were plagued by warlord conflicts, frequent regime changes, and local political turbulence. The absence of effective governance created a power vacuum, leading to widespread social disorder. Additionally, corruption in local administration, coupled with continuous natural disasters and social crises, forced many people to turn to banditry as a means of survival, making Tianshui one of the most severely affected areas by banditry in Gansu. In summary, banditry in Tianshui and Longnan during the Republic of China was characterized by its large scale, substantial numbers of bandit groups, high level of organization, and extensive areas of activity (Liu, 2015).

One of the most notorious bandit incidents involved Bai Lang. According to the Gazetteer of Wushan County, in 1914 (the third year of the Republic of China), Bai Lang from Henan gathered a large group of followers and entered Wushan County through Gaolouzi. They attacked thirteen villages, including Zhaojiagenzi, Yuanyangju, and Chejia’an, resulting in the massacre of hundreds of people in Wushan County. Among these villages, Chejia’an suffered the most severe devastation. During the fourth and fifth months of the lunar calendar, Bai Lang’s troops carried

out another large-scale massacre at Yangjiadian Fortress in Yanfenli, causing immense fear among the residents of Lijiamen, who fled into the deep mountains for safety.

Summary of the mechanisms behind the formation of the localized fortress cultural landscape in Tianshui. Diachronicity and synchronicity are concepts proposed by the Swiss linguist Ferdinand de Saussure. Synchronicity refers to the coexistence of elements within the same period, focusing on similarities, differences, and the current state of the subject of study—it is static. Diachronicity, on the other hand, examines the evolutionary process of the same phenomenon over time—it is dynamic (Liu, 2020). Applied to the study of the fortress cultural landscape, synchronicity investigates the structural characteristics of fortress cultural landscapes from a spatial perspective, while diachronicity explores their developmental relationships and historical evolution from a temporal perspective. Diachronicity facilitates a better understanding of synchronicity, while synchronicity reflects diachronicity at the present level. The two perspectives complement and refine each other, enabling a scientific understanding of the fortress cultural landscape.

By reviewing historical documents on Tianshui and analyzing the main construction periods of both historical and existing fortresses, it can be concluded that the primary characteristic of the diachronic localization process of the fortress cultural landscape is cultural sedimentation. Cultural sedimentation serves as the fundamental mechanism driving the localization of Tianshui's fortress cultural landscape. Wu Bihu (1996), in *Research on Cultural Sedimentation in China's Mountain Scenic Areas*, extended the concepts of geomorphology and sedimentology into cultural sedimentology. He discovered that cultural sedimentology exhibits characteristics distinctly different from traditional geomorphological processes—cultural sediments are not only deposited and preserved in mountainous landscapes but also embedded in human consciousness and cognition through cultural processes and knowledge dissemination (Wu, 1996).

An analysis of key historical periods in Tianshui reveals that the region, with its long history, has also been frequently affected by warfare. During periods of conflict, a large number of fortresses were constructed. However, in times of peace, as their defensive value diminished, fortresses underwent transformation—some were demolished or fell into disrepair, gradually fading from memory, becoming ruins, or even vanishing entirely. Meanwhile, many fortresses continued to be used by local residents, integrating into the regional culture. Their physical defensive function weakened, while their role in cultural and psychological defense grew stronger. This cyclical process, occurring repeatedly over the course of history, led to the accumulation of local culture—some aspects preserved as tangible heritage, while others endured through texts, perceptions, beliefs, and other intangible forms. This diachronic process of cultural sedimentation is precisely how the fortress cultural landscape of Tianshui was formed.

In conclusion, the localization of the fortress cultural landscape in Tianshui is not merely the accumulation of material and non-material elements related to fortresses themselves; rather, it is a process of cultural layering, which has contributed to the unique regional identity of Tianshui. The fortresses represent a distinct element within this broader cultural framework.

Discussion

The geographical distribution of Tianshui fortresses exhibits significant regularity, influenced primarily by the reasons for fortress construction, settlement distribution, and topographical features. Based on GIS quantitative analysis, this study employs a

combination of quantitative and qualitative methods, along with field investigations, to analyze the geographical distribution characteristics of Tianshui fortress clusters. It is found that the distribution of Tianshui fortresses shows correlations and causal relationships with factors such as terrain, river systems, and roads. Through comprehensive analysis, the geographical distribution patterns and influencing factors of Tianshui fortresses are identified, with the landscape playing a major role. These findings provide solutions and reference values for addressing the lack of quantitative research on fortresses in Tianshui, Gansu, the incomplete conceptual framework of fortress studies, and the absence of a human geography perspective in Chinese fortress research.

The distribution of fortresses in Tianshui is not solely determined by topography and water systems but is rather the result of long-term historical evolution and the interaction between natural conditions and human activities. From a macro perspective, the region's complex and variable mountains, hills, and river systems form a natural defense system, providing fortresses with unique protective barriers. At the same time, they regulate the spatial and temporal distribution of water resources, which is essential for residents' livelihoods and agricultural irrigation. Our study finds that, echoing Wang's conclusion on the "proximity to mountains and water" in the study of Lao Cheng Village in southern Ningxia, fortresses in Tianshui are generally located in areas with rugged terrain while being close to water sources. This geographic advantage not only enhances defense against external threats but also fosters economic activities and social stability (Wang, 2024). Additionally, Pang's research on the Songlong Ancient Road fortress cluster further emphasizes the crucial role of water sources and topography in fortress spatial distribution, illustrating the fundamental influence of the natural environment in ancient fortress site selection (Pang, 2024). Compared to previous studies, this research introduces new theoretical and methodological advancements. Traditional studies have primarily focused on the direct impact of natural environmental factors on fortress site selection (Tuo and Li, 2024; Wu, 2024). In contrast, this study incorporates population distribution and agricultural productivity as intermediary variables, constructing a comprehensive impact factor chain from macro-level natural conditions to micro-level socio-economic factors. It is evident that the natural environment not only directly determines the defensive function of fortresses but also indirectly influences population concentration, economic activities, and agricultural development. This dual mechanism has historically enabled fortresses to better adapt to environmental changes and social needs.

Many early studies primarily relied on qualitative descriptions and historical literature reviews, such as Wang's exploration of fortress settlements in China (Wang, 2003). In contrast, this study utilizes quantitative methods such as remote sensing technology, GIS spatial analysis, and geographical detectors to systematically analyze fortress spatial clustering, morphological complexity, and correlations with surrounding environments, making the conclusions more convincing. Although previous studies have provided theoretical foundations for fortress cultural preservation and inheritance, they lacked precision in data and methodological integration (Zhang and Li, 1957; Jie et al. 2020). These studies mainly focused on the relationship between fortress site selection and geographical elements such as topography, water systems, and villages. However, through a multi-scale, cross-level analytical approach, this study systematically examines the spatial distribution patterns of fortresses in Tianshui, offering more detailed, comprehensive empirical support and a more structured methodology. In the context of deepening regional cultural heritage protection and historical geography research, this macro-

to-micro, nature–society integrative approach holds significant theoretical and practical value.

Despite this, the study has certain limitations. Due to research constraints, the collected data on fortresses in Tianshui is not comprehensive, as not all fortresses in the city were accounted for. Future research should further refine and improve the dataset. This study delineates fortress settlements within the administrative boundaries of Tianshui, yet surrounding areas such as Tongwei County in Dingxi City and Li County in Longnan City also contain numerous fortresses, sometimes with even higher local densities. Further field investigations are needed to refine the database and improve analytical accuracy. Moving forward, as experimental conditions and data collection methods continue to advance, this research will enhance precision in both data quality and spatial dimensions. First, utilizing high-resolution imagery and 3D modeling technology, fortress ruins can be reconstructed at a micro-scale, facilitating a more precise exploration of the correspondence between specific landscape forms and topographical environments. This will contribute to digital archiving and virtual exhibitions for cultural heritage preservation. Furthermore, with the support of big data and artificial intelligence, a broader fortress database can be developed for cross-regional comparative studies. This will provide new perspectives for exploring commonalities and differences in natural conditions, socio-economic structures, and cultural transmission across diverse historical and cultural contexts. By transcending localized characteristics, this approach offers a universal methodology for the preservation and utilization of fortress heritage in Tianshui and beyond.

Conclusion

Based on the collection and spatial analysis of Tianshui fortress data, this study conducted a statistical analysis of the morphological characteristics and geographical distribution of Tianshui fortresses, leading to the following conclusions:

- (1) Based on field surveys and geographic information technology, a cultural landscape database of Tianshui fortresses has been established, containing detailed information on these fortresses. Through a comprehensive approach that combined remote sensing image recognition, on-site inspections, survey questionnaires, and a review of literature and records, alongside the use of various geographic information system (GIS) technologies, first-hand data on the number, names, and accurate spatial locations of all existing fortresses within the jurisdiction of Tianshui City were obtained. It was determined that there are a total of 718 existing fortresses, collectively defined as the Tianshui fortress group. Regarding morphological features, the minimum area of existing Tianshui fortresses is 235 square meters, and the maximum is 119,875 square meters, with an average of 5338 square meters. The average size can be understood as fortresses with dimensions of ~60 m on each side. In terms of distribution characteristics, the highest density of existing Tianshui fortresses can reach 17 per hundred square kilometers, with an average spacing of 2.28 km. In Wushan County, where the density is highest, the average spacing is 1.71 km.
- (2) There are 718 existing fortresses in Tianshui, exhibiting multidimensional characteristics in spatial distribution, area, perimeter, density, proximity, and morphology, with significant influences from topography and water sources. Spatially, Wushan County has the highest number of fortresses, while Qingshui County has the least. The overall distribution is clustered, though certain counties, like Gangu, show a random distribution pattern. The average

distance between fortresses in Tianshui is 2.28 km. In terms of area, the smallest fortress covers 235 m², while the largest reaches 119,875 m², with most ranging between 1000 and 5000 m² and an average of ~3600 m². Perimeters range from a minimum of 61 m to a maximum of 1671 m, with an average of 272 m. Regarding density, Wushan, Gangu, and Maiji have the highest concentrations, reaching up to 17 fortresses per 100 km². Morphologically, the average shape index is 1.1354, with most values below 1.2, indicating predominantly regular shapes such as circular, oval, and square. Fortress locations and forms are greatly influenced by topography, often following the contours of ridges and hilly terrain, while rivers and water sources also significantly affect site selection.

- (3) The geographic distribution of Tianshui fortresses is shaped by a combination of natural and human factors, with elevation and water systems being the primary determinants, though individual factor detection results show relatively low values. Most fortresses are concentrated in the 1000–2200 m elevation range, with the highest density occurring between 1600 and 1800 m, reflecting a west-to-east topographic pattern of high-low-high across Tianshui. Additionally, fortresses are primarily located on slopes ranging from 0° to 30°, with a significant preference for south-facing orientations, aligning with traditional settlement preferences in the region. Spatial analysis of relationships with water systems, roads, and natural villages reveals a transmission mechanism through which land productivity and population carrying capacity influence settlement patterns and ultimately determine fortress locations. Although individual factor impacts appear low, the overall analysis confirms the crucial role of interactions between natural and human factors in shaping the spatial distribution of fortresses. Notably, landform landscapes exert a significant influence, with fortresses primarily distributed in areas characterized by loess hills and erosional river valleys.
- (4) The transmission chain influencing the geographic distribution of Tianshui fortresses follows the sequence of “natural conditions—land grain productivity—land population carrying capacity—population distribution—settlement distribution—fortress distribution.” By examining key historical events, it is evident that the primary period of fortress construction in Tianshui occurred during the Tongzhi Hui Rebellion in the Qing Dynasty, driven by local residents’ spontaneous efforts for self-defense. The historical evolution of Tianshui fortresses encompasses both material and cultural dimensions, reflecting a cyclical process shaped by periods of conflict and peace. This cultural accumulation has played a fundamental role in shaping the cultural landscape of Tianshui fortresses. Further analysis reveals that rural settlement distribution is the decisive factor in determining the spatial pattern of fortresses. Fortresses are scattered around nearly every rural settlement, lacking hierarchical distinctions or differences in strategic importance. Their structural specifications and distribution patterns exhibit randomness and homogeneity, differing significantly from the military defense hierarchy of fortresses along the Great Wall or the centralized clustering characteristics of fortresses in the Qin River Basin in Shanxi.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Author contributions

SS: Drafting, data collection, research, editing; SW: Conceptualization, editing, data collection, supervision; XL: Editing, revision, data collection and analysis, supervision; ZW: Editing, revision, data analysis and interpretation, supervision; LZ: Editing, revision, supervision; CS: Editing, data analysis and interpretation; DX: Editing, revision; JZ: Editing, revision; ZH: Editing, revision; HL: Revision; JZ: Revision.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

Informed consent was not required as the study did not involve human participants.

Additional information

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