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A quantitative evaluation model of ancient military defense efficiency based on spatial strength—take Zhejiang of the Ming Dynasty as an example

Yinggang Wang[1], Lifeng Tan[2], Zao Zhang[1*], Huanjie Liu[1], Jiayi Liu[3†], Yukun Zhang[1†] and Mengqi Mu[1†]

Abstract

In the study of the defense capacity of ancient military settlements, most existing studies have evaluated the defense capacity of citadels qualitatively from a historiographical perspective. There are fewer quantitative studies on defense efficiency in a specific regional context. This paper takes the coastal defense citadels system of Zhejiang in the Ming Dynasty of China as the research object. It adopts a combination of digital historical data mining and quantitative research to study the defense efficiency of the military defense area in Zhejiang in the Ming Dynasty. This paper first analyzes the defense pattern of Zhejiang's sea defense citadels system in the Ming Dynasty. It determines the control points of defense groups, quantifies the defense group area with a Voronoi diagram, and classifies and assigns the entropy value to the deployment data of guard forts in historical data. Finally, the assigned forces are superimposed on the defense area to obtain the quantified defense efficiency of each defense group, and the defense results are verified. This paper innovatively proposes an "area-force" perspective. It introduces spatial segmentation and quantitative research methods to study the defense efficiency of a specific regional defense group system in ancient times. It proves that this method is feasible and can be applied to the study of other ancient military defense areas. It also expands the scientific perspective of ancient military fortification systems, which can contribute to systematically preserving ancient military settlement heritage on a larger scale.

Keywords Ming Dynasty, Ancient citadel, Military defense, Areal control, Force deployment

Introduction

The ancient Chinese military cultural heritage is an essential part of the world's cultural heritage [1] and the Ming Dynasty's coastal defense system and the army institutions are crucial representatives of it [2]. The Ming Dynasty was the first time in history that a systematic sea defense system was built on a large scale to defend against Japanese pirates, maintain a prohibition policy at sea, and protect shipping routes [3]. In the 1460 s and 1470 s, Japan entered the Sengoku period, and ronin and pirates often plundered China's coastal areas on a large scale [4]. Due to its crucial geographical location and developed economy, the site of Zhejiang was the most frequently invaded by Japanese pirates, and the number of naval defense settlements was the largest and most densely distributed [5]; the naval defense system in this area formed a hierarchical defense network, with the highest ranking being the Wei citadel, the second highest

†Jiayi Liu, Yukun Zhang and Mengqi Mu contributed equally to this work.

*Correspondence:
Zao Zhang
zao.zhang@tju.edu.cn
[1] School of Architecture, Tianjin University, Tianjin 300072, China
[2] School of Architecture and Urban Planning, Tianjin Chengjian University, Tianjin 300072, China
[3] School of Marine Science and Technology, Tianjin University, Tianjin 300072, China

ranking being the Suo citadel. The third highest ranking is the water fortress and Xunjiansi citadel [6]. During the Jiajing period of the Ming Dynasty (1522–1566 A.D.), to defend the area against the Japanese pirates, a garrison defense system was established based on the original citadels. The various defense areas were fortified together, with natural and social factors contributing to the specificity of the defense system [7].

Most existing studies on ancient military defense systems are based on qualitative analysis [8]. Scholars R. Yan et al. applied the theory of landscape ecology to qualitatively analyze the influencing factors and historical changes in the development of ancient village fortification sites in Yuxian, Hebei, China [9]; scholars Elizabeth Arkush and Charles Stanish critically evaluated the archaeological record to infer military fortification architecture in the ancient Andean region inferred from the archaeological record [10]. The above research results are similar to the research object of this paper, and the perspective of its exposition has important guiding significance for this paper. However, the qualitative analysis of ancient military is often negatively affected by the subjective judgment of scholars, which is not conducive to the accurate presentation of objective facts and lacks the scientific nature of quantitative analysis.

And most existing studies focus on the efficiency of the single defense of citadels. Taking the study of ancient Chinese military settlements as an example: Yumin Du et al. analyzed the characteristics of the forts of the Ming Great Wall military defense system in Qinghai, China [11]; and Yinan Luo et al. analyzed the spatial morphological characteristics of Pu Zhuang Suo in the Ming Dynasty [12]. However, ancient Chinese military settlements were built quickly in response to war, and their architectural monoliths show a high degree of similarity. There is a lack of quantitative analysis of regional defense from a spatial perspective.

At the same time, the wide application of GIS technology provides a brand new technical support for the study of ancient military settlements. The existing GIS-based spatial analysis is mainly based on the study of the geographical environment of the heritage site and the determination of the location of the area but lacks in-depth quantitative research in the historical context, such as the analysis of environmental factors on the spot and layout of military settlements in Zhejiang during the Ming Dynasty by Lifeng Tan et al. [13]. And Nabil Bachagha et al. used the GIS-based feature extraction method to determine the location of the ancient Roman military fortress site in southern Tunisia and carried out systematic restoration [14]. The above two examples can be taken as representatives of the research on the influence of environmental factors on the distribution of ancient military settlements, but the establishment of them, which mainly serves for military defense, will inevitably be affected by man-made factors such as the deployment of troops and the composition of soldiers, which is an indispensable link in the process of the formation, refinement and development of ancient military settlements.

Research aims

The deployment of troops and the composition of forces are the keys to influencing the defense efficiency of the ancient military defense system. This paper attempts to quantify the impact of the deployment of troops and soldiers on the overall spatial defense efficiency of military defense in ancient times and establish a quantitative evaluation model of defense efficiency based on historical facts. Through this perspective and method, we can reduce the subjectivity of judging the defense efficiency of ancient military settlements, generate a deeper understanding of the ancient regional military defense, and improve the scientificity of quantitative research on the distribution of ancient military forces.

Study area

Zhejiang is located on the southeast coast of China, with a mainland coastline of about 2,200 km and convenient land and water transportation [15]. The administrative division of Zhejiang was the same as today after the 9th year of Hongwu of the Ming Dynasty (1375 AD), with six Fu (Administrative divisions from the Tang to Qing dynasties, one level higher than the county) bordering the East China Sea from north to south: Jiaxing, Hangzhou, Shaoxing, Ningbo, Taizhou, and Wenzhou. The superior geographical environment promoted the economic and social development of Zhejiang but simultaneously made Zhejiang suffer from the Japanese pirates. In terms of the general situation of the Ming Dynasty's strategy (Fig. 1), Zhejiang guarded Nanjing and was located in the middle of the coastal provinces, which gradually made it the linchpin of the Ming Dynasty's naval defense system [16, 17].

Materials and Methods

Study object

The evaluation of defense efficiency must be preceded by the definition of the selection of defense factors. The citadel garrison system can quickly gather troops in wartime, and the composition mode is mostly mixed military and militia. This study takes the defense space as the benchmark to evaluate its spatial defense efficiency and focuses on the comparison of troop deployment status.

Fig. 1 The location of the study area. The map of China was provided by the Ministry of Natural Resources of China (approval number: GS(2019)1673)

Defense space of Zhejiang citadel garrison system in Ming Dynasty

After the construction of the naval defense system of Zhejiang was completed in the Ming Dynasty, there were 40 citadels, with Wei citadels and Suo citadels as the control points [18]. In the Jiajing period of the Ming Dynasty, the defensive areas were divided into administrative areas. The spatial defense pattern was formed with "four Canjiang (Sub-regional Assistant Commander) and six Bazong(Company Commander)" The four defensive areas in Zhejiang were divided into Hang-Jia-Hu for Hangzhou, Jiaxing, and Huzhou;

Ning-Shao for Ningbo and Shaoxing; Tai-jin-Yan for Taizhou, Jinhua, and Yanzhou; and into Wen-Chu for Wenzhou and Chuzhou. Within the defense areas, Bazong stationed in each Wei citadel: Bazong of Haining, Bazong of Dinghai, Bazong of Linguan, Bazong of Changguo, Bazong of Songhai, and Bazong of Jinpan [19]. The pattern of "four Canjiang and six Bazong" in the defense area and the corresponding relationship with Fu of Zhejiang are shown in Table 1.

Composition of the military strength of the citadel garrison system of Zhejiang in the Ming Dynasty

The army of the Ming Dynasty was divided into two categories: military and militia, and the main types of defense forces were naval and land forces. The citadel garrison system was based on Wei citadels and Suo citadels, and the garrison's strength was relatively constant. The location and layout of the citadels took advantage of the geographical environment, and the troops were flexible and mobile [20], concentrating their strength in the citadels during regular times and dispersing them to various estuaries and important areas during the flood season.

Data sources

In this paper, the DEM (horizontal accuracy of 12.5 m) published by the Computer Network Center of the Global Academy of Sciences and the geographic coordinates of each fortification are determined by combining the data from the *Chou Hai Tu Pian* [21], various local chronicles, and field research. [13] The location of each citadel in relation to the terrain is presented in Fig. 2. These are the data base for the study in this paper.

According to the first volume of *Quan Zhe Bing Zhi Kao* [22], the composition of the water and land forces of Zhejiang in the Ming Dynasty under the pattern of "four Canjiang and six Bazong" is summarized in Table 2.

Methods

The spatial defense efficiency of the citadel garrison system was derived by quantifying and comparing each defense area's average spatial strength values. The difference in the combat strength of the same type of soldier in different areas of the Ming Dynasty is slight [23]. Still, the difference in the combat strength of different soldiers is significant. Therefore, the type and number of soldiers assigned will significantly impact each area's defense efficiency. And the quantitative analysis should clearly distinguish different soldiers of the same kind (Fig. 3).

Definition of factors affecting the efficiency of spatial defense

The defense of the citadel garrison system has the following characteristics.

(1) The Wei citadels are the spatial layout control points, and the strength is the measure of the combat power in the area [24].

The land forces of the citadel garrison system were mainly stationed in the Canjiangs' zone of the inland Wei citadels, and the coastal defense was mostly taken care of by the Cangjiangs' naval forces. The strength of Suo citadels was flexibly mobilized.

(2) The strength of naval and land forces became the core factor.

The distribution of the strength of naval and land forces in different areas became the focus. In the middle and late Ming Dynasty, sea defense gradually shifted from land defense to naval defense [25]. Because of the small size of Japanese ships, the Ming naval forces could use the advantage of ship size to annihilate Japanese pirates at sea in naval battles [26].

Table 2 shows that the proportion of naval forces in each defense area is much more significant than that of land forces. The strength ratio of the Ning-Shao is

Table 1 The spatial pattern of defense of "four Canjiang and six Bazong" and the correspondence between Fu of Zhejiang in the Ming Dynasty

Fu	Citadel garrison system defense area	Canjiang	Bazong	Bazong's garrisoned Wei citadel
Hangzhou、Jiaxing、Huzhou	Hang-Jia-Hu	Canjiang of Hang-Jia-Hu	Bazong of Haining	Haining
Ningbo、Shaoxing	Ning-Shao	Canjiang of Ning-Shao	Bazong of Dinghai	Dinghai
			Bazong of Linguan	Linshan、Guanhai
			Bazong of Changguo	Changguo
Taizhou、Jinxiang、Yanzhou	Tai-Jin-Yan	Canjiang of Tai-Jin-Yan	Bazong of Songhai	Songmen、Haimen
Wenzhou、Chuzhou	Wen-Chu	Canjiang of Wen-Chu	Bazong of Jinpan	Jinxiang、Panshi

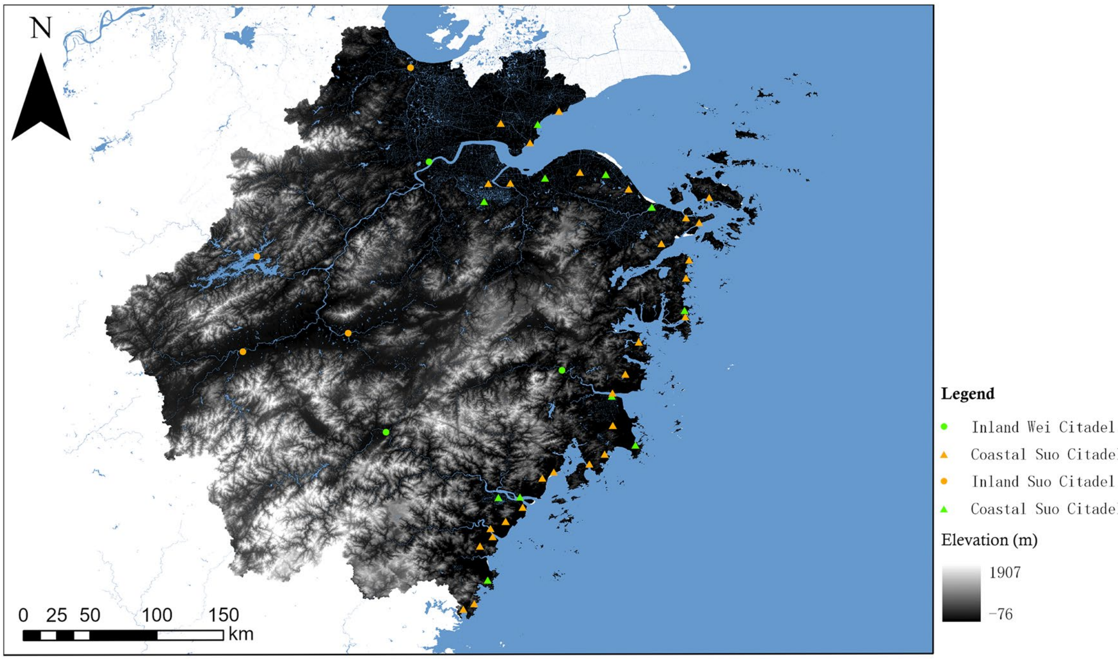

Fig. 2 The coordinate registration of the coastal defense citadels in Zhejiang province during the Ming dynasty. The base map was from ASTER GDEM (30 m elevation data)

Table 2 The composition of the naval and land forces in Zhejiang during the Ming Dynasty under the pattern "four Canjiang and six Bazong" pattern of the composition of the naval and land forces of Zhejiang in the Ming Dynasty

Citadel garrison system defense area	Deployment of forces	Number of land forces	Number of water forces
Hang-Jia-Hu Land force: 2185 Water force: 2725	Xundao of Military(Surveillance Vice Commissioner of Soldiers)	Militia: 437	Militia: 468 Military: 76
	Canjiang of Hang-Jia-Hu	Militia: 874 Military: 874	Militia: 242 Military: 17
	Bazong of Haining	0	Militia: 1670 Soldier: 252
Ning-Shao Land force: 5246 Water force: 11,152	Xundao of Military(Surveillance Vice Commissioner of Military)	Militia: 542 Military: 0	Militia: 100 Military: 60
	Canjiang of Ning-Shao	Military and Militia: 539	Militia: 1603 Military: 363
	Bazong of Dinghai	0	Militia: 2968 Military: 740
	Bazong of Linguan	Militia: 1812 Military: 1812	Militia: 1282 Military: 157
	Bazong of Changguo	Militia: 0 Military: 541	Militia: 2744 Military: 1135
Tai-Jin-Yan Land force: 2753 Water force: 4322	Xundao of Military	Military: 589	0
	Canjiang of Tai-Jin-Yan	Militia: 1623 Military: 541	Militia: 790 Military: 215
	Bazong of Songhai	0	Militia: 2004 Military: 1313
Wen-Chu Land force: 5752 Water force: 8735	Xundao of Military	Militia: 498 Military: 120	Infantry: 128 Cavalry: 35
	Canjiang of Wen-Chu	Militia: 3600 Military: 1534	Militia: 2220 Military: 840
	Bazong of Jinpan	0	Militia: 3622 Military: 1890

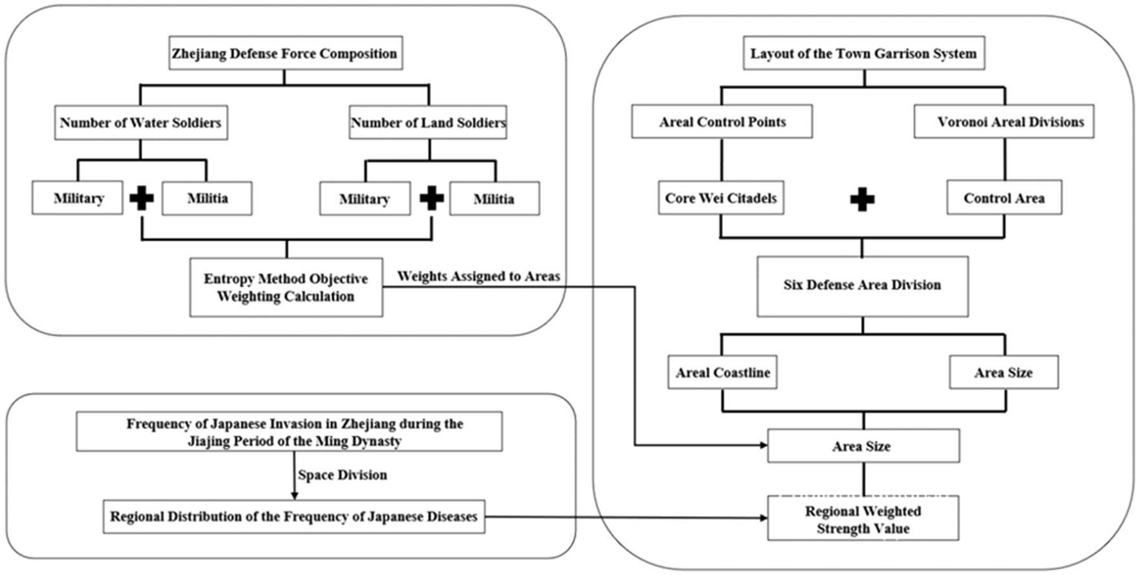

Fig. 3 The logical framework

dominant, followed by the Wen-Chu, and the Hang-Jia-Hu has the lowest strength of naval and land forces.

The land area and the length of the coastline of each defense area become essential indicators for calculating the average combat strength value of the area. Due to the different military and militia combat power, the distribution of military and militia in the naval and land forces must be weighted.

Quantification of spatial geographic factors of defense

The study first determined the division of defense groups and control points. The spatial coordinates of the Japanese pirates during the Jiajing period of the Ming Dynasty of Zhejiang were obtained by combining historical data and field research, which were used to test the rationality of the coastal defense area of the Ming Dynasty of Zhejiang. The forces of the citadel garrison system were concentrated in each Wei citadel or Suo citadel and mobilized uniformly in each defense area according to the scale of the Japanese pirates during the war. Therefore, the group was divided according to the affiliation of each Wei citadel and Suo citadel, and the points of the Wei citadel in each defense area were used as control points.

Currently, the primary methods to measure the spatial distribution pattern of points are the nearest neighbor index, the closest point average method, etc. [27–29]. At the same time, the Kolmogorov–Smirnov formula and Lorenz curve can count the number of target bodies in the grid [30]. In this paper, we analyze the spatial distribution characteristics of the forts of Zhejiang's sea defense system using the Voronoi diagram.

The Voronoi diagram is a spatial partitioning algorithm introduced by the Russian mathematician Georgi Voronoi [31]. It is a continuous polygon consisting of a set of perpendicular bisectors of lines connecting two adjacent points, where the distance from any point in the graph to the control points of the polygon is less than the distance to the control points of other polygons [32, 33]. The Voronoi diagram is used as a mathematical structure to partition the plane into regions, each region containing a discrete point and containing all other points closest to that point. It is widely used in geometry, geography, meteorology, information systems, etc. [34–36]. It is also used in archaeology and settlement research [37, 38]. For example, Hodder's analysis of ancient castles in southern England during the Roman occupation period in 1972 is consistent with the patterns of resource control and human-land relations obtained by other means [39]; Charles Duyckaerts and Gilles Godefroy, French scholars, have made a systematic discussion of the use of Voronoi diagrams for numerical density and spatial distribution analysis [40].

The generation of Voronoi diagram includes: determining the set of points, constructing the region centered on each point, and generating the boundary, three main steps. Under the garrison system of defense in Ming Dynasty Zhejiang, the 11 Wei citadels along the coast were the superior military units of the Suo citadels in the region, and the Wei citadels had direct mobilization authority over the military strength of the Suo citadels under its jurisdiction, which fit well with the principle of Voronoi diagram's control of the region by discrete point set generation. Therefore, this study chooses to use the method of Voronoi diagram for spatial division. Among them, the Wei citadel points in Zhejiang are used as discrete point sets. Theoretically, the regions generated by the point sets are the ranges corresponding to the fastest speed of sending troops to the battlefield in each Wei citadels, and the generated spatial Voronoi diagrams are unique.

Then, the scope of the computational area is determined. The areal size of the Zhejiang sea defense was used to verify the rationality of the macro layout of the Zhejiang sea defense system. According to the coordinates of the Japanese pirates' invasion points along the coast of Zhejiang during the Jiajing period of the Ming Dynasty, the proximity analysis between the spatial location of the invasion points and the coastline was conducted using ArcGIS, and the closest distance between the invasion points and the coast was obtained for 62 determined spatial locations. 97% of the invasion points were less than 37,000 m away from the coast in a straight line, and the invasion area was defined using the buffer zone tool in ArcGIS. Except for the Zhoushan Islands in eastern Zhejiang, the citadels are mostly armed to defend the coastline, so the invasion range is defined as the land side of the coastline.

The Voronoi diagram is calculated by taking 11 Wei citadels of Zhejiang as control points, as shown in Fig. 4 Voronoi spatial pattern of coastal Wei citadels, and the coastal defense area is divided into 11 areas in the Voronoi diagram with Wei citadels as control points, and the point locations of the Suo citadels are put into the diagram to obtain that, except for Sanshan Suo under Linshan Wei, which is located in the Voronoi diagram with the Guanhai Wei as a control point, the other Suo citadels are all within the space of their respective Wei citadels.

Determine the spatial scale criteria for evaluating sea defense in Zhejiang during the Ming Dynasty, i.e., land area and coastline length (Table 3).

Quantification of strength factors in the defense area

Due to the difference in military and militia combat power, it is necessary to calculate the weight value of different types of soldiers. The concept of "entropy" is introduced in the weight calculation, and the entropy method is used to calculate the weight of the force composition; the first part is the force weight of naval and land forces, and the second part is the respective military and

Table 3 Defensive space efficiency calculation basis table

Defense area of "four Canjiang and six Bazong"	Length of coastline /km	Land area /km^2
Hang-Jia-Hu	254.163	5220.096
Ning-Shao	2778.319	13,325.993
Tai-Jin-Yan	1195.738	5720.633
Wen-Chu	852.149	6055.128

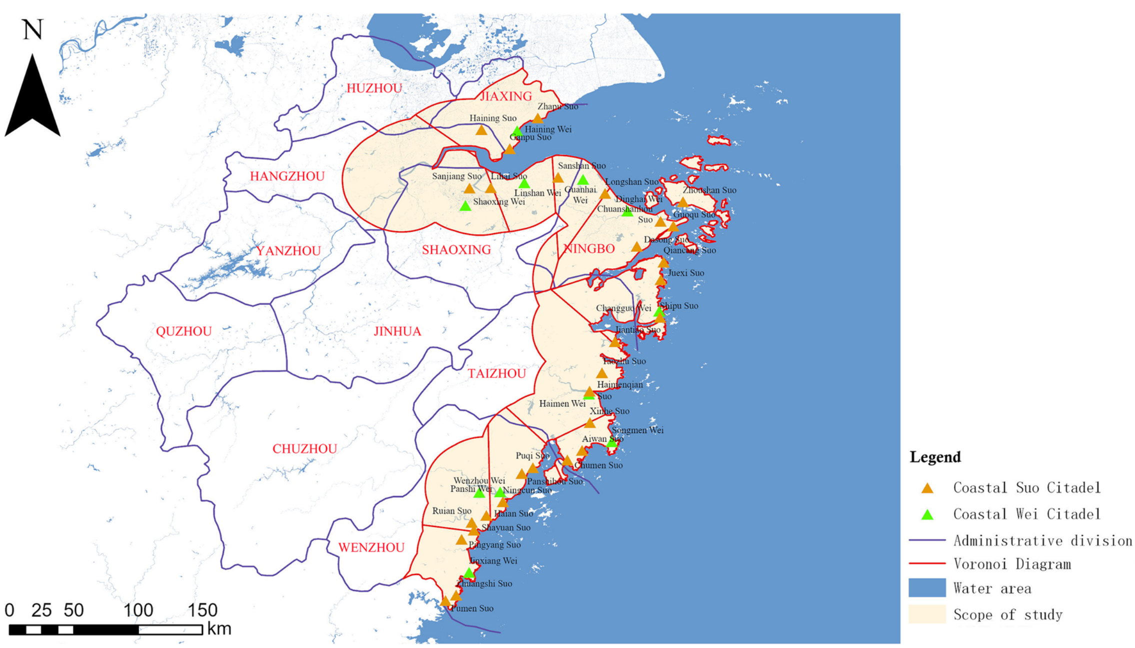

Fig. 4 Spatial division of Voronoi in the Wei Citadels

militia weights of naval and land forces (Additional file 1: Table S1).

Entropy is originally a thermodynamic concept, a parametric quantity that describes the degree of disorder in a system [41]. In information theory, entropy is the average amount of information in each message received [42], which can be analyzed and compared to its reference value and the amount of change. The higher the entropy, the more information is transmitted; the lower the entropy, the less information is shared [43, 44]. In this paper, the entropy value method is used to analyze information about the composition of forces in the sea defense area of Zhejiang during the Ming Dynasty, and the entropy value is calculated for the forces.

Combining the land area and coastline length of each defense area and the weight of the force composition, the quantitative values of the average land force and average sea force defense are obtained.

We compare the quantitative values of the defense of each defense area with the frequency of Japanese pirates' invasion, evaluate the defense efficiency of the defense area of the citadel garrison system in Zhejiang of the Ming Dynasty, analyze the defense strategy in the Middle and Late Jiajing Period of the Ming Dynasty with the quantitative results, and finally summarize the conclusions of the study (Table 4).

Calculation

When calculating the defense efficiency of the four defense areas, it is necessary to calculate the weights of the military and militia and to count the weighted values of the military and militia for the sum of the strength of the naval and land forces in each defense area.

The entropy value method is used to analyze the information on the strength of the four defense areas. The entropy value of the power of the naval and land forces is calculated for the "four Cangjiang and six Bazong" respectively. There are m military and militia composition scenarios (naval and land forces are calculated separately), denoted as $S=\{S_1, S_2, \ldots\ldots, S_m\}$; there are n corresponding attribute values, represented as $C=\{C_1, C_2, \ldots\ldots, C_n\}$. The two indicators are in the same unit; no normalization calculation is required. If the attribute value of scheme S_i for attribute C_i is b_{ij}, then the specific steps are as follows.

①The information entropy value of the attribute output is:

$$e_i = -(\ln n)^{-1}\sum_{i=1}^{m} b_{ij}\ln b_{ij}, j = 1, 2, \ldots, n \tag{1}$$

When $b_{ij}=0$, it is specified that $b_{ij} \ln b_{ij}=0$, then $0 \le e_{ij} \le 1$.

②Calculate the coefficient of the degree of variation of the attribute d_j:

$$d_j = 1 - h_j, j = 1, 2, \ldots, n \tag{2}$$

③Calculate the weighting factor for each attribute:

$$w_j \frac{d_j}{\sum_{j=1}^{n} d_j}, j = 1, 2, \ldots, n \tag{3}$$

As shown in Tables 4 and 5, by calculating the entropy value method for the land and naval forces composition, we can see that the weight coefficients of militia and military are 52.31% and 47.69%, respectively, in the land force system. The weight coefficients of militia and military are 38.44% and 61.56%, respectively, in the naval force system.

The militia of the land force system was slightly more important than the military. This is because the government and civil society supported the temporary recruitment of soldiers during wartime in the middle and late Ming dynasty. Material incentives were provided by the policy of exemption from corvée, rent and grain [45], which significantly boosted the morale of the militia and made its role in land warfare more critical than that of the military. The opposite is true for the weight of the naval force system, as shown in Table 5, where the importance of naval forces was 61.56%, more than 20% higher than the weight of militia. Naval force operations require long-term specialized training [46], and the military has a vital specialization advantage over the militia in surface warfare.

According to Tables 4 and 5, the weighted strengths of the "four Canjiang and six Bazong" defense areas can be

Table 4 Entropy method of calculating weights for land soldiers

Item	Information entropy value(e)	Information utility value(d)	Weighting factor(w)
Militia of the Land Forces	0.6634	0.3366	52.31%
Military of the Land Forces	0.6932	0.3068	47.69%

Table 5 Entropy method of calculating weights for naval soldiers

Item	Information entropy value(e)	Information utility value(d)	Weighting factor(w)
Militia of the naval Forces	0.8576	0.1424	38.44%
Military of the naval Forces	0.7719	0.2281	61.56%

Table 6 Defensive area efficiency calculation basis table

Defense area of "four Canjiang and six Bazong"	Force Composition	Strength weights of military and militia	Length of coastline / km	Land area /km^2
Hang-Jia-Hu	Land Soldiers	1103	254.163	5220.096
	Water Soldiers	1127		
Ning-Shao	Land Soldiers	2609	2778.319	13,325.993
	Water Soldiers	4854		
Tai-Jin-Yan	Land Soldiers	1388	1195.738	5720.633
	Water Soldiers	2014		
Wen-Chu	Land Soldiers	2932	852.149	6055.128
	Water Soldiers	3997		

Table 7 Entropy method weighting table for land and naval forces

Item	Information entropy value(e)	Information utility value(d)	Weighting factor(w)
Weighted Strength Value of Land	0.6775	0.3225	45.06%
Weighted Strength Value of Sea	0.6068	0.3932	54.94%

calculated to obtain the total weighted powers of naval and land forces in each defense area and the quantitative data basis for calculating the efficiency of the defense area can be summarized with Table 6.

Results

The entropy method weighting calculation of the strength of four major defense areas of the naval and land forces (Table 7) shows that the weighted strength of the sea is higher than the weighted strength of the land by about 10%, which indicates that the power of the citadel garrison system focuses on the sea defense and the influence of the land forces decreases, and reflects the characteristics of the citadel garrison system with the main focus on the defense of the forces and the flexible movement of the strength in the defense area (Table 8).

Through the entropy value method of weight calculation, the four major defense areas of Zhejiang naval defense in the Ming Dynasty can be evaluated separately:

(1) Wen-Chu

In the quantitative calculation of each defense area, the average land and sea force of the Wen-Chu defense area ranked the highest, so the weighted quantitative value of the average areal force of the Wen-Chu defense area ranked first. From the 31st year of Jiajing to the last year of Jiajing, there were 14 Japanese invasions in the Canjiang of Wen-Chu defense area and the Bazong of Jinpan, accounting for about 12% of the total number of Japanese invasions in Zhejiang during the Jiajing period (110). The weighted quantitative value of military strength in this area positively correlated with the frequency of invasions.

(2) Hang-Jia-Hu

The average spatial strength of the Hang-Jia-Hu defense area is the second highest, but the number of Japanese invasions in this area is 33, which is lower than that of the Ning-Shao defense area. The reason is that the Hang-Jia-Hu area was the most taxed in Zhejiang during the Ming Dynasty [47]. The most significant motive for the Japanese invasion was to plunder property, so they were desperate to take risks despite multiple defenses [48], followed by considering defense strength [49].

The average land strength of the Hang-Jia-Hu defense area is ranked third, only 0.21 people/km^2. However, the sea strength reaches 4.43 people/ km^2, the inland depth

Table 8 Quantification of the areal defense value of "four Canjiang and six Bazong"

Defense area of "four Canjiang and six Bazong"	Average strength on land(people/km^2)	Ranking	Average strength on marine(people/km)	Ranking	Average strength-weighted value of the area	Ranking
Hang-Jia-Hu	0.211	3	4.435	2	2.532	2
Ning-Shao	0.126	4	1.747	3	1.017	4
Tai-Jin-Yan	0.243	2	1.685	4	1.035	3
Wen-Chu	0.484	1	4.691	1	2.795	1

of the Hang-Jia-Hu area is significant, and once the Japanese pirates land on a large scale, they will cause substantial damage to the inland.

(3) Tai-Jin-Yan

This defensive space was invaded 19 times during the Jiajing period. Compared to other defense areas, this one focuses more on land defense. Although its naval defense force ranks only fourth, and its average force-weighted value is lower than that of the Hang-Jia-Hu defense area, its defense effect is better than that of the Hang-Jia-Hu defense area, indicating that appropriate deployment of forces and types of troops can effectively improve the efficiency of area defense.

(4) Ning-Shao

The Ning-Shao defense area was the most severely attacked area during the Jiajing period, with 44 invasions accounting for about 40% of the total invasions in Zhejiang. Without distinguishing the weight of military and militia, 5,246 land soldiers and 11,152 water soldiers were in this defense area. Due to the long and winding coastline of this defense area [50], the average strength of the sea is only third after the average power of the area, and the weight of military and militia is superimposed. After weighing the average strength of the area by land and coastline, this area is ranked the lowest in terms of defense capability, which is consistent with its level of invasion.

By superimposing the map of Japanese invasion points in the Jiajing period of the Ming Dynasty on the map of the coastal Wei citadels of Voronoi (Fig. 5), it can be concluded that: 1. The plain in the Hang-Jiang-Hu was vast, and Japanese pirates could enter the area directly. The lack of land forces in the Hang-Jia-Hu defense area and the prosperous economy of the Hang-Jia-Hu area led to the repeated invasion by Japanese pirates due to several factors [7]. 2. Tai-Jin-Yan and Wen-Chu defense area along the river and the state of invasion can not be ignored, the deployment of forces focused on land effect is obvious. This strategy of actively combining areal characteristics in the deployment of forces made the Jin-Yan-Tai and Wen-Chu areas less vulnerable to the Japanese invasion in the Jiajing period.

In summary, both the coastal defense groups and the force layout show the following spatial distribution pattern: the structure of the Voronoi diagram generated by the control points of the defense groups corresponds to the subordinate relationship between the Wei citadels and the Suo citadels as recorded in the historical records; the forces of the defense groups are laid out according to the minimum areal distance centered on the control points.

The ratio of military to the militia and the ratio of naval forces to land forces in each defense area of the citadel garrison system was flexibly adjusted according to the land area, and coastline length of each defense area and

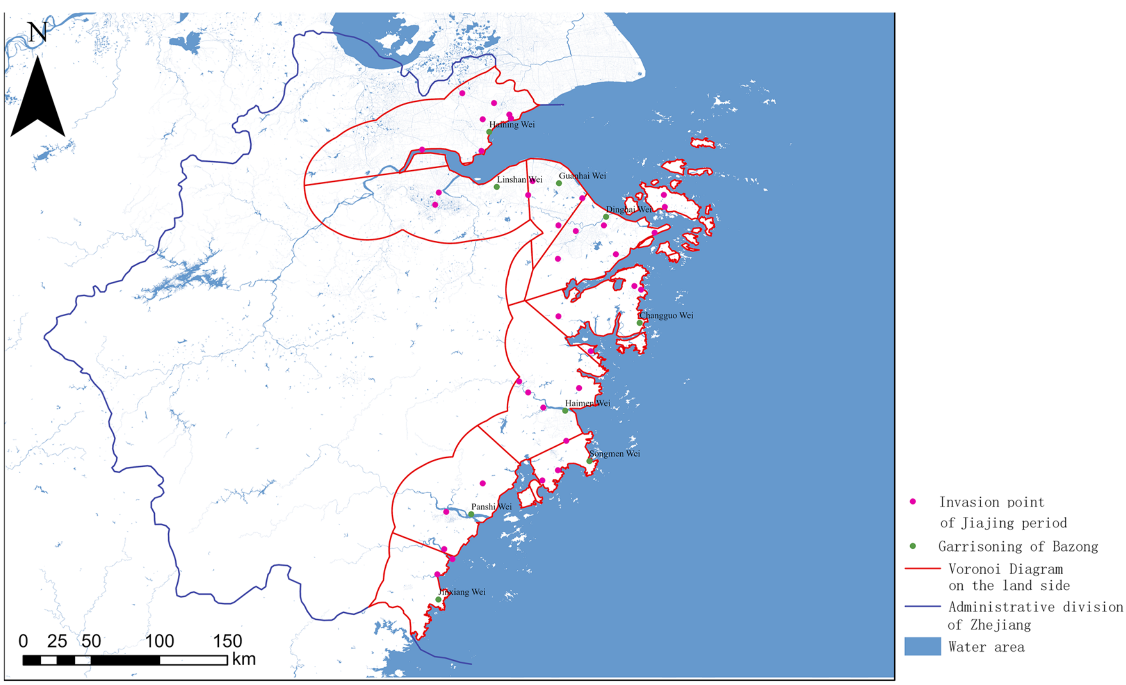

Fig. 5 Geographical distribution of Japanese invasion and Bazong's defense space during the Jiajing period of the Ming Dynasty (Self-drawn by the author)

its effectiveness in resisting the widespread invasion of Japanese pirates after its establishment proves the overall rationality of the above measures. Therefore, it can be concluded that the areal layout of ancient Chinese military settlements was a close combination of defense efficiency requirements and areal environment.

Discussion

In ancient China, there was the Great Wall and the sea defense system; in the world, there was the Great Wall of ancient Rome, the Amsterdam defense line, and so on. The construction of these military cultural heritages is dynamic, continuous, and planning, and the focus of fortification and the main influencing factors are very different in each period. Using quantitative analysis, we can conduct in-depth research on the areal layout and defense characteristics of specific areas to summarize the standard methods for overall research instead of just staying in the qualitative analysis of historical history and political background [51, 52].

Although this paper concludes the defensive efficiency of the sea defense system in Zhejiang during the Ming Dynasty, there are still shortcomings:

(1) Due to the vast geographical area covered by the study and a large amount of data, the data on the location of the Wei and Suo citadels points and the frequency of invasion within the spatial and temporal area covered by the paper may be missing. Some of the data can only be reasonably inferred from local records, the war situation, and the social background, and the process will inevitably have subjective components in the process, which may cause errors in the analysis.

(2) The design of the citadel garrison system primarily prioritized spatial defense strength. Notably, factors such as topography, hydrology, population structure, degree of social development, and political system exerted substantial influence in the determination of guardhouse system locations. However, it's worth noting that this study confines its scope exclusively to the assessment of spatial defense strength. The intricate interplay of topographical features, hydrological considerations, demographic structures, socio-economic development, and political dynamics remains a promising avenue for future research endeavors. Subsequent studies can build upon this foundation by harnessing more comprehensive, precise, and reliable datasets, enabling more targeted investigations within specific geographical regions.

This paper selects to get the quantitative research method itself also has the place that can be further improved:

(1) In this paper, soldiers are categorized into military and militia according to the composition of soldiers, and into two categories of water soldiers and land soldiers according to the types of soldiers, and the weights are quantified on this basis. However, it is difficult to specifically quantify the individual combat ability and military training differences of soldiers of the same type, especially in smaller scale battles, the impact of individual differences will be magnified.

(2) The Voronoi diagram is a method of dividing space on a plane. The creation and operation of ancient military settlements and the outbreak of battles were under the influence of both nature and man. The number of troops in each area directly affects its defense capability, but natural factors such as terrain and weather conditions still have an impact on coastal defense, which are more difficult to represent in this method.

Both of these have an impact on the accuracy of quantifying defense efficiency in each space.

Nevertheless, combining digital historical excavation and quantitative analysis provides a new perspective for studying ancient military settlements. Compared with the previous qualitative research based on historical materials, this method has made a breakthrough in analytical accuracy and capability. It can reach the defense efficiency of each defense area of the sea defense system in the Ming Dynasty Zhejiang area more refinedly and establish a reliable quantitative evaluation model.

In the context of the digital preservation of ancient cultural heritage, data archives are the basis of cultural heritage value mining. This paper's statistical analysis of data is of great significance for the quantitative study of the defense efficiency of ancient military settlements. During field research, it was found that preserving Ming Dynasty sea defense military settlement sites is worrying. The data review showed that keeping ancient military and cultural heritage worldwide needs urgent attention. The research trend of ancient military settlements shows diversified characteristics. With the rapid development of information technology, statistics, and other disciplines, many more efficient research methods are being incorporated into studying ancient military and cultural heritage. Discovering historical clues and using digital tools for spatial quantification research can better explore ancient military wisdom, provide richer and more diverse means for the future conservation of ancient military settlement heritage, and raise awareness of preserving each ancient military cultural heritage.

Conclusion

This paper utilizes spatial segmentation and quantitative research methods, the four defense areas and their troop deployments of the Zhejiang naval defense system during the Ming Dynasty were used as samples. The quantitative data on troop deployments were quantitatively analyzed in relation to the length of coastline and land area in each space to derive spatial average troop strength weights, and finally compared with the frequency of invasion during the Jiajing period for each defense area and made an evaluation. The study proves that the layout of citadel point groups and the composition of forces in the Zhejiang garrison system was closely related to defense efficiency, and the deployment of troops was the core factor affecting the defense efficiency of the garrison system. Comparing the quantitative values of the defense area with the invasion frequency, the average strength value is positively correlated with the land area and coastline length of the defense area, which proves the overall rationality of the layout of the defense area in Zhejiang during the Ming Dynasty. However, the analysis also reveals the unreasonable layout of the defense area, such as the sizeable inland depth of the Hang-Jia-Hu, but the low average land strength, resulting in low defense efficiency.

From data collection, model construction, and information extraction to a conclusion, this method can be used in other studies of quantitative analysis of the areal layout of ancient military settlements. Future research will carry out more detailed data collection and model building for the Ming Dynasty naval defense system to provide a basis for subsequent in-depth research and heritage conservation.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40494-023-01098-w.

Additional file 1: Table S1: The location and frequency of Japanese invasion in Zhejiang during the Jiajing period of the Ming Dynasty.

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Author contributions
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Availability of data and materials
All data generated or analyzed during this study are included in this published article (and its Supplementary Information files).

Declarations

Competing interests
The authors declare no competing interests.

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