RESEARCH

Temporal and spatial distribution characteristics of the Ming Great Wall

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Abstract

The Great Wall during the Ming Dynasty (1368–1644) was the most prominent engineering volume and the most perfect military defense structure in the history of China. By combining traditional historical textual research, site surveys, and GIS database analysis, this paper reveals the Ming Great Wall's spatial and temporal distribution characteristics and the immediate causes of their formation are discussed in the nine military districts of the frontier. The results show that: (1) The general rule of the Ming Great Wall was to set up military forts, passes, piers, and other related defensive facilities before constructing the continuous wall. (2) The Great Wall spatial and temporal distribution of the phases is relatively apparent, divided into five construction phases in the Ming Dynasty (1368–1620): Hongwu to Xuande (1368–1435), unbuilt the wall; Zhengtong to Tianshun (1436–1464), the consecutive wall appeared; Chenghua to Zhengde (1465–1521), the first construction climax of the Great Wall; Jiajing period (1522–1566), the second construction climax of the Great Wall; Longqing to Wanli (1567–1620), the completion of the whole line of the Great Wall.(3)The warfare and defense posture was the immediate factor that prompted the construction of the Great Wall between the Ming Dynasty and Mongolia. This study has some reference significance for restoring the integrity and authenticity of the Ming Great Wall, and contribute to the preservation of the cultural heritage of.

Keywords The Ming Great Wall, Nine Military Districts of the Frontier, ArcGIS Database, Characteristics of Spatial and Temporal Distribution

Introduction

The Great Wall of China is an ancient military defense project with the longest cumulative construction time in the world [1].In the history of China, more than 20 vassal states and dynasties built the "Great Wall" along their frontiers to safeguard their territories. The Great Wall built during the Ming Dynasty (1368–1644) is China's most representative World Heritage Site.

The Great Wall was widely distributed along the northern borderland of ancient China in Ming Dynasty. The government of the Ming Empire (1368–1644)

constructed successively and managed a substantial defensive work on its north borderland called "Nine Military Districts of the Frontier" (九边重镇 *JiuBian Zhongzhen*) from the eastern Liaodong Town to the western Gansu Town.In the Ming Dynasty, the Great Wall was often called the "frontier wall," closely related to China's severe northern military defense situation. For the government, the frontier defense was essential. The "frontier wall" undertakes the organization of small-scale invasion, the transmission of warning information, and daily observation.

O Lattimore comprehensively discusses the origin [2], formation, and role of the Great Wall of China's frontier from the perspective of the social sciences, and proposes the term "Great Wall frontier"(the Chinese version was first published in 2008) [3]. Through field research, the scholars detailed the location of the Great Wall along the route, the general direction, and the relevant remains

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in Ming Dynasty (1988) [4]. AN Waldron have pointed out that the existing Great Wall of China is basically the Great Wall of Ming Dynasty, and the direct historical reason for its construction is considered to be the Ming Dynasty's political and military policy turn in the sixteenth century(1992) [5]. The application of remote sensing technology [6–9], UAV photogrammetry [10–12], and 3D point cloud [13–16] in architectural heritage has provided a certain degree of technical refference for the measuremente and visualization of the Great Wall heritage [17–19]. Lovell told the story of the Great Wall as she shows how China was shaped over the course of 2000 years by interactions with Central Asia and the peoples of the steppe (2007) [20]. The structure of the Great Wall at Yansui Town in 1474 is referred to as the "frontier wall age", which reveals that the Ming dynasty's system of frontier defense shifted from the construction of forts to the Great Wall (2009) [21]. Scholar A Jing generalized the historical process of the construction of the Great Wall of China through the ages (2015) [22]. The School of Architecture of Tianjin University utilizes the GIS spatial digital humanities method. The research group has spent twenty years on the integral research on the Ming Great Wall from 2003 to 2023 [23, 24].

Studies have also been conducted on some critical sections of the Ming Great Wall. Five typical study cases illustrate the spatial and temporal evolution of the wall section of Liaodong Town (1989) [25], Yansui Town, Ningxia Town, Guyuan Town, and Gansu Town (2017) [26]. Scholars Y Du et al. analyzed the architectural form (2021) [27], distribution characteristics (2017) [28] and surrounding environment (2019) [29] of the Ming Great Wall site in Qinghai Province. Scholars Y Cao et al expand a new vision of the relationship between the Ming Great Wall and military defense settlements through the fractal structur e (2018) [30]. Some researches focus on a typical section of the Ming Great Wall, studying the layout [31], spatial distribution and integration [32], and so on.

The above research results are similar to the object of this paper, and the perspective of their presentation is an essential source of guidance for the study. However, most focus on qualitative research, which is not conducive to accurately presenting objective facts and needs a more scientific nature of quantitative analysis [33]. The spatial and temporal layout characteristics of the Ming Great Wall still need to be improved.

Research aims
The formation and development of the Ming Great Wall did not happen overnight; it was a dynamic, giant project. The study uses ArcGIS Pro digital humanities spatial visualization, combined with relevant documents to quantify the construction length of the Great Wall at different stages in the Ming Dynasty and tries to explore the Great Wall's spatial and temporal distribution characteristics. Through this perspective and method, we can reduce the subjectivity of perception of the Great Wall and provide a reference for promoting the integrity and protection of the Great Wall's large-scale heritage.

Materials and methods
Study area
The Ming Great Wall is distributed in the northern regions of China, stretching along 156 counties in ten provinces (autonomous regions and municipalities) from east to west, including Liaoning, Hebei, Tianjin, Beijing, Shanxi, Inner Mongolia, Shaanxi, Ningxia, Gansu, and Qinghai. There are the Yellow River, Haihe River, Luanhe River, Huaihe River, Liao River, and other vital rivers distributed among them.

According to the results of China's Great Wall Resources Survey in 2007, The total length of the Ming Great Wall is 8,851.8 km, of which the length of artificial walls is 6,259.6 km, the length of trenches is 359.7 km, and the size of natural hazards is 2, 232.5 km [34]. The Ming Great Wall starts from Hushan Mountain in Liaoning Province, and the Hushan Great Wall is the starting point of the eastern, with the coordinates 124°30′50″E, 40°13′19″N. From Gansu Jiayuguan in the west, the Yidun Great Wall is the western endpoint with the coordinates of 98°11′57″E, 39°44′36″N. It should be indicated that the study area excludes Zhenbao Town, Chang Town, and the Wall of Qinghai, where the total length of the study is 7,894.17km (Fig. 1).

The so-called "JiuBian Zhongzhen" (九边重镇) were nine major frontier defense regions at the core of the Ming Dynasty in northern China. The resident military troops in each defense zone defined their jurisdictions based on the principle of territorial defense. The nine towns along the Great Wall were initially established as Liaodong Town, Xuanfu Town, Datong Town, and Yansui Town, followed by Ningxia Town, Gansu Town, and Jizhou Towns. Then, Shanxi Town and Shaanxi Town were added. From east to west are Liaodong Town, Jizhou Town, Xuanfu Town, Datong Town, Shanxi Town, Yansui Town, Ningxia Town, Guyuan Town and Gansu Town. Later, to strengthen the defense of the capital and the imperial tombs, the addition of Zhenbao Town and Chang Town formed eleven military towns of military defense pattern [35].

Data sources
According to the research needs, the essential databases established include: (1)The construction period of the Great Wall in the Ming Dynasty is mainly derived from official books, anthologies, local chronicles, and related
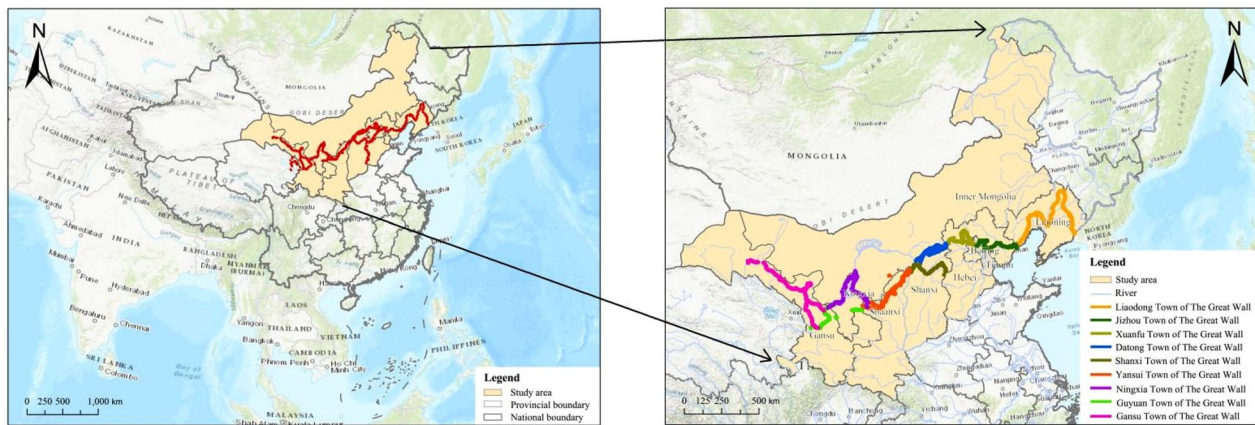
Fig.1 Study area

maps. Modern books come from the "Ming Dynasty Great Wall Resource Survey Report"issued by provinces along the Great Wall of China and related publications. (2) The spatial data of the Ming Great Wall obtained by the Key Laboratory of the Department of Culture and Tourism of Information Technology of Architectural Heritage Inheritance at Tianjin University, based on field research and a literature search. (3) A DEM (Digital Elevation Model) was obtained by a spatial data cloud platform built by the Science Data Center of the Computer Network Information Center, Chinese Academy of Sciences.

Method
Fieldwork and data practice
Compared with a single architectural heritage, the Ming Great Wall is huge in scale, meandering and complex in terrain. It is very difficult to achieve the measurement and digitization of the whole line of the Ming Great Wall. Therefore, for over two years, since 2019, we have conducted external aerial surveys of the Ming Great Wall.

More than 2 million photographs were taken using a drone for three flight paths and multi-angle views, with the overlap rate of adjacent pictures up to 70% and the average resolution at the centimeter level (Fig. 2) [23]. The image data alone is nearly 800,000 photos, allowing artificial intelligence to identify, retrieve, and compare images with a storage capacity of almost 8T. The group completed a close photographic survey of 5500 km of the artificial walls and obtained much first-hand data. For the first time, the whole line of the Great Wall was realized without blind spots and high-definition 3D digitization, establishing "the imagery and 3D database of the entire line of the Ming Great Wall" [36].

By combing the relevant materials on the basic construction of the Ming Great Wall, this paper uses ArcGIS Pro software digital humanities visualization technology to organize the construction information of the wall segments into the database [37]."Field"in ArcGIS Pro includes the construction section, construction start and end points, construction time, construction personnel, and construction length. Thus, it can realize the free access to the historical information and geographic data of the Ming Great Wall.

Positioning geographic coordinate of the Ming Great Wall
According to the relevant information collation, we divided the positioning of the starting and ending point data of the wall of the Ming Great Wall into the following four conditions:

1. Mainly from the GPS location data of the fieldwork, we determined the geographic coordinates of the starting and ending points of the Great Wall section built simultaneously and in the same military town.
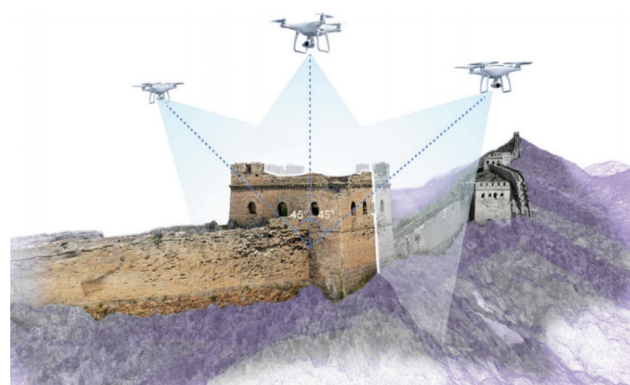

Fig.2 Schematic diagram of three drone routes for UAV photographing the Ming Great Wall

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2. Since most of the starting and ending points described are military ports (or beacon towers) along the Great Wall in the historical documents. We can combine the distance and direction between the military settlement and the Great Wall and deduce the coordinates of the starting and ending points of the Great Wall section to mark them in ArcGIS Pro. For example, the Great Wall of Shanxi Town was built from Yajiaodun to Laoniuwan in 1466 the coordinates of Yajiaodun are 111.208°E, 39.230°N, and the coordinates of Laoniuwan are 111.873°E, 39.607°N [40]. By analogy, the starting and ending points of the construction sections of the Ming Great Wall can be completely determined. We try to find different clues and historical sources to verify each other for the same Great Wall section.

3. In the relevant works (monographs, journals and conferences, dissertations, etc.) of modern scholars, some of them have examined and researched the Great Wall sections built by some military towns [25, 26].

4. If it is impossible to determine the Great Wall's exact starting and ending points, it will not be counted in the marking scope.

Spatial and temporal visualization of the Ming Great Wall

Based on the above conditions, the ArcGIS Pro calibrates the sections recorded in the historical names with modern geographical locations. The starting and ending spots of wall sections in the same period and the same military town are marked with spatial information to determine the coordinates accurately. Then, according to these coordinates, multiple distributed walls were selected and merged, thus forming a complete wall section.

It should be emphasized that the units of wall construction length recorded in historical documents need to be standardized. It is often used for "miles", "feet", "steps", and so on, and most of them are approximate ("about", "remainder", and so on).To more accurately calculate the length of the walls, the paper will be divided into the following three situations for conversion:

1. The wall segments described by the miles need to be calculated according to the number of miles in the Ming Dynasty, that is, 1 mile = 572.4 m.

2. The wall segments described by the feet need to be calculated according to the unit of measure in the Ming Dynasty, that is, 1 step = 5 feet, 1 foot = 0.319 m [38].

3. For wall segments that do not have a documented length but only a start and end point, calculate the wall length using the "Calculate Geometry" command in the property sheet of the ArcGIS Pro software. The unit is "m".(The results are shown in Table 2 to Table 4.)

By quantifying the construction length of each wall section through the above method, the specific segments constructed were inferred at successive periods during the Ming Dynasty. The error is minimized as much as possible to improve the visualization and digitization practice of the whole line of the Ming Great Wall. (Fig. 3).

Results

Based on the historical documents, the research results of the previous researchers, and "the imagery and 3D database of the entire line of the Ming Great Wall", the construction of the Great Wall was statistically determined (Table 1). The construction of the Great Wall can be divided into five phases: Hongwu to Xuande period (1368–1435), the period of no extended wall, mainly to build passes and set up fire beacon towers; Zhengtong to Tianshun (1436–1464): the presence of the Great Wall; Chenghua to Zhengde (1465–1521): the first large-scale construction; Jiajing (1522–1566): the climax of the construction; Longqing to Wanli (1567–1620): the completion of the construction of the whole line.

Hong-wu to Xuan-De in the Ming Dynasty (1368–1435)

During the period from Hong-wu to Xuan-de (1368–1435), the defensive boundary was not the continuous wall between the Ming Dynasty and the Mongolian tribes. Instead, military forts and significant passes were used to defend against the Mongolian troops, which formed a preliminary Ming Great Wall defense system from east to west along the Chinese northern frontier. A series of 453 military forts (including passes) were constructed in nine frontier military districts, constituting the general military defense path.[1] Also, the Ming Dynasty government constructed the beacon tower [39] to defend against the Mongolian army during this period. According to official historical records, more than 130 smoke piers were constructed along the Ming Great Wall. However, now there are no survivors (Fig. 4, Fig. 5).

Zhengtong to Tianshun period in Ming Dynasty (1436–1464)

Liaodong Town was the first to construct the wall, marking the beginning of the Great Wall in the Ming dynasty from 1437 to 1442 [40]. The length of construction is 869.45km, accounting for 71.34% of the whole

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1 According to the "Ming Great Wall defense system space−time database" built by the research group statistics.
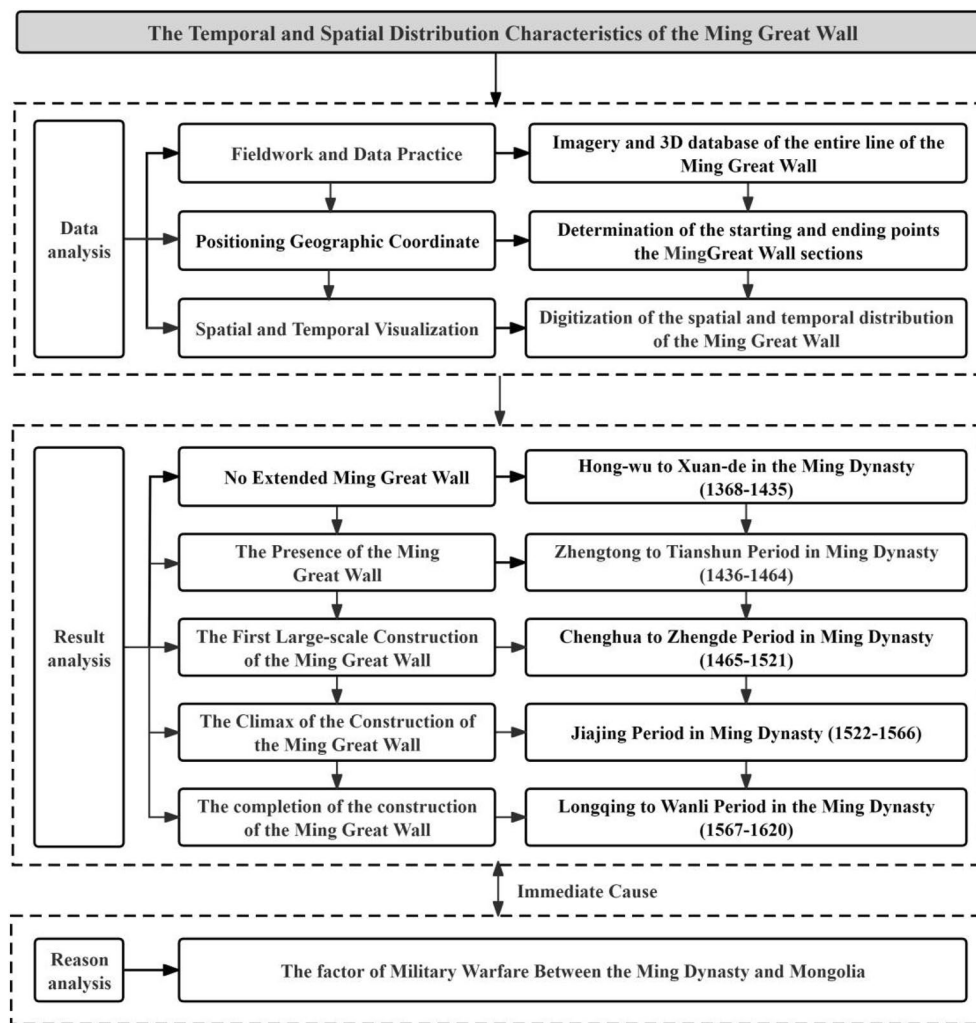
Fig.3 The logical framework

Table 1 The Ming Great Wall construction statistics (chronological)

Name	The dating of China	Calendar year/AD	Construction of wall segments	Number of repairs	Total length (km)
Liaodong town	Zhengtong 3rd–Chenghua 5th	1437–1469	4	7	1218.81
Shanxi town	Chenghua 2nd–Jiajing 23th	1466–1544	6	11	560.67
Yansui town	Chenghua 9th–Chenghua 10th	1473–1474	2	7	1105.18
Ningxiatown	Chenghua 10th–Jiajing 36th	1474–1557	9	2	793.70
Datong town	Chenghua 20th–Jiajing 25th	1484–1546	4	6	903.74
Xuanfu town	Chenghua 20th–Jiajing 28th	1484–1549	3	7	756.97
Guyuan town	Hongzhi 15th–Wanli 27th	1502–1599	6	2	478.86
Gansu town	Hongzhi 16th–Wanli 27th	1503–1599	5	2	1377.15
Jizhou town	Hongzhi 17th–Hongzhi 18th	1504–1505	2	6	699.09

wall in Liaodong Town. The project is divided into two sections. The first section from Haizhouwei (海洲卫) to Shenyang Zhongwei (沈阳中卫) was constructed in 1437.

This section is the earliest Great Wall project in the Ming Dynasty, with a length of 157.640km. The second section starts from ShanhaiGuan Pass to Kaiyuan in 1442, with a
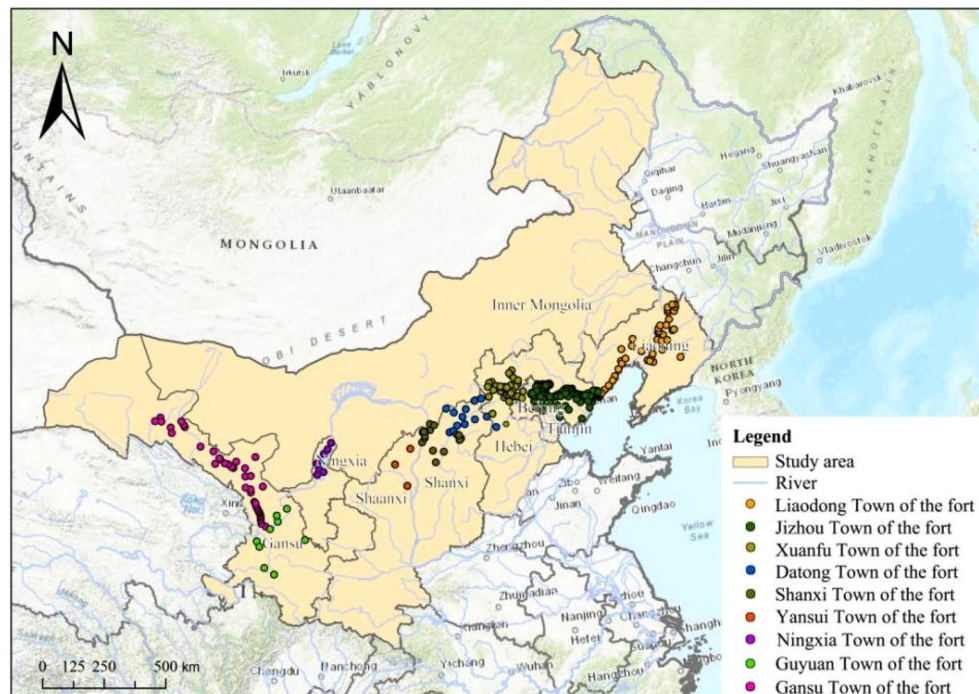
Fig. 4 Distribution of military forts in the nine military districts of the frontier in 1368–1435

length of 711.811km, connected to the wall built in 1437 (Fig. 6).

During the period from Jingtai to Tianshun period (1450–1464), due to the shorter time, coupled with the influence of the "Tumu Fort Change" (土木堡之变),[2] the Ming dynasty regime alternation was frequent. Therefore, there is no time to consider the wall's construction.

Chenghua to Zhengde period in Ming Dynasty (1465–1521)

The period from Chenghua to Zhengde (1465–1521) was the first climax of the Great Wall construction in the Ming Dynasty. Large-scale wall construction was thoroughly carried out in the nine military districts of the frontier, which extended to a length of 5,415.87 km The construction began in 1466 and ended in 1517 in Shanxi town. Among them, the walls of Liaodong Town, Jizhou Town, and Yansui Town were finished. Datong Town and Xuanfu Town had a higher degree of completion, more significant than 80% (Figs. 7, 8).

The wall of Yansui Town created in 1474, is the symbol of the first large-scale construction of the Great Wall in the Ming Dynasty, which is also the most extended extant

wall section in this period. In addition, the existing length of the wall constructed by Gansu Town in 1503 is shorter than that of Yansui Town. However, from the historical records, this wall section should be the most extended wall project built from 1466 to 1521(Table 2).

Jiajing period in Ming Dynasty (1522–1566)

The Jiajing period (1522–1565) was the second climax of the Ming Dynasty's construction of the Great Wall. The wall operation in this period should be discussed in two situations.

Firstly, the newly constructed wall mainly concentrated in Xuanfu Town, Datong Town, Shanxi Town, Ningxia Town, Guyuan Town, and Gansu Town. The total length of the construction was 1,338.94 km. It was started by Ningxia Town in 1529 and ended by Guyuan Town in 1517. Among them, the walls of Xuanfu Town, Datong Town, Shanxi Town, and Ningxia Town were finished. As a result, the Great Wall formed the most prominent and longest-spanning military defense works in the history of China throughout the dynasties (Fig. 9, Table 3).

Secondly, the renovation of existing walls is complicated. All the nine frontier military districts are involved, with a length of 3,782.95 km. It was started by Liaodong Town in 1522 and ended by Datong Town in 1558. The length of renovation was greater than 50% of the total length of the walls in Jizhou Town, Yansui Town, Shanxi Town, Datong Town, and Xuanfu Town. In particular,

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[2] "The Tumu Fort Change" refers to the events that took place on September 1, 1449 in Ming Dynasty, when the Ming army lost to the Mongol tribes at Tumu Fortress (10 km east of present-day Huailai County, Hebei Province).

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Three-dimensional point cloud model of
Jiayuguan Pass(嘉峪关)

Three-dimensional point cloud model of the current condition and
restoration of the beacon tower

Physical photograph of typical military forts along the Ming Great Wall

Fig. 5 The related military defensive facilities along the Ming Great Wall. Three-dimensional point cloud model of Jiayuguan Pass (嘉峪关). Three-dimensional point cloud model of the current condition and restoration of the beacon tower. Physical photograph of typical military forts along the Ming Great Wall

Jizhou Town is the largest, with its whole line renovated in 1551 (Fig. 10, Table 4).

Longqing to Wanli period in the Ming Dynasty (1567–1620)
The most striking feature of the Longqing period (1567–1572) was the emergence of hollow watch towers in Jizhou Town [41]. One thousand one hundred ninety-four hollow watch towers were built in Jizhou Town between 1569 and 1571(Fig. 11). However, these were only the construction of additional defenses on existing walls, not new ones.

The whole line of the Ming Great Wall was completed mainly during the Jiajing period. Therefore, from 1567 to 1620, only Guyuan Town and Gansu Town constructed the new walls, which were finished. The length of construction was 269.91 km. Guyuan Town created the Peijiachuan Great Wall about 230 "li" in 1571; the existing was 118.093km. The Ming Dynasty repaired the Songshan Great Wall under the joint management of Guyuan Town and Gansu Town, with more than 400 "Li" in total in 1599. The existing length is 151.816km.

During this period, the renovation of the existing walls was mainly concentrated in Liaodong Town, Datong Town, Yansui Town, and Gansu Town, which had a length of 2,566.80 km. The most considerable work was done in Liaodong Town, which repaired 1,050 km in 1608, accounting for 86.15% of the town's total length. Until 1644, there was no more large-scale construction of the Great Wall in the Ming Dynasty (Fig. 12, Fig. 13).

Discussion
The construction of the Great Wall during the Ming Dynasty was in a different and complex order in the "Nine Military Districts of the Frontier." There was no continuous Great Wall in the Ming Dynasty before the Zhengtong period. The Great Wall appeared in Liaodong Town in 1437, with a length of 869.45 km. Large-scale construction of the Great Wall began in 1466, and by 1521, the length of the Ming Great Wall had reached 7,242.95 km. Until 1566, the Ming Great Wall was 8,581.89 km at its peak. In 1644, the Ming Great Wall formed a complete military defense project of 8,851.8 km.
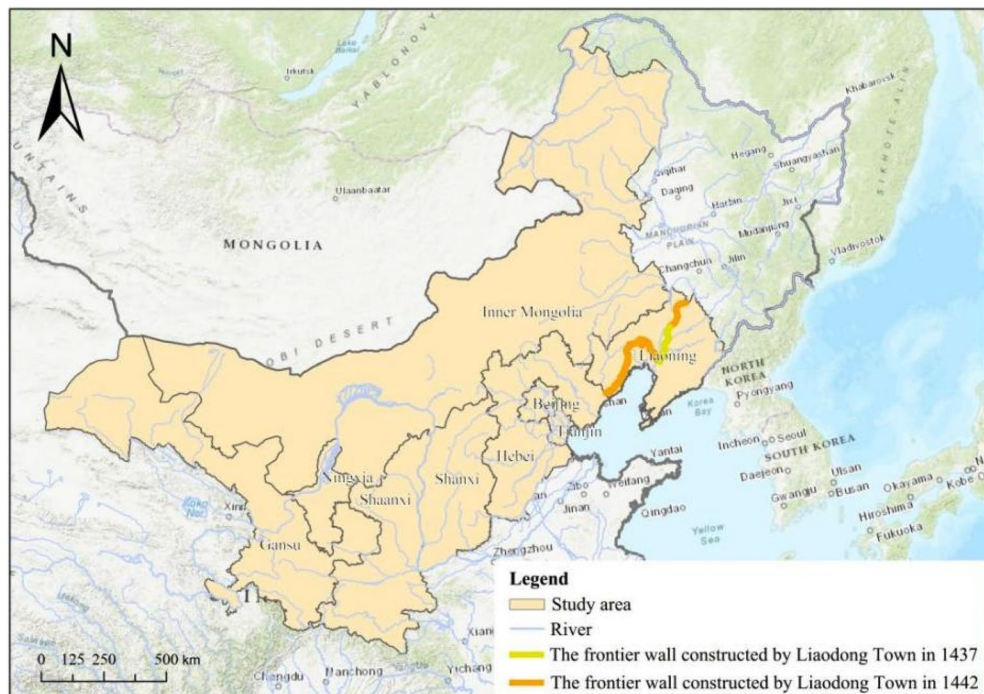
Fig. 6 Construction of the Great Wall from 1436 to 1464 in the Ming Dynasty
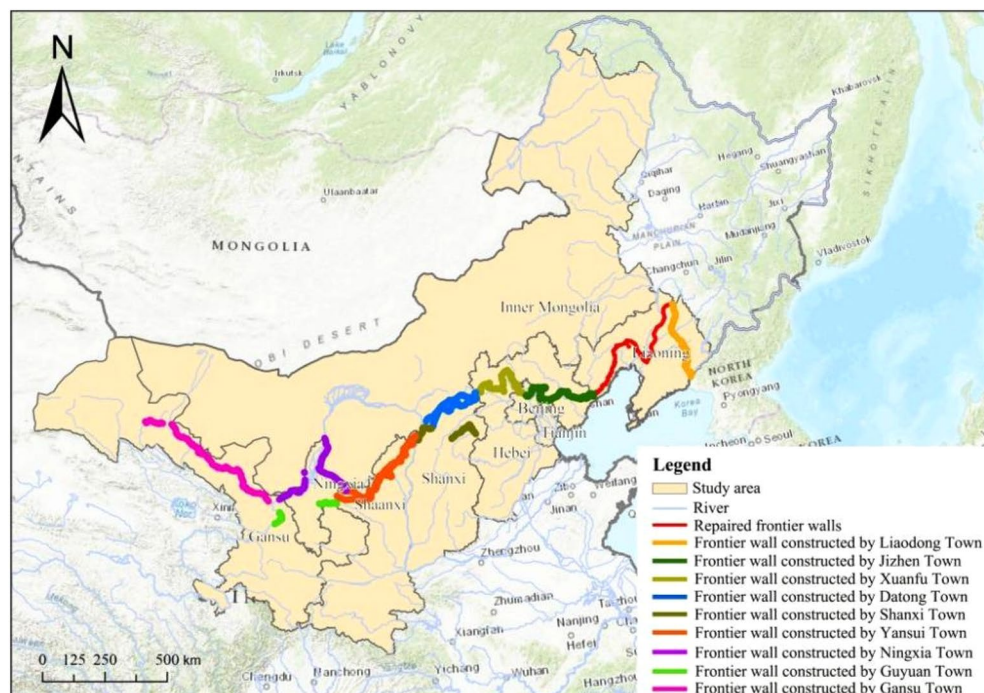

Fig. 7 The Construction of the Great Wall from 1465 to 1521 in the Ming Dynasty

Using quantitative analysis, we can conduct an in-depth study of the overall process and spatio-temporal characteristics of the Ming Great Wall, as far as possible to summarize the standard methodology for the integrity study of the Great Wall heritage instead of just staying in the qualitative analysis of historical materials [27].
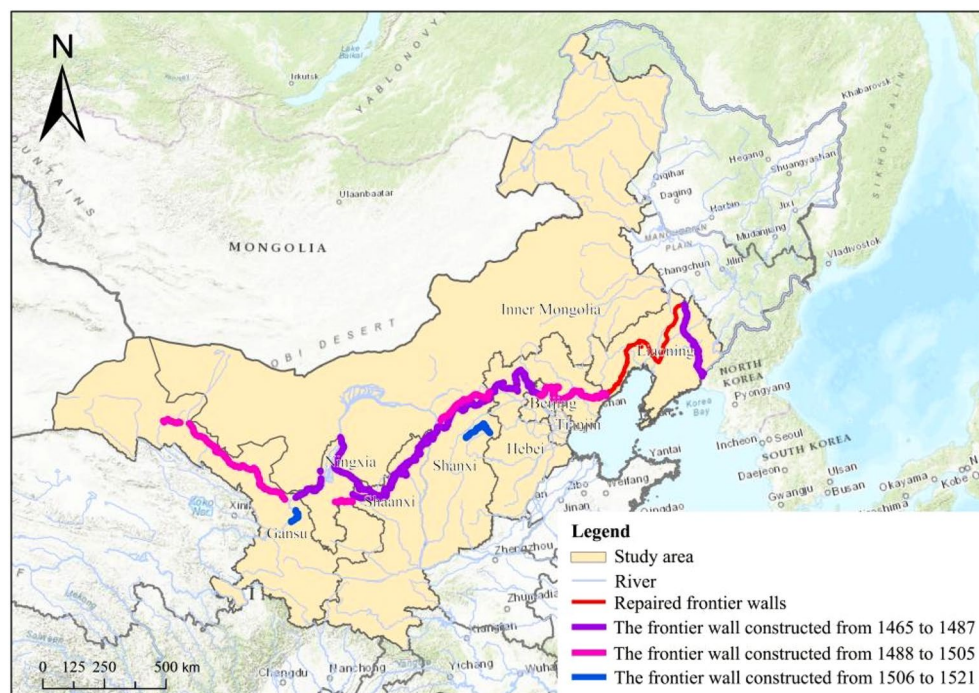
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Fig. 8 The chronological distribution of the walls constructed from 1465 to 1521 in the Ming Dynasty

Although, the data of the Great Wall in different periods of the Ming Dynasty is analyzed as a whole, there are still some points to be discussed.

Immediate cause for the construction of Great Wall in the Ming Dynasty

According to the official records and the relevant local chronicles along the Great Wall, the number of significant campaigns in nine frontier military districts was counted during the Ming Dynasty (1368–1644), which can roughly reflect the significant defense situation between the Ming Dynasty and Mongolia. The factor of military warfare was the immediate reason that urged the Ming Dynasty to construct the Great Wall (Fig. 14) [42].

The military was influential during the Hongwu period (1328–1398) when Zhu Yuanzhang (the first emperor of the Ming Dynasty) took the initiative to conquer. The Mongolian tribes had just withdrawn beyond the Great Wall and had no strength to fight against the newly founded Ming Dynasty. During the Yongle period (1403–1424), the Mongolian tribes had broken up into the Eastern Mongol (present-day south of Lake Baikal and most of Mongolia), the Western Mongol (present-day western Mongolia, and the area around the Junggar Basin), and the Wu Liangha tribe (present-day Inner Mongolia and the Liao River valley region). Five northern expeditions by Zhu Di (the third emperor of the Ming Dynasty) prompted the more powerful Eastern and Western Mongols to evade the north desert and could not respond. As a result, the number of wars during the Hongwu and Yongle periods was relatively less. Hongxi period and Xuande period rested and recuperated. There were no severe conflicts on the northern frontier,

During the Zhengtong period (1436–1449), Liaodong Town was more frequently invaded by the Wu Liang Ha tribe. Therefore, Liaodong Town was the first to have a continuous Great Wall to resist the intrusion. After the "Tumu Fort Change," the Ming Dynasty's military frontier policy changed from active aggression to passive defense. The relationship between the Ming court and the Mongolian tribe deteriorated.

Eastern Mongolia became increasingly powerful and frequently invaded the Hetao district between Chenghua and Zhengde (1465–1521). They threatened the frontier security of Datong Town, Shanxi Town, Ningxia Town, Yansui Town, and Gansu Town. There was a frequent conflict between the Ming and the Mongolia, especially during the Hongzhi period (1488–1505), which peaked at an average of more than ten fights yearly [43]. Therefore, this period formed the first climax of constructing the Great Wall to prevent the eastern Mongolian tribes in the Ming Dynasty.

Mongolian invaders seriously plagued the Ming Dynasty in the Jiajing period (1522–1566). The Eastern Mongolian tribes constantly infested the areas of Shanxi Town, Xuanfu Town, Datong Town, and Jizhou

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Table 2 Construction time of the Great Wall in 1465–1521 (chronological)

Name	The dating of China	Calendar year/AD	Starting point coordinates (X, Y)	Ending point coordinates (X, Y)	Literature records of length (km)	Existing length (km)	Total length (km)	Percentage (%)
Shanxi town	Chenghua 2th	1466	111.208°E, 39.230°N	111.873°E, 39.607°N	>137.376	155.193	374.610	66.81
	Zhengde 11th	1517	112.790°E, 39.189°N	113.944°E, 39.290°N	Not Recorded	219.417		
Liaodong town	Chenghua 5th	1469	124.3117°E, 42.857°N	124.514°E, 40.223°N	Not Recorded	349.359	349.359	28.66
Yansui town	Chenghua 10th	1474	107.2867°, 37.366°N	111.165°E, 39.341°N	1209.33	1105.18	1105.18	100
Ningxia town	Chenghua 10th	1474	106.440°E, 38.3715°N	107.707°E, 37.550°N	171.72	156.939	513.477	64.69
	Chenghua 13th	1477	105.043°E, 37.454°N	105.765°E, 38.229°N	>57.24	145.969		
	Chenghua 15th	1479	106.751°E, 39.426°N	106.448°E, 38.369°N	>105.894	133.447		
	Chenghua 23th	1484	104.608°E, 37.275°N	105.0547°E, 37.451°N	Not Recorded	77.122		
Datong town	Chenghua 23th	1487	114.152°E, 40.711°N	111.826°E, 39.628°N	>425.83	478.378	788.707	87.27
	Hongzhi 14th	1501	111.629°E, 39.874°N	114.1197°E, 40.740°N	560.952	310.329		
Xuanfu Town	Chenghua 23th	1487	114.126°E, 40.746°N	116.506°E, 40.487°N	Not Recorded	605.588	605.588	80.00
Gansu town	Hongzhi 15th	1502	101.367°E 38.581°N	104.101°E, 37.204°N	1532.89	832.588	832.588	60.46
Guyuan town	Hongzhi 15th	1502	106.447°E, 37.115°N	106.769°E, 37.164°N	572.40	74.590	147.273	30.75
	Zhengde 2st	1506	104.404°E, 36.409°N	104.615°E, 36.805°N	Not Recorded	72.683		
Jizhou town	Hongzhi 17th	1504	116.537°E, 40.454°N	119.735°E, 40.114°N	858.60	680.512	699.09	100
	Zhengde 8th	1513	119.735°E, 40.114°N	118.785°E, 40.204°N	Not Recorded	18.574		

Fig. 9 The Construction of the Great Wall from 1522 to 1566 in the Ming Dynasty

Town, and there were frequent battles. In addition, the Ming dynasty was excessively reliant on walls at this time. During the Jiajing period, they witnessed the second climax of wall construction.

After the Longqing peace, the Ming Dynasty government ended nearly two hundred years of Mongolian hostilities. The northern frontier was peaceful and stable. However, by the middle to late Wanli period, Mongolian tribes gradually occupied the Songshan Grassland area of China, which connected the Hetao, Songshan, and Qinghai regions. It is why the "Songsan Xinbian" mentioned above was constructed.Then, It should be emphasized that the rapidly rising Jurchen tribes (女真部族) plunged the Liaodong Town into crisis. Therefore, Liaodong Town renovated its 1,050 km Great Wall in 1608. Then, the Qing Dynasty invaded the ShanhaiGuan Pass (山海关) [44]. The Ming Dynasty was overthrown.

On quantifying the spatial and temporal distribution of the Ming Great Wall

Based on the ArcGIS Pro digital humanities technology, combined with the database and historical documents, the starting and ending points of the Ming Great Wall construction sections are one-to-one correspondence with the existing data to obtain accurate coordinates. More detailed quantitative data were accessed through screening, calculation, and integration. It clarifies the

essential characteristics of the spatial and temporal distribution of the Ming Great Wall, which makes up for the previous shortages of qualitative analysis. The study further demonstrates the authenticity of the Ming Great Wall heritage, providing a reference for expanding its integrity research and contributing to the development of the Great Wall National Cultural Park in China.

It should be emphasized that the document could have been more extensive and sketchy in the Ming Dynasty due to the wall's long and complex construction process. There are errors in labeling the coordinates of the start and end positions of wall segments, which can only be minimized as much as possible. Due to the large degree of destruction of the Ming Great Wall, it was impossible to quantify the precise length of the surviving wall segments. They must be converted according to historical documents using the Ming Dynasty construction units. In addition, the paper did not analyze the spatial and temporal distribution characteristics of the wall section of Zhenbao Town, Changzhen Town, and Xining Wei (西宁卫) during the Ming Dynasty. The author will add it in the future research.

With the continuous construction of military defense facilities in northern areas, the military defense system of the Great Wall was gradually improved in the Ming Dynasty. The frontier defense also relied more and more on the defensive effect of the Great Wall. The Ming imperial government's excessive reliance on the Great Wall

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Table 3 Construction time of the Great Wall in 1522–1566 (chronological)

| Name	The dating of China	Calendar year/AD	Starting point coordinates (X, Y)	Ending point coordinates (X, Y)	Literature records of length (km)	Existing length (km)	Total length (km)	Percentage (%)
Ningxia town	Jiajing 9th	1529	106.646°E, 39.210°N	106.816°E, 39.165°N	30.91	20.216	280.223	35.31
	Jiajing 10th	1531	105.798°E, 37.958°N	105.861°E 38.296°N	28.62	17.712		
	Jiajing 10th	1531	106.385°E, 39.050°N	106.569°E, 38.975°N	> 45.792	73.987		
	Jiajing 17th	1538	105.837°E 38.245°N	106.634°E 39.198°N	Not Recorded	154.65		
	Jiajing 19th	1540	105.789°E, 38.363°N	105.861°E, 38.296°N	28.042	13.658		
Gansu town	Jiajing 10th	1531	102.749°E, 38.198°N	103.837°E, 36.072°N	Not Recorded	314.565	461.062	33.48
	Jiajing 15th	1536	101.366°E, 38.581°N	102.749°E, 38.198°N	> 57.24	131.738		
	Jiajing 18th	1539	98.200°E, 39.747°N	98.202°E, 39.756°N	17.172	14.759		
Shanxi town	Jiajing 13th	1534	112.527°E, 39.073°N	112.636°E, 39.089°N	46.24	20.497	186.064	33.19
	Jiajing 19th	1540	112.123°E, 39.298°N	112.331°E, 39.102°N	73.267	73.267		
	Jiajing 23th	1544	111.874°E, 39.648°N	111.879°E, 39.591°N	12.164	12.164		
	Jiajing 23th	1544	111.874°E, 39.590°N	112.118°E, 39.2306°N	80.136	80.136		
Guyuan town	Jiajing 16th	1536	106.093°E, 37.378°N	106.450°E, 37.114°N	71.55	15.036	145.176	30.32
	Jiajing 32th	1553	103.290°E, 36.070°N	104.418°E, 36.421°N	171.72	145.176		
Datong town	Jiajing 25th	1546	112.844°E, 40.202°N	113.503°E, 40.487°N	> 74.412	115.034	115.033	12.73
Xuanfu town	Jiajing 28th	1549	115.433°E, 40.791°N	116.133°E, 40.731°N	Not Recorded	79.452	151.382	20.00
	Jiajing 28th	1549	115.507°E, 40.825°N	116.195°E, 40.800°N	Not Recorded	71.930		
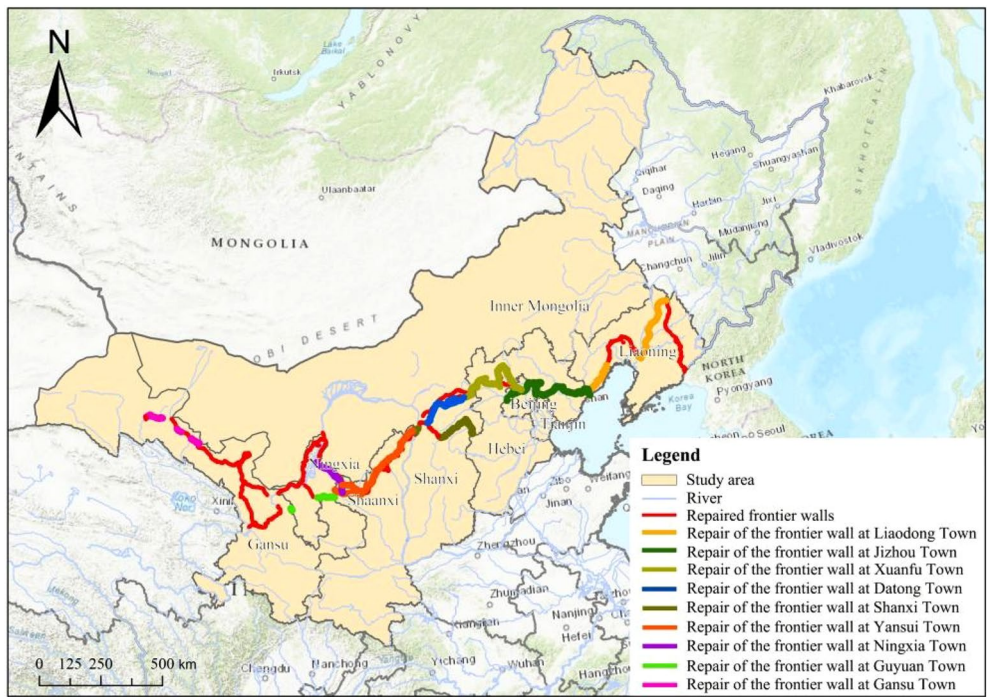
Fig. 10 The Repair of the Great Wall from 1522 to 1566 in the Ming Dynasty

military defense system contributed to a great contradiction between the economy, population, and resources. Meanwhile, it also laid the groundwork for the social turmoil at the end of the Ming Dynasty, which profoundly affected the destiny.

The establishment and visualization of "the imagery and 3D database of the entire line of the Ming Great Wall" has overcome the constraints of the vast spatial scale and considerable geographical segmentation of the remains, improved the efficiency of heritage information

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Table 4 Repair time of the Great Wall in 1522–1566 (chronological)

Name	The dating of China	Calendar year/AD	Starting point coordinates (X, Y)	Ending point coordinates (X, Y)	Literature records of length (km)	Existing length (km)	Total length (km)	Percentage (%)
Liaodong town	Jiajing 1st	1522	122.438°E, 41.065°N	124.304°E, 42.8569°N	> 286.20	319.132	517.719	42.47
	Jiajing 25th	1546	120.423°E, 40.483°N	120.817°E, 40.952°N	> 144.00	198.587		
Guyuan town	Jiajing 9th	1530	106.447°E, 37.115°N	106.769°E, 37.164°N	171.720	74.590	74.590	15.57
Shanxi town	Jiajing 11th	1532	112.646°E, 39.150°N	113.244°E, 39.397°N	Not Recorded	250.359	391.192	69.77
	Jiajing 21th	1542	113.747°E, 39.559°N	113.958°E, 39.258°N	> 80.136	140.833		
Ningxia town	Jiajing 15th	1536	106.751°E, 39.426°N	106.448°E, 38.369°N	> 105.894	133.447	133.447	16.81
Yansui town	Jiajing 15th	1536	107.287°E, 37.366°N	108.505°E, 37.191°N	> 91.584	114.739	631.442	57.13
	Jiajing 25th	1546	107.619°E, 37.536°N	111.082°E, 39.377°N	858.60	516.703		
Jizhou town	Jiajing 30th	1551	116.335°E, 40.499°N	118.785°E, 40.204°N	Not Recorded	699.086	699.086	100
Xuanfutown	Jiajing 23th	1544	114.379°E, 40.796°N	115.129°E, 40.814°N	Not Recorded	155.161	538.27	71.11
	Jiajing25th-Jiajing 27th	1546–1548	116.030°E, 40.842°N	116.335°E, 40.499°N	Not Recorded	383.109		
Datong town	Jiajing 25th	1546	111.826°E, 39.623°N	114.152°E, 40.711°N	372.06	372.06	463.644	51.3
	Jiajing 37th	1558	113.059°E, 40.368°N	113.059°E, 40.368°N	91.584	91.584		
Gansu town	Jiajing 26th	1547	99.733°E, 39.472°N	99.931°E, 39.369°N	> 34.355	158.327	158.327	11.5
	Jiajing 27th	1548	98.207°E, 39.831°N	99.001°E, 39.826°N	> 34.355			
	Jiajing 27th	1548	100.434°E, 39.154°N	100.803°E, 38.957°N	> 40.068			

Fig. 11 Three-dimensional model of the current condition and restoration of the hollow watch tower

processing and the accuracy of site observation, and accelerated heritage exploration and the formulation of scientific protection strategies.

Conclusions

In this study, based on the GIS spatial digital humanities analysis method, the immediate causes of the Ming Great Wall construction are systematically analyzed, and the essential rules of the wall construction about the Ming Dynasty are clarified. The starting and ending locations of each construction section corresponded one by one with the existing wall, which helps to strengthen the understanding of the chronological phasing of constructing the Great Wall and demonstrate the authenticity of the Great Wall's heritage.

The military war dynamic between the Ming imperial government and Mongolia was the direct reason for the construction of the Great Wall for the Ming dynasty. As a result, The formation and development of the Great Wall was a dynamic giant project, which generally experienced

Fig. 12 The Construction of the Great Wall from 1567 to 1620 in the Ming Dynasty
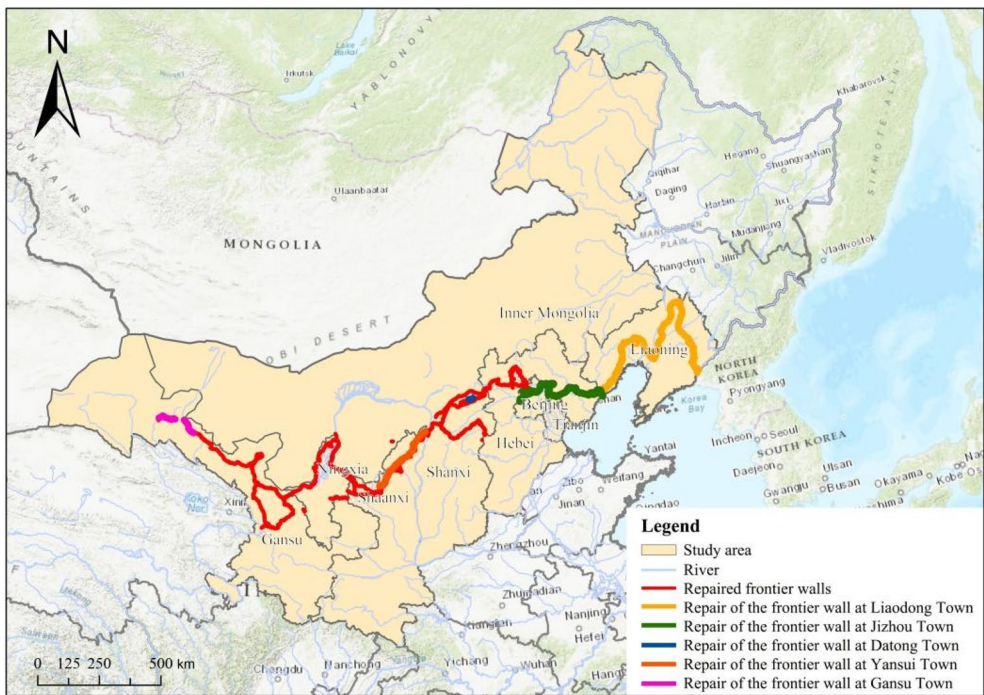

Fig. 13 The Repair of the Great Wall from 1567 to 1620 in the Ming Dynasty

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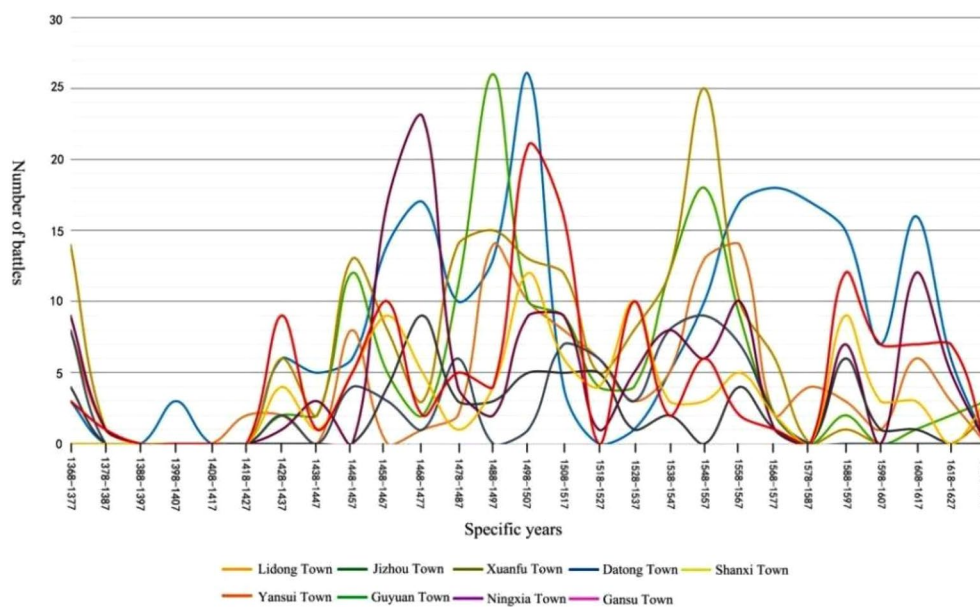
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Fig. 14 War defense situation line chart between Ming and Mongolia

the entire process of setting up military settlements and related facilities → construction of the wall → refurbishment of the wall.

Explicitly speaking, The temporal and spatial distribution of the Great Wall in the Ming Dynasty has apparent characteristics, which can be divided into five construction phases: Hongwu to Xuande (1368–1435), the period without wall when military settlements, passes, and fire beacon towers were used for defense; Zhengtong to Tianshun (1436–1464): the emergence of walls from Liaodong Town; Chenghua to Zhengde (1465–1521): the first construction climax, started by Shanxi Town in 1466. The completion of the wall in Yansui Town marked the entry of the Ming dynasty into large-scale wall construction in 1474. The rest of the towns were newly established; in the Jiajing period (1522–1566), the second construction climax, the wall was primarily connected to the line. In addition to new construction, the wall was also refurbished on a large scale and operated in nine military districts of the frontier; Longqing to Wanli (1567–1620): The entire Ming Great Wall was completed, forming 8,851.8 km of integral the wall defenses.

From historical information extraction, model construction, and data correction to a conclusion, this method can provide the basis for quantitative analyses of other linear cultural heritages. Future research will provide more detailed digital practice and reproduction of the Ming Great Wall to promote the holistic conservation and sustainable development of large-scale cultural heritage.

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