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RESEARCH ARTICLE

Analysis of spatial structure and influencing factors of the distribution of national industrial heritage sites in China based on mathematical calculations

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Abstract
An in-depth analysis of the spatial distribution characteristics and overall pattern of industrial heritage sites in China provides not only a comprehensive understanding of the current status of industrial heritage but also a reference for its protection and ongoing utilization. A total of 170 industrial heritage sites that were included in the List of National Industrial Heritage of China were selected as the research objects. Their spatial structure characteristics were quantitatively analyzed based on a kernel density analysis of ArcGIS and imbalance and Gini coefficient index of function calculations. The results show that the distribution of industrial heritage sites in China presents a strong aggregation trend and a distribution pattern of four cores, six centers, and multiple scattered points. The distribution of industrial heritage sites in 34 administrative regions is extremely imbalanced. A total of 170 industrial heritage sites are distributed across 27 administrative regions; 52.35% are concentrated in the East and Southwest divisions. According to the index definitions, this research analyzed their influencing factors from perspectives of the natural and social environments. The results show that the industrial heritage sites in China are mainly distributed in traditional agricultural and commercial areas with rich natural or water transport resources. The current study of major historical events in modern China and the growth curve of industrial heritage concludes that China's industry has experienced five stages of development: Ancient, Beginning, Accelerated Development, Climax, and Slowdown. The geographical divisions and distribution of categories show colonial and socialist characteristics.

Keywords Mathematical calculation · Industrial heritage · Influencing factor · Kernel density · List of national industrial heritage · Spatial distribution characteristics

Introduction

Industrial heritage is an important carrier of industrial culture that records important information relating to different stages of industrial development. In the most recent decade, the community has formed a broad consensus to strengthen the protection and utilization of industrial heritage. Each country has unique industrial heritage characteristics. In China, the variety in and complex preservation status of its industrial heritage has caused several old industrial facilities to shutter and move away as industrial transformation has accelerated, and several issued industrial heritage sites are facing the risk of being lost (Berta et al. 2018, Li et al. 2018). In April 2006, the first paper on the protection of China's industrial heritage by the state administration of cultural relics in Wuxi was published, which marked the beginning of the government-sponsored protection of industrial heritage sites (Niu et al. 2018). However, compared with traditional western industrial countries, China started its industrial heritage protection initiative very late (Zhang et al. 2020). As such, there are still gaps in the research. In the reuse process, the lack of comprehension of the core value of industrial heritage presents the risk of causing secondary damage or even causing it to disappear (Joseph 2019, Yang 2017). These problems highlight the seriousness and urgency of

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strengthening the protection of industrial heritage sites in China. As an important and necessary part of the disciplinary research on the statistical analysis of industrial heritage sites in China, scholars have mainly focused on those inscribed in the World Heritage List issued by the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Yang & Li 2019, Zhang 2017, Zhuang et al. 2019). In addition, although scholars have studied the spatial distribution characteristics of industrial heritage sites in China, all studies are based on the lists of industrial heritage protection sites issued by social institutions (Li Jiang-min and Chai 2019, Yongqi 2020). The List of National Industrial Heritage of China was issued by the Ministry of Industry and Information Technology of China in 2017 (MIIT 2017). At present, China follows a centralized system, and the resources and power of all aspects of society are highly concentrated in the hands of the central government (Tian 2016), including in the fields of urban construction and cultural protection. To date, a few provinces and cities have formulated protection lists for industrial heritage resources within their jurisdiction (Yang et al. 2019). However, compared with other types of protection, this initiative has extraordinary significance for industrial heritage protection in China as it creates a national inventory of China's socialist industrial heritage and indicates that the protection of industrial heritage has entered a new stage (XING et al. 2007). Compared with previous lists, the National List is far more comprehensive in terms of the number, categories, construction time, and covered regions of industrial heritage sites. To date, it is the most authoritative list for the study of China's industrial heritage. The list selects the heritage sites that have played an important role in industrial technological progress, transfer, and diffusion and reflects the great influence of technology development on historical progress and social change in China (Zhang et al. 2021c). However, at present, the academic community has not been involved in the compilation of this list, and there is no research on national resources. In particular, there is a lack of comprehensive analysis of the overall spatial distribution characteristics of industrial heritage in China from a macroperspective, and the influencing factors of its distribution also need to be further explored. Performing statistical analysis on the list issued by the central government can promote targeted protection and regeneration work that is comprehensive and authoritative.

Based on this situation, this research takes the 165 national industrial heritage projects on the list as research objects. Through quantitative analysis, this research reveals the characteristics of the spatial structure of industrial heritage sites in China to provide theoretical guidance for the management, protection, and reuse of industrial heritage sites and the development and planning of ongoing heritage protection efforts.

The paper is structured as follows. First, sections "Research aims" and "Data sources and research methods" introduce the research goals, data sources, and methods. Second, sections "Analysis of the spatial structure characteristics of industrial heritage sites in China" and "Influencing factors in the spatial distribution of industrial heritage sites in China" provide the main findings, analysis, and a description of the outcomes. Finally, sections "Results" and "Discussion" summarize and discuss the perspectives for continuing research.

Research aims

This research aims to conduct a statistical analysis of the List of National Industrial Heritage in China from a distribution of regions and establish a primitive National Industrial Heritage database in China. Then, based on this database, through kernel density estimation, imbalance index, and Gini coefficient index calculation, the industrial heritage sites on the list after screening are analyzed from two levels—the administrative region and geographical division—to obtain the spatial distribution characteristics of industrial heritage sites in China.

On this basis, from the geographical and social environments and the historical development period of industrial heritage in China using spatial distribution factors as the starting point, combined with China's modern colonial history and national characteristics of socialism, this research aims to deeply discuss the causes of the spatial distribution characteristics of industrial heritage sites in China and provide theoretical support for the protection and reuse of China's industrial heritage sites while providing a relevant reference for world heritage with colonial or socialist characteristics.

Data sources and research methods

Data sources

This research takes the List of National Industrial Heritage issued by the MIIT as its primary source. This list mainly includes the industrial production, storage, transportation, and activity sites built in China before 1990 that have distinctive industrial characteristics and industrial cultural value, a well-preserved main body, and clear property rights (MIIT 2017). As of mid-2021, 4 batches of 165 projects were issued. Some of the projects on the list were composed of a series of sites or a linear site that refers to more than one area. To ensure the scientific accuracy of the database, industrial heritage projects with more than one site or that cross municipal borders are calibrated to reflect multiple geographical locations such that cross-regional industrial heritage projects have multiple geographical coordinates. With the help of Google Earth's geographic coordinate picker, the geospatial coordinates of national industrial heritage sites were calibrated, and the data were imported into ArcGIS10.2 software. Finally, based on the original list, the final data used for statistical research were sorted into 170 sites. National industrial heritage is distributed across 170 geographical locations in China. According to the relevant registration information using ArcGIS10.2 as the technical platform, the related information for each site was linked as its attributes, and the spatial database was then established to generate the geographic distribution map of industrial heritage sites in China (Fig. 1).

Research method

This research analyzed the overall spatial distribution characteristics and pattern of industrial heritage sites in China in depth through spatial structure analysis, which is a common method in planning research (Du Plessis and Boonzaaier 2015, Kang et al. 2018, Wagner and Fortin 2005). This research took the "hotspot" analysis method, which is widely used in academic fields such as geography (Silverman 2018, Xie and Yan 2008). Kernel density estimation analysis is a common and mature hotspot analysis method; it is easy to implement and can properly reflect the attenuation effect in the spatial distribution of geographical phenomena (Borruso 2008, Sheather and Jones 1991, Tobler 1970). In traditional urban and regional analyses, kernel density estimation analysis is mainly used as a visualization tool

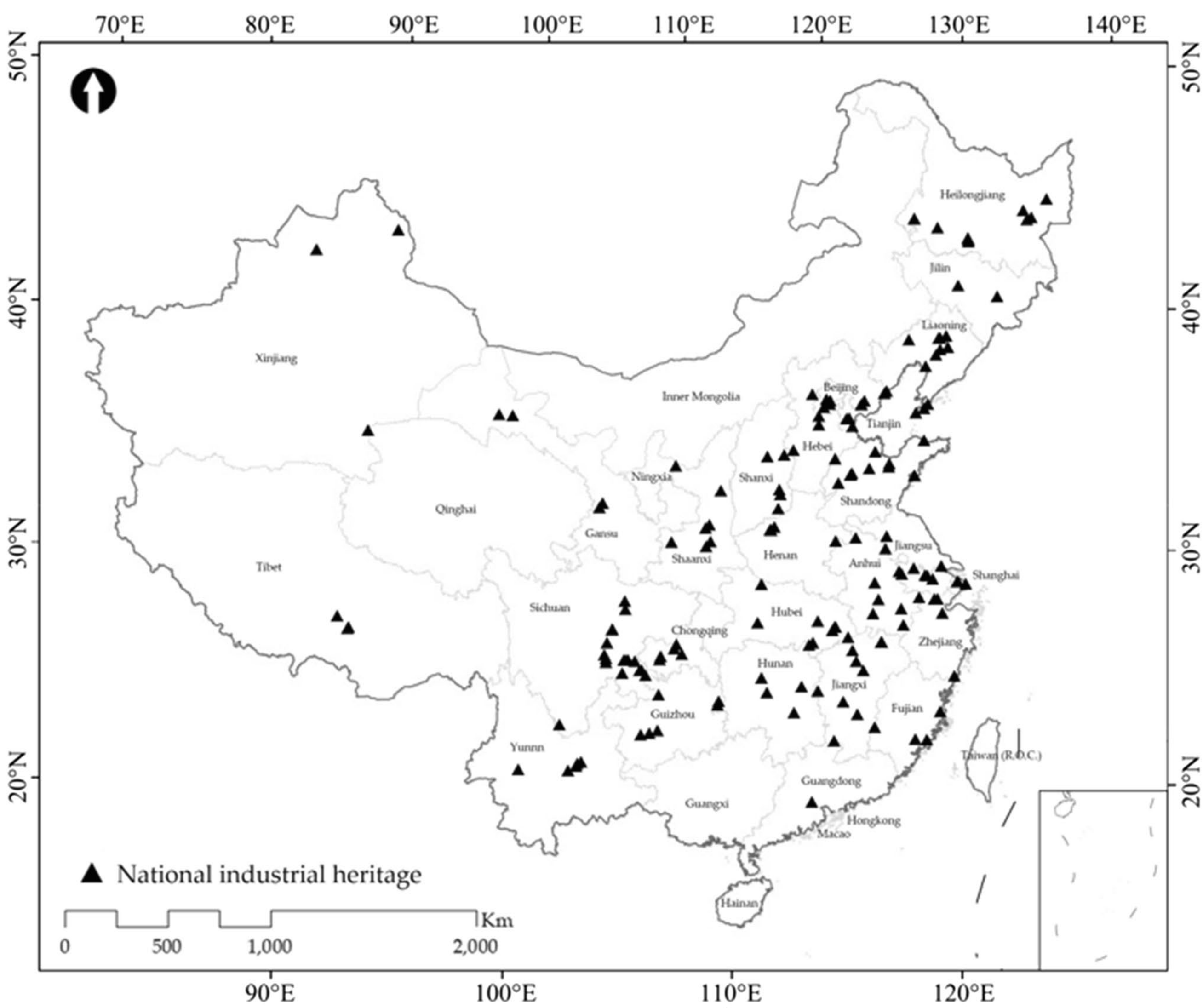


Fig. 1 Geographic distribution of industrial heritage sites in China, ©Authors

to describe the first-order basic attributes of geographical phenomenon feature distribution (Elgammal et al. 2002). Visualizing the density calculation results allows readers to simply and intuitively obtain the distribution characteristics, such as aggregation or dispersion, of the relevant groups. However, there is a lack quantitative statistical evaluation on this subject, and the calculation of the imbalance and Gini coefficient indices can compensate for this (Han et al. 2016, Wang et al. 2021). Combining the above analysis methods, this research can obtain a comprehensive and deep quantitative hotspot analysis (Zhang et al. 2021a).

Kernel density estimation

Different kernel density calculation methods can be established based on different spatial distance concepts (Wu 2004). To minimize error, this research used the nonparametric estimation model, which does not attach any assumptions to the data distribution and analyzes the distribution characteristics of the data sample itself (Han et al. 2008). Using the kernel density estimation method, this research can determine the aggregation of industrial heritage sites in China in geographical space. This method is used to evaluate the degree of spatial aggregation of industrial heritage sites at the administrative region level, and the formula (Węglarczyk 2018) is:

$$f_n(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - X_i}{h}\right) \tag{1}$$

where f_n presents the kernel density estimation value, n presents the amount of industrial heritage, k presents the kernel function, $x - X_i$ presents the distance of the estimated point x to the sample X_i, and h presents the search radius.

Imbalance index

The discrepancy in industrial heritage spatial distribution presents discrepancies in different regional industrial heritage densities. The imbalance index S is used to reflect the balanced distribution of industrial heritage sites at the administrative region level, and the formula (Li Jiang-min and Chai 2019) is:

$$S = \frac{\sum_{i=1}^{n} Y_i - 50(n+1)}{100n - 50(n+1)} \tag{2}$$

where n represents the number of administrative regions (n =34), and Y_i represents the cumulative percentage of the i th region in the total amount. Given, $0 \leq S \leq 1$, if S=0, it implies industrial heritage is evenly distributed in all regions; if S =1, it implies industrial heritage is concentrated in one of the regions; if the value of S is approaching 1, it presents a more imbalanced distribution of industrial heritage sites.

Gini coefficient

This research used the Gini coefficient in spatial structure analysis to describe the distribution of spatial elements in discrete divisions, which can judge the spatial distribution of industrial heritage sites on the geographical division level. The formula (Chen et al. 2010) is:

$$G = \frac{-\sum_{i=1}^{n} P_i \ln P_i}{\ln N} \tag{3}$$

$$C = 1 - G \tag{4}$$

where G is the Gini coefficient, P_i presents the proportion of the number of industrial heritage sites in the i th geographical division, N presents the number of partitions, and C presents the distribution uniformity. Theoretically, the Gini coefficient is between 0 and 1, and the larger the Gini coefficient is, the higher the concentration (Milanovic 1997).

Analysis of the spatial structure characteristics of industrial heritage sites in China

Overview of industrial heritage sites in China

After sorting out and statistically analyzing the list, it is found that the sites are distributed in a scattered and concentrated manner in 27 administrative regions (Table 1).

Using the category system of the European Route of Industrial Heritage for reference (Douet 2013), combined with the actual situation in China, industrial heritage was divided into 10 categories with 27 subcategories. In this category system, industrial heritage sites in China mainly involve production and manufacturing with the subcategories of food, drink, agriculture, and tobacco (Fig. 2).

China is a typical agricultural country (Liu 2018) and as an agricultural civilization dominated by a small-scale peasant economy for a long time, the huge population's demand for food has led to a variety of advanced farming methods and food ctypes. However, the spread of modern industry in China is restrained for various reasons. These two characteristics are reflected in the stock of industrial heritage categories. The heritage sites dominated by the agricultural handicraft industry have an absolute advantage, while the large machinery industry has a relative advantage.

In terms of quantity and variety, industrial heritage sites in China are relatively rich. However, from the perspective of regional distribution, due to different resource endowments and development conditions, there are great

Table 1 Statistics on the regional distribution of industrial heritage sites in China

No	Administrative region	Amount	Proportion/%	Cumulative proportion/%
1	Sichuan	17	10.00	10.00
2	Shandong	12	7.06	17.06
3	Jiangxi	11	6.48	23.54
4	Heilongjiang	11	6.48	30.02
5	Liaoning	10	5.89	35.91
6	Anhui	10	5.89	41.80
7	Hebei	9	5.30	47.10
8	Jiangsu	9	5.30	52.40
9	Shanxi	8	4.72	57.12
10	Hubei	8	4.72	61.84
11	Beijing	7	4.12	65.96
12	Guizhou	6	3.52	69.48
13	Shaanxi	6	3.52	73.00
14	Chongqing	5	2.94	75.94
15	Hunan	5	2.94	78.88
16	Yunnan	5	2.94	81.84
17	Zhejiang	4	2.35	84.17
18	Henan	4	2.35	86.52
19	Gansu	4	2.35	88.87
20	Fujian	4	2.35	91.22
21	Tianjin	3	1.76	92.98
22	Shanghai	3	1.76	94.74
23	Tibet	3	1.76	96.50
24	Xinjiang	2	1.17	97.67
25	Jilin	2	1.17	98.84
26	Guangdong	1	0.58	99.42
27	Qinghai	1	0.58	100.00
28	Ningxia	0	0.00	100.00
29	Guangxi	0	0.00	100.00
30	Inner Mongolia	0	0.00	100.00
31	Hainan	0	0.00	100.00
32	Hongkong	0	0.00	100.00
33	Macao	0	0.00	100.00
34	Taiwan (the Republic of China)	Not available	0.00	100.00

differences in the distribution of industrial heritage categories among regions (Fig. 3).

China is a unified multiethnic country. In ancient times, most of the territory was limited to the Central Plains and the South, and the population was mostly concentrated in these areas (Hao 2020). The concentrated population represents the traces of production and life (e.g., Sichuan, Shandong, Jiangxi). Therefore, there are many industrial heritage relics in these areas, especially in the agricultural and food industries. Taking grain planting as the center of a diversified economy is the leading form of China's traditional agricultural production. However, the Northern Grassland has been occupied by nomadic nationalities for many years (e.g., Xinjiang, Ningxia, Inner Mongolia) (Zhang et al. 2007); the land is vast and sparsely populated, and the nomadic economy is dominant, so there are few industrial relics in these areas.

Spatial distribution pattern of industrial heritage sites in China

The imbalance of industrial heritage distribution shows that industrial heritage has unique spatial distribution characteristics, and the kernel density estimation can break the administrative region boundary limit, thus providing an application method for exploring the spatial aggregated area. The kernel density analysis tool in ArcGIS10.2 is developed according to the calculation model of Formula (1). According to the natural breakpoint classification method in ArcGIS10.2

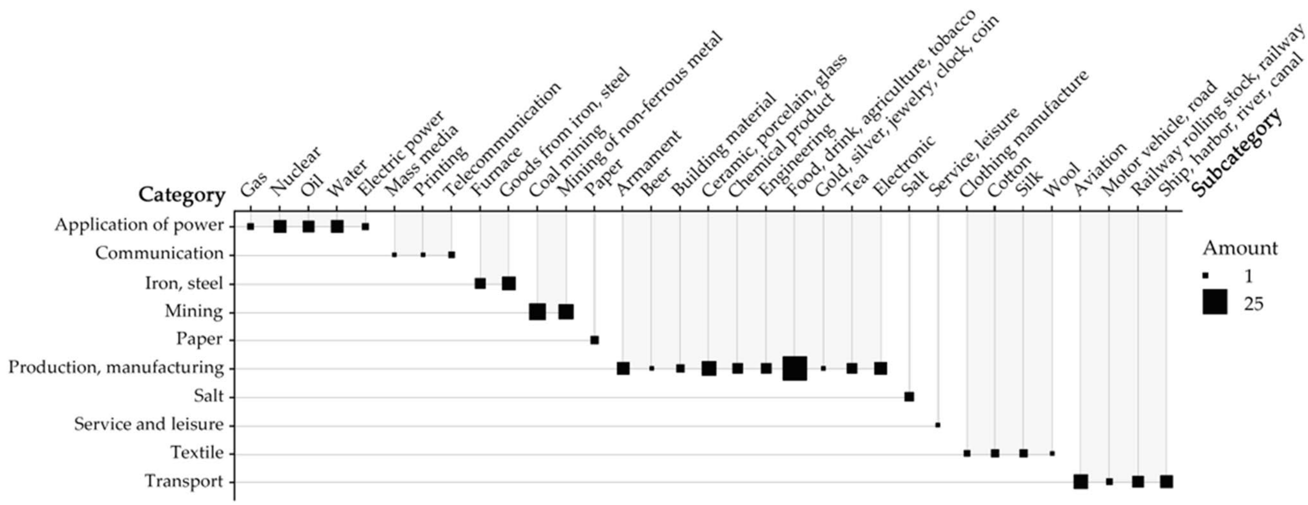
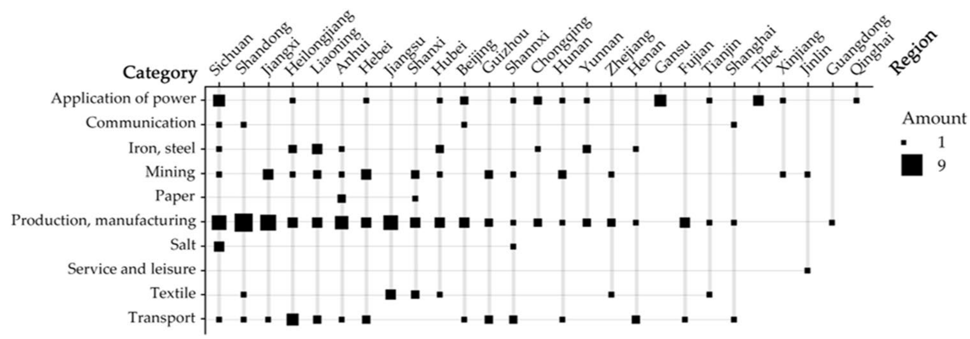


Fig. 2 Classification and distribution of industrial heritage sites in China, ©Authors

Fig. 3 Regional distribution of industrial heritage sites in China classification, ©Authors



(Table 2), the calculated density value can be divided into four levels: core density, high density, medium density, and low density. Finally, the spatial kernel density distribution of industrial heritage sites in China can be generated (Fig. 4). Figure 4 shows that industrial heritage sites in China are unevenly distributed and have obvious aggregation.

Its distribution has an obvious aggregation trend showing a distribution pattern of "Four Cores, Six Centers, and Multiple Scattered Points:"

"Four Cores" refers to the four core density regions, with Sichuan (17) as the core and radiating to Chongqing (5) and Guizhou (6); Jiangsu (9) as the core and radiating to Shanghai (3) and Zhejiang (4); and Beijing (7) as the core and radiating to Tianjin (3) and Hebei (9). The remaining Liaoning (10) core is a single-core area. The kernel density index of the core density was greater than 1.05.

"Six Centers" refers to six high-density core regions, with Jiangxi (11) as the center and radiating to Anhui (10) and Hubei (4); Shanxi (8) as the center and radiating to Henan (4) and Shaanxi (8); Heilongjiang (11) as the center and radiating to Jilin (2); and the remaining Shandong (12); Yunnan (5) and Tibet (3) center are the three single-center areas. The kernel density index of the high-density area is in the range of 0.17 to 1.79.

"Multiple Scattered Points" refers to six scattered points—Hunan (4), Fujian (4), Qinghai (1), Gansu (4), Xinjiang (1), and Guangdong (1)—which are distributed throughout the rest of China. The kernel density index of the medium density and low density is in the range of 0.17 to 1.04.

Spatial distribution discrepancies of industrial heritage sites in China

According to Formula 2, after calculating and analyzing the data in Table 1, the imbalance index S=0.486558 further indicates the imbalance in the spatial distribution of industrial heritage sites in China.

Combined with the Lorenz curve (Fig. 5) of industrial heritage sites in China distributed in different administrative regions (Fig. 1), the sum number of industrial heritage sites in Sichuan, Shandong, Jiangxi, Heilongjiang, Liaoning, Anhui, Hubei, and Jiangsu provinces alone reached 52.35% of the total. A total of 170 industrial heritage sites

Table 2 Kernel density analysis of industrial heritage sites in China

Density classification	Administrative region	Amount	Kernel density zone
Core-density	*Sichuan	17	1.80–3.21
	Chongqing	5	1.05–1.79
	Guizhou	6	1.05–1.79
	*Jiangsu	9	1.80–3.21
	Shanghai	3	1.80–3.21
	Zhejiang	4	1.05–1.79
	*Beijing	7	1.80–3.21
	*Tianjin	3	1.80–3.21
	Hebei	9	1.05–1.79
	*Liaoning	10	1.80–3.21
High-density	*Jiangxi	11	1.05–1.79
	Anhui	10	1.05–1.79
	Hubei	9	1.05–1.79
	*Shanxi	8	1.05–1.79
	Henan	4	1.05–1.79
	Shaanxi	8	1.05–1.79
	*Heilongjiang	11	1.05–1.79
	Jilin	2	0.17–0.52
	*Shandong	12	1.05–1.79
	*Yunnan	5	1.05–1.79
	*Tibet	3	0.53–1.04
Medium-density	Hunan	4	0.53–1.04
	Fujian	4	0.53–1.04
	Qinghai	1	0.17–0.52
	Gansu	4	0.53–1.04
Low-density	Xinjiang	2	0.17–0.52
	Guangdong	1	0.17–0.52

*Represents the core of the zone

are distributed in 27 administrative regions, which account for 79.41% of administrative regions.

Spatial distribution cluster of industrial heritage sites in China

In this research, the 34 administrative regions in China were generally divided into 7 geographical divisions: East, Southwest, North, Northeast, Central, Northwest, and South (Table 3) according to their geographical, economic, and cultural similarities and differences.

This research analyzed the Gini coefficient of the spatial distribution of industrial heritage sites in 7 geographical divisions to judge the degree of distribution uniformity at the geographical division level. Through Formulas (3) and (4), G=0.879, and the distribution uniformity C=0.121. The results show that the distribution of industrial heritage sites in 7 geographical divisions is highly concentrated, and the distribution uniformity is very low.

Specifically, the spatial distribution of industrial heritage sites in 7 geographical divisions is quite different. The distribution proportion in the East and Southwest divisions alone reached 52.35% of the total. There is a difference of 52 sites between the East division, which has the most industrial heritage sites, and the South division, which has the least industrial heritage sites.

Influencing factors in the spatial distribution of industrial heritage sites in China

Industrial heritage is essentially a historical legacy of the process of human social development. To analyze the influencing factors of the spatial distribution of industrial heritage sites in China and the factors behind their construction, this research collated and counted the spatiotemporal statistics of the geographical division and category distribution of the listed industrial heritage sites in China (Fig. 6). It is noteworthy that China began the Self-Strengthening Movement in 1840, which was the first large-scale movement in modern China to imitate and learn from Western industrialization, thus marking China's entrance to the era of

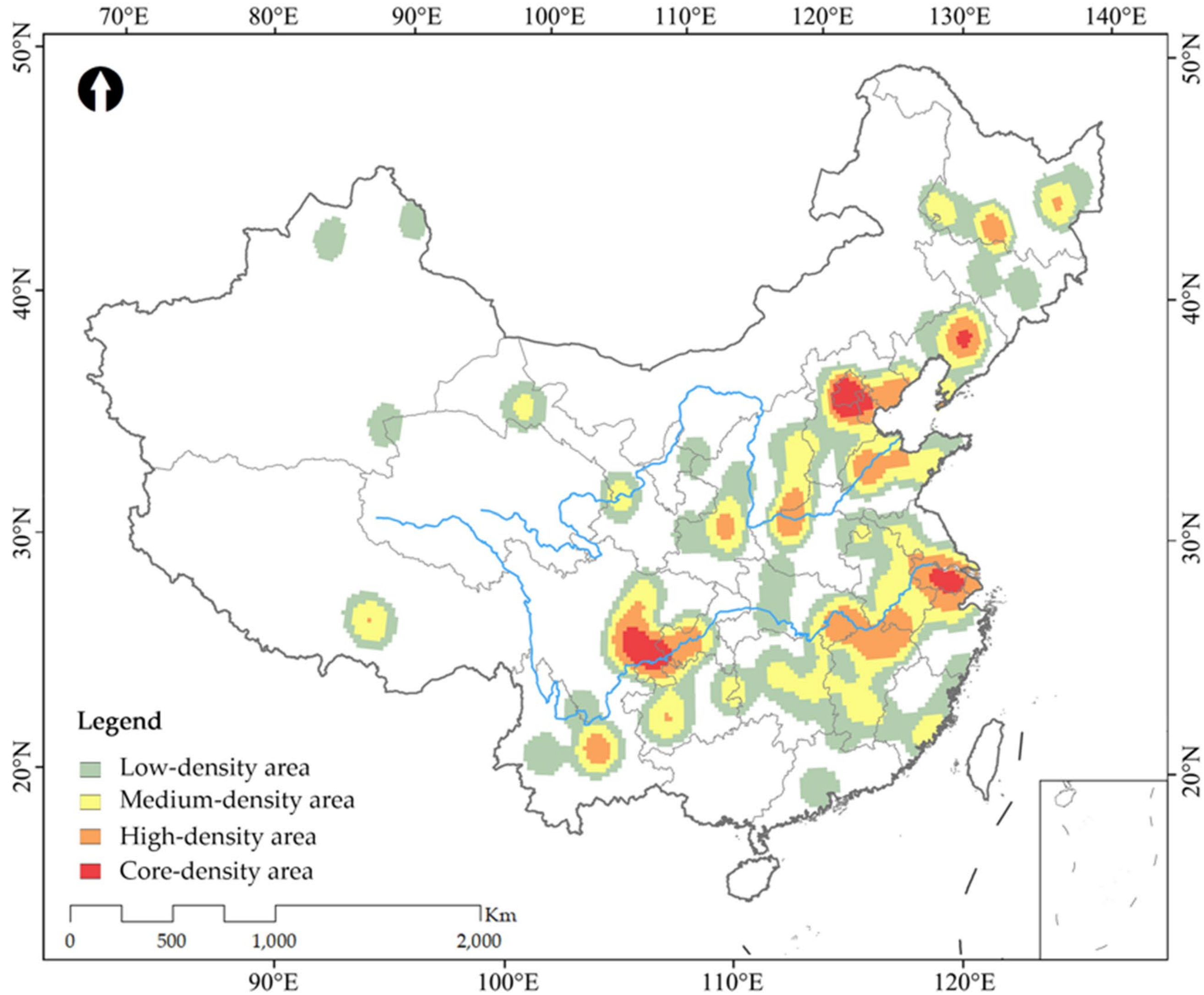


Fig. 4 Spatial kernel density distribution of industrial heritage sites in China, ©Authors

industrialization (Wright 1998). Therefore, in this research, the industrial heritage sites that were founded before 1840 are classified as ancient industrial heritage sites.

According to the statistical analysis of the information provided in Fig. 6, this research summarized the influencing factors of geographical division and category distribution change rules of industrial heritage sites in China as the geographical environment, social environment, and historical development period.

Influencing factors of the geographical environment

The territory areas of the 7 geographical divisions (from large to small) are as follows: Northwest (320 million km^2), Southwest (234 million km^2), North (218 million km^2), Northeast (145 million km^2), East (83 million km^2), Central (56 million km^2), South (45 million km^2) (website 2021). However, the numbers of industrial heritage sites (from large to small) are as follows: East (53), Southwest (36), North (27), Northeast (23), Central (17), Northwest (13), South (1).

The main reasons of the above incoordination for geographic factors are as follows.

China has a vast territory with a rich variety of climate types and landform conditions. The East division, which has the most industrial heritage sites, is located in the estuary area of the middle and lower reaches of the Yangtze River, with abundant seaports and river ports (Chen et al. 2020, Veenstra and Notteboom 2011). It is rich in water transport resources and is located in the alluvial plain area of the estuary, with gentle terrain (Wu and Tan 2012). Meanwhile, the subtropical monsoon climate zone, with suitable temperature and abundant precipitation, is suitable for human habitation and production.

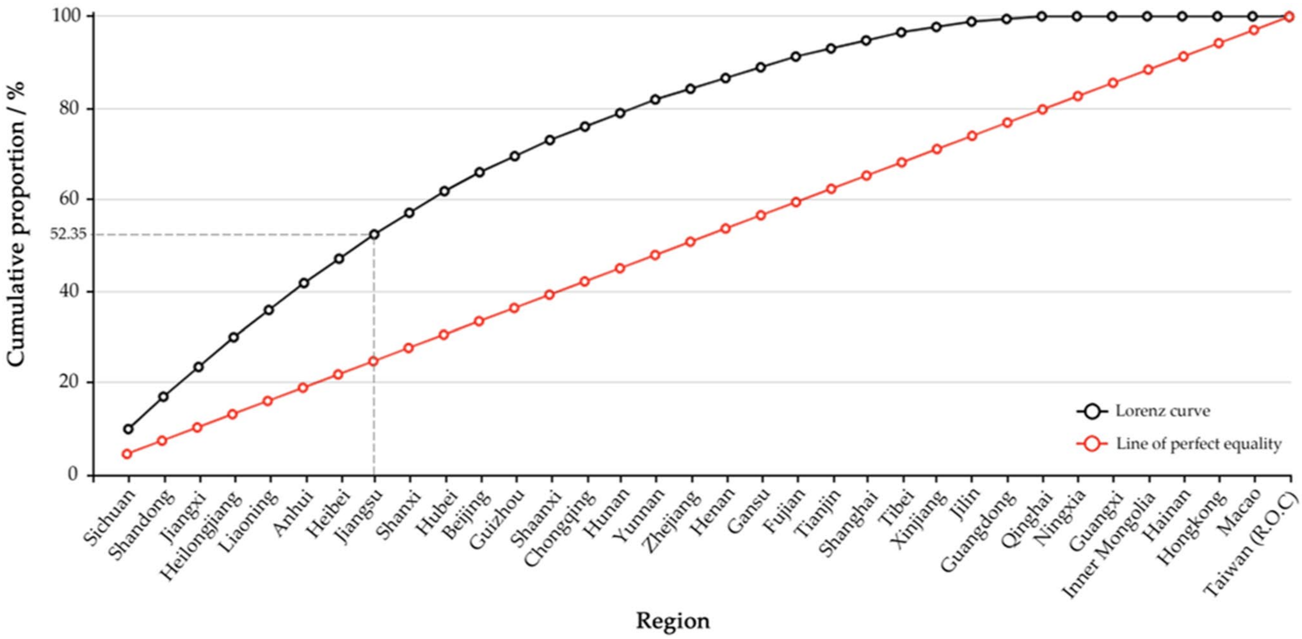


Fig. 5 The Lorentz curve of the spatial distribution of industrial heritage sites in China, ©Authors

The industrial heritage sites of the Southwest division are mainly concentrated in the Sichuan Basin, which is rich in coal, natural gas, and other fossil energy, as well as minerals such as salt, apatite, and sulfur (Caineng et al. 2011, Zou et al. 2016). The marginal mountain area is the base of various economic timber forests in the Sichuan Basin (Bramall 1995). The cultivated land at the bottom of the basin is contiguous, and it is the largest rice- and rapeseed-producing area in China. Since ancient times, the Sichuan Basin has been the most densely populated, convenient, and economically developed area in the Southwest division (Sun et al. 2018).

In the Northwest division, which has the largest territory area in China, the number of industrial heritage sites is very limited because the natural environment of the Northwest division is uninhabitable and characterized by drought and minimal precipitation, vast land, and sparse population (Wang and Qin 2017). The impact of human activities is limited; therefore, the area of industrial culture transmission is limited as well. Second, the level of economic development in the Northwest division is relatively backward, and the driving force of industrial development is weak.

Through an analysis of the influencing factors of the geographical environment, it is found that the differences in natural geographical conditions such as climate, topography, and landform and the regional differences of urban, transportation, and economic conditions will inevitably affect the layout of industrial heritage sites, and the areas with superior resources and environment have become the key areas of industrial development. As a result, the distribution areas with medium density and above are almost uniformly distributed in areas with developed water transport resources, such as the Yangtze River, the Yellow River basin, or coastal areas.

Influencing factors of the social environment

The category distribution of industrial heritage sites in China is closely related to regional socioeconomic development throughout its history. First, regions with a long history of development and a developed economy have more mature consumer markets and manufacturing processes (Dillon 1976). Their industries are mainly concentrated on beer, salt, food, textiles, etc. Most of the industrial heritage sites that provide residents with means of living and consumption are concentrated in the densely populated eastern coastal regions in the East division and the Sichuan Basin in the Southwest division. As a country with a large population, it needs to consume much energy and means of living in the process of production and life. Therefore, mining, application of power, production, and transport industries have been growing at a high speed for a long time, accounting for a relatively high proportion of the new constructions.

From the perspective of the social environment, we found that the distribution of many typical historic craft workshops that have experienced modern industrialization shows intensive and group distribution and strong regional characteristics. According to the local conditions, eating habits and natural resources in different regions, many regions have characteristic industries that are often clustered in particular

Table 3 Statistics of the distribution of industrial heritage sites in 7 geographical divisions in China

No.	Administrative division	Amount	Proportion/%	Cumulative proportion/%	Representative site
1	East (Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Shandong, Fujian, Taiwan (R.O.C.)	53	31.18	31.18	 Shimao deep pit hotel, Shanghai, ©Barcroft images
2	Southwest (Chongqing, Sichuan, Guizhou, Yunnan, Tibet)	36	21.17	52.35	 Dongwo hydropower station, Luzhou, ©Sichuan online
No.	Administrative division	Amount	Proportion/%	Cumulative proportion/%	Representative site
3	North (Beijing, Tianjin, Shanxi, Hebei, Inner Mongolia)	27	15.88	68.23	 Capital steel works, Beijing, ©Southern metropolis daily
4	Northeast (Heilongjiang, Jilin, Liaoning)	23	13.53	81.76	 China industrial museum, Shenyang, ©Song WANG
5	Central (Henan, Hubei, Hunan)	17	10.00	91.76	 Hanyang arsenal, Wuhan, ©Bao XIAO
6	Northwest (Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang)	13	7.65	99.41	 Jiuquan satellite launch base, Jiuquan, ©ifeng.com
7	South (Guangdong, Guangxi, Hainan, Hong Kong, Macao)	1	0.59	100.00	 Yingde tea factory, Yingde, ©soho.com

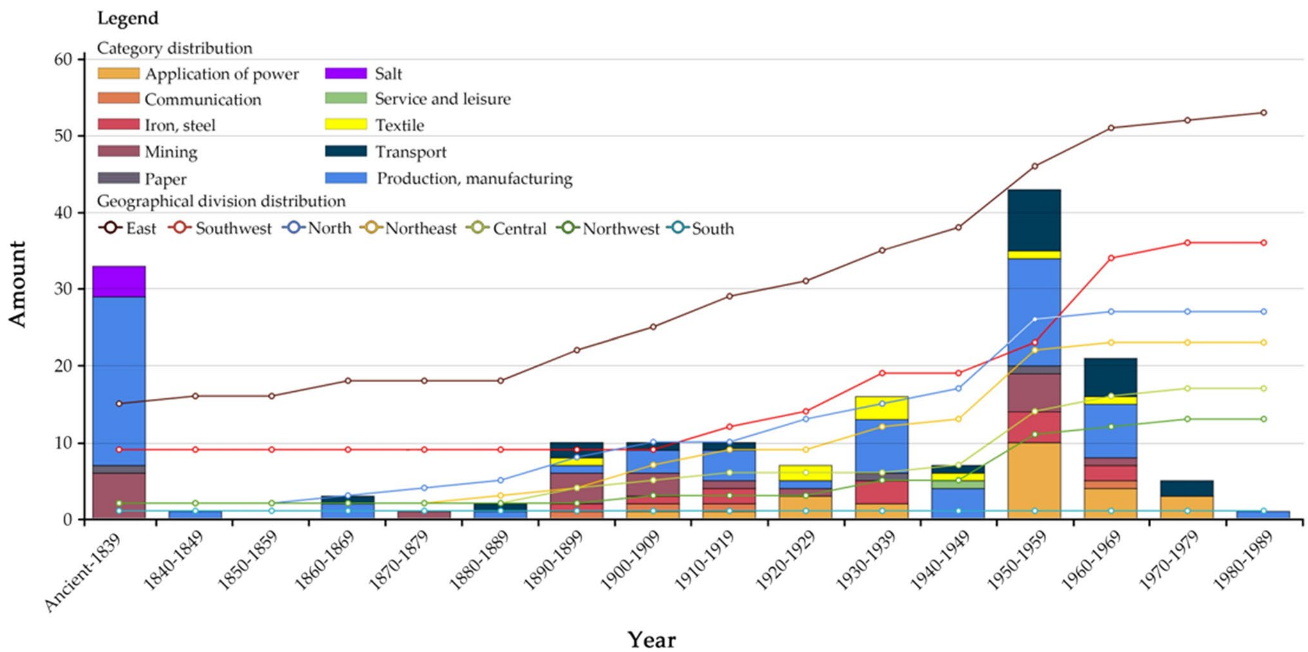


Fig. 6 Spatiotemporal statistical chart of geographical division and category distribution of industrial heritage sites in China, ©Authors

geographical locations. For example, Zigong City, Sichuan, has produced salt for more than 1000 years and been nicknamed the "salt capital" since ancient times (Bowen 1980); three such heritage sites have been recorded on the list. In addition, the Jingdezhen porcelain industry in Jiangxi Province has become an independent source of handicraft porcelain production and has created the most brilliant Chinese ceramics over the past thousand years. The Jingdezhen porcelain industry has set up a unique handicraft production system (Yanyi 1987). Its achievements, influence, exquisite skills, and variety are unmatched by any kiln in any other era. There are four ceramic factory sites in Jingdezhen alone that have been recorded on the list.

Historical development period

The industry development route in China shows that it has experienced five periods from its birth to its current development (Fig. 7): Ancient (0–1839), Beginning (1840–1930), Accelerated development (1931–1948), Climax (1949–1963), and Slowdown (1964–1989).

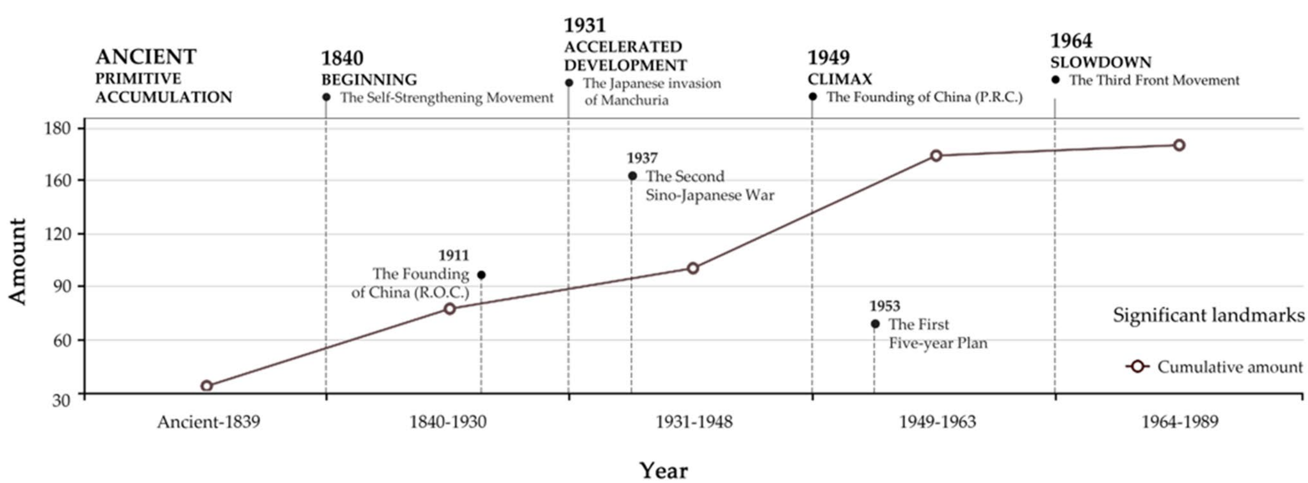


Fig. 7 Industrial heritage sites in China: developmental periods and historical landmarks, ©Authors

Ancient (0–1839)

In a broad sense, historical sites related to human production activities are industrial heritage sites (Zhang et al. 2021b). Therefore, the industrial heritage sites on the list can be traced back to the mill, mine, porcelain factory, and other historical sites from 200 BC. In this research, the industrial heritage sites built before 1839 are collectively referred to as comprising the primitive accumulation period. Most of the industrial heritage sites left during this period are located in traditional populations and agricultural provinces, such as Sichuan and Shandong.

Beginning (1840–1930)

In 1840, the First Opium War was a series of military engagements between Britain and the Qing Dynasty (Mao 2016). After this war, advanced industrial machinery production from the West rapidly poured into China, which forced Chinese officials to make contact with the world and start to establish a modern military and its civil industry. At that time, most of the enterprises were located in Shanghai, Hubei, and other regions with well-developed waterway transportation resources, and they gradually radiated to inland regions. In 1911, the Revolution broke out, ending China's last imperial dynasty—the Manchu-led Qing Dynasty—resulting in the establishment of China (R.O.C.) (Yu 1991), after which national industry has developed rapidly. In the process of modern industrial development, industrial categories changed from export processing to import substitution and were gradually enriched, but were always dominated by light industry. The process of industrial development was affected by the comprehensive effects of natural, social, and economic factors, and early natural resources, policies, and systems played a significant role. With the construction of ports and railways, changes in the transportation system stimulated and promoted the transformation of the industrial paradigm.

With the rapid development of the industrial era and the progress made in science and technology, several industries emerged and were upgraded; thus, the industrial heritage site categories began to become multisource and the spatial distribution of industry began to take shape.

Accelerated development (1931–1948)

In 1931, Japan began to invade the Northeast Division of China and set up a colony, which objectively promoted the accumulation of industrial bases in the Northeast Division of China (Wilson 2003). During this period, the number and quality of industrial enterprises increased, which also increased the overall distribution of industrial heritage sites in China (Min 1992). During that time, the industry in China was still mainly serviced by colonial suzerain. Meanwhile, foreign forces still held important ports and resources in China. These objectively aggravated the imbalance in industrial distribution, which led to the regional aggregation of industrial heritage sites.

The Japanese War of Aggression Against China broke out in 1937, which completely interrupted China's industrial development (Guo 2015). To preserve industrial power and provide war materials, China formed the most large-scale and typical industrial space transfer movement in its modern history. A large number of industrial enterprises went from the eastern coastal areas to the western inland areas and metallurgical industry was built to support the war, which promoted the modernization of heavy industry in the West division. In the process of its development, China's modern industry has always served the domestic and foreign markets at the same time, which has changed in response to the domestic and foreign markets. After the outbreak of the Sino-Japanese War, war factors became the leading factors affecting industrial development and its layout.

Climax (1949–1963)

In 1949, under the leadership of the communist party of China, the People's Republic of China (P.R.C.) was established. As a socialist country, its industry has the characteristics of a planned economy, and the industrial layout is completely controlled by the party central committee (Andrews and Andrews 1994). At the same time, to compete with Western capitalist countries, China has made great efforts to develop its heavy industry and military industry, and it has made breakthrough progress in nuclear technology, rocket technology, etc., which have also formed socialist industrial heritage sites. Meanwhile, the distribution of industrial heritage sites in most regions of the country has been established. At the same time, Chinese people's cognition of *industry* has gradually changed, and the role of the concept has become prominent. Based on early development, large cities have further aggregated the capital, labor, technology, raw materials, transportation, market, power, communication, and other infrastructure required for industrial development. As such, the business environment is relatively stable, the attraction to the industry is enhanced, urban industrial development is significant, and the region is expanding (Liu 2021).

Slowdown (1964–1989)

In 1964, the Third Front Movement was engineered, which was a large-scale construction of the national defense, science and technology, industrial, electric power, and transportation infrastructure carried out by the government of China to prepare for war (Naughton 1988). The third front region is a military geographical concept, including 13 provinces and autonomous regions in the Central and West of China. Its core areas are in the Northwest and Southwest divisions. Its background is in response to the escalation of the Vietnam War and the US military offensive on the southeast coast of China, as well as the vicious relationship between China and the Soviet Union, the small-scale armed conflict between the two countries, and the crisis of all-out war (Fan and Zou 2015). During this period, to avoid the impact of war on the new industrial enterprises, the location of these enterprises is relatively scattered in space, and most of them are located in the remote mountainous areas of the Central and West divisions. This also explains why there are a large number of industrial heritage sites in the remote areas of the West division, which expands the spatial distribution of China's industrial heritage sites.

Results

This research performed a statistical analysis of 170 industrial heritage sites on the List of National Industrial Heritage of China and discussed the spatial structure characteristics from three aspects: kernel density analysis, spatial distribution difference, and aggregation region analysis (Table 4). The following results are drawn:

1. At present, 170 industrial heritage sites are distributed in 27 regions of China, and the distribution of each region is imbalanced. There is a large gap in the number of heritages between the province with the largest number of heritage sites and the province with the smallest number of heritage sites, which reaches 52.
2. From the perspective of the 7 geographical divisions, industrial heritage sites in China are highly concentrated and unevenly distributed. The proportion of industrial heritage sites in the East division and Southwest divisions alone has reached 52.35% of the total.
3. The distribution of industrial heritage sites in China has an obvious gathering trend, which shows a distribution pattern of four cores, six centers, and multiple scattered points.

Table 4 The spatial indices of industrial heritage sites in China based on function calculation

No	Function	Index
1	Kernel density estimation	0.17–3.21
2	Imbalance	0.486558
3	Gini coefficient	G=0.879, C=0.121

To explore the influencing factors behind these characteristics, this research mainly analyzed the following aspects:

1. From the perspective of the natural environment, the main reason is that the macroscale distribution of industrial heritage sites in China is affected by the geographical environment, which is mainly concentrated in the regions with rich geomorphic types and mineral resources, suitable climate, and favorable water transport conditions (i.e., near rivers or sea entrances), such as the East division, which has the largest number of industrial heritage sites at the geographic division level.
2. From the perspective of the social environment, as a traditional agricultural country, China has a huge population base. As its primary industry is agriculture, its industrial heritage related to this industry is considerable in number and in densely populated areas, and the developed regions throughout history have often had a rich industrial heritage, such as Sichuan, which has the largest amount of industrial heritage sites at the regional level.
3. From the perspective of the historical development period, the industrial enterprises set up by the capital of the great powers in the late Qing Dynasty objectively opened the curtain of China's modern industry, and the industrial layout of this period had colonial characteristics. To ensure the development of its national industry, China's industrial spatial pattern was transferred to the Central and Southwest divisions after Japan launched the War of Aggression, which affected the pattern of the industrialization process of the Central and Southwest divisions. On the other hand, the socialist construction in the early days of the founding of China (P.R.C.), as well as geopolitical factors, has objectively enriched and expanded the distribution of industrial heritage sites in China, and the industrial layout of this period had socialist characteristics. The list promotes the release of cultural documents, which show that industrial heritage in China has gradually attracted the attention of the government and society.

Discussion

In recent years, the number of industrial heritage entries on the list has increased significantly, which is closely related to the deepening recognition of the value of protecting industrial heritage in China. At present, registered heritage is very unbalanced in terms of spatial structure and type. It is necessary to comprehensively consider the balance, credibility, and representativeness of the criteria to make the heritage sites on the list balanced and diversified. Using the international mainstream experience as a reference, the protection, management, and redevelopment of industrial heritage in China still face several challenges. In the future, scholars can carry out research from the following aspects:

1. When sorting out the list, it is found that although certain industrial heritage sites are included that are still in an idle state, the MIIT should continue to improve the relevant regulations to avoid the phenomenon by which local governments apply for heritage status but do not effectively protect and manage the sites.
2. Scholars can further study the influence of microfactors such as industrial change, division of production, and mode of operation on the spatial distribution of industrial heritage.
3. With the slowdown of industrial construction and urban development in China, the postindustrial era is coming. A large number of industrial facilities will be transformed, upgraded, or eliminated. China has a vast territory and many kinds of industrial heritage sites. There are regional differences in the distribution, industrial categories, formation characteristics, and methods of protection and utilization of industrial heritage sites. Therefore, one of the future research directions is to propose different classifications for protection and reuse methods for each region.
4. Given the continuous publication of lists and the improvement of sample data, the results can be further optimized. Based on the achievements of the present study, follow-up research will have a more comprehensive understanding of the industrial heritage sites in China from the aspects of plant construction time, industry category, and distribution area.

Conclusions

The results show that the spatial distribution of industrial heritage in China is agglomerative and uneven. From the administrative region view, it is mainly distributed in provinces with rich natural resources, dense populations, and developed water transportation resources, such as Sichuan and Jiangxi. From the geographical view, the southwestern Sichuan Basin, Yangtze River Delta region, Beijing Capital Circle, and Northeast China formed the four core-density accumulation areas. These distribution characteristics are mainly caused by the historical process of colonization and socialist industrial construction of modern China.

For the first time, this research not only discussed the current distribution characteristics of industrial heritage sites in China from the perspective of space but also considered internal differentiation from the perspective of industrial categories and excavated the colonial and socialist characteristics. It also comprehensively analyzed the causes of the distribution in different developmental periods and geographical regions from the natural and social environmental influencing factors and historically significant landmark events, which are of great significance scientifically understanding and mastering the geographical spatial distribution of industrial heritage sites in China and have certain reference value for their protection and utilization.

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Data availability Authors do not have the right to share the data. However, it will be made available to the reader upon reasonable request.

Declarations

Ethical approval All authors affirm that objectivity and transparency in research have been ensured and accepted principles of ethical and professional conduct have been followed.

Consent All authors agree with the content and have given their explicit consent to submit the paper.

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