An analysis of the Spatial Evolution and Influencing Factors of Rural Settlements along the Shandong Section of the Grand Canal of China

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Keywords:	rural settlements, spatial evolution, impact factors, quantitative methods, Shandong section of the Grand Canal

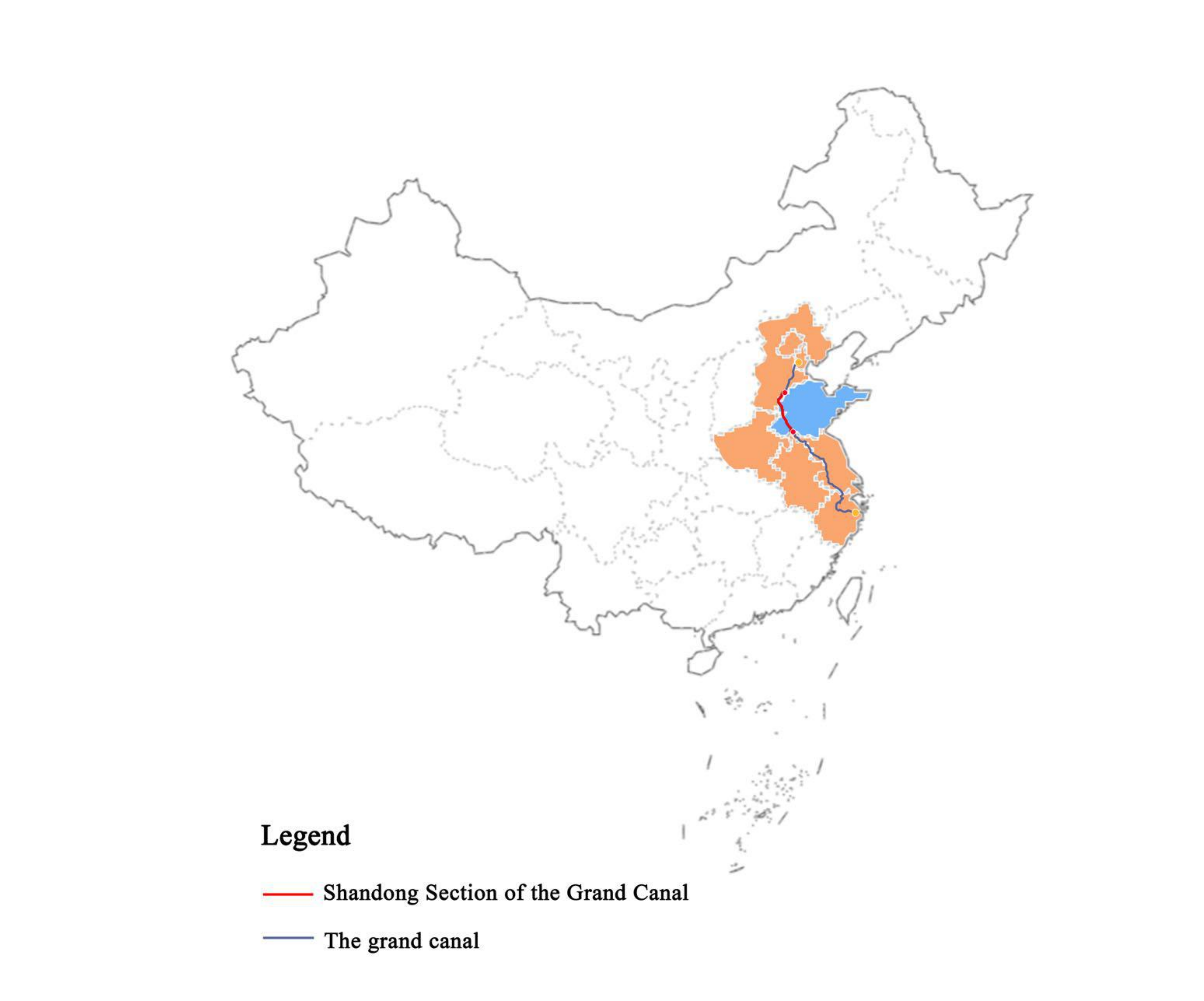


Figure 1-a The location of the Grand Canal in China and Shandong Province

Figure 1-b Schematic diagram of each section of the Grand Canal of China

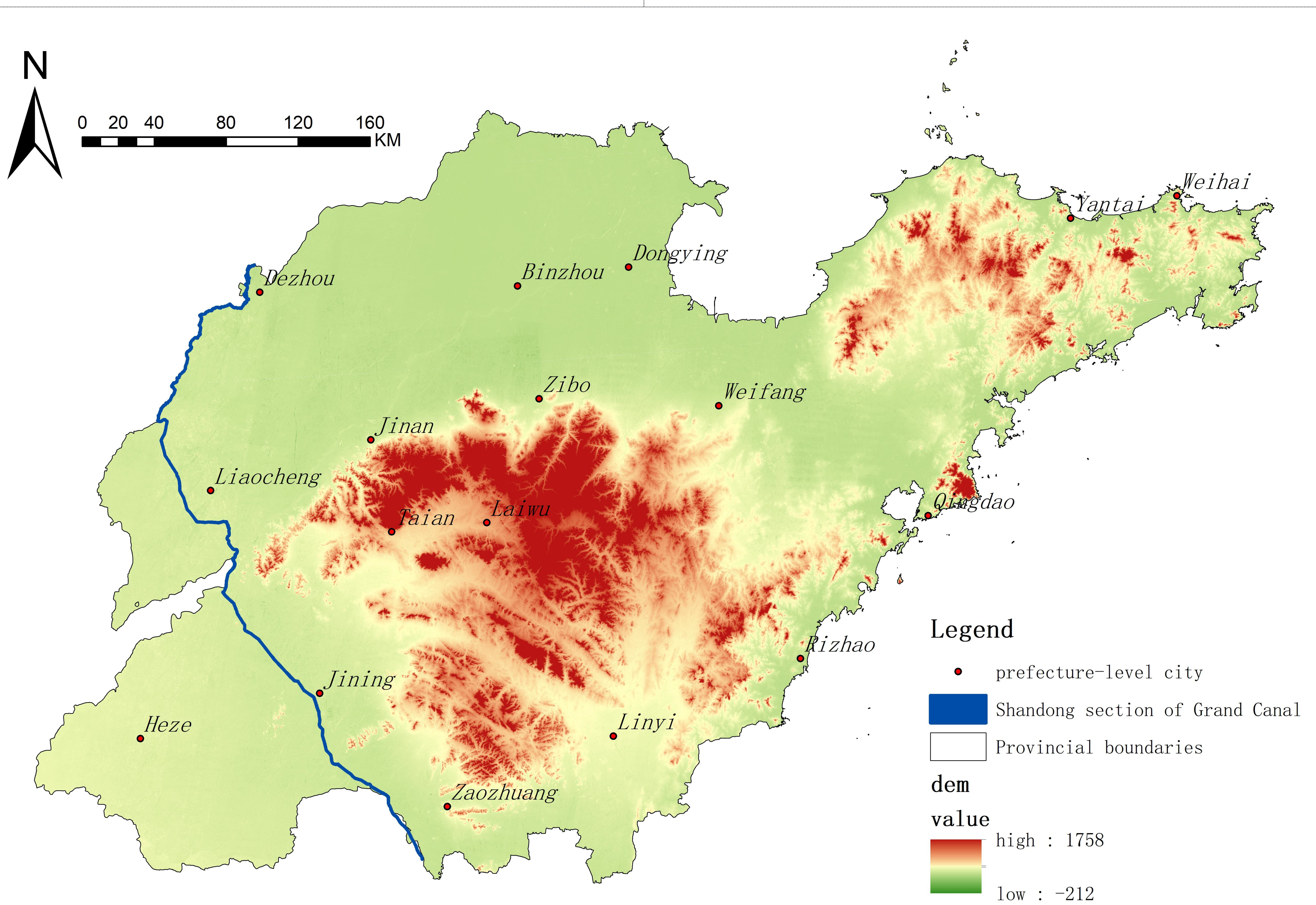


Figure 1-c Shandong section of Grand Canal

Figure 1 Location map of China Grand Canal and its Shandong section

Province	City	County	Number
Shandong A	Dezhou I	DechengQu	A- I -1
		WuchengXian	A- I -2
		XiajinXian	A- I -3
	Liaocheng II	LinqingShi	A-II-1
		RenpingXian	A-II-2
		DongchangfuQU	A-II-3
		YangguXian	A-II-4
		GuanXian	A-II-5
		DongeXian	A-II-6
	Taian III	DongpingXian	A-III-1
	Jining IV	LiangshanXian	A-IV-1
		WenshangXian	A-IV-2
		RenchengQu	A-IV-3
		JiaxiangXian	A-IV-4
		YutaiXian	A-IV-5
		WeishanXian	A-IV-6
	Zaozhuang V	TengzhouShi	A-V-1
		XuechengQu	A-V-2
		YichengQu	A-V-3
		TaierzhuangQu	A-V-4
Hebei B	Handan I	GuantaoXian	B- I -1
	Hengshui II	GuchengXian	B-II-1
	Xingtai III	QingheXian	B-II-1
		LinxiXian	B-II-2
Henan C	Puyang I	TaiqianXian	C- I -1
Jiangsu D	Xuzhou I	FengXian	D- I -1
		PeiXian	D- I -2

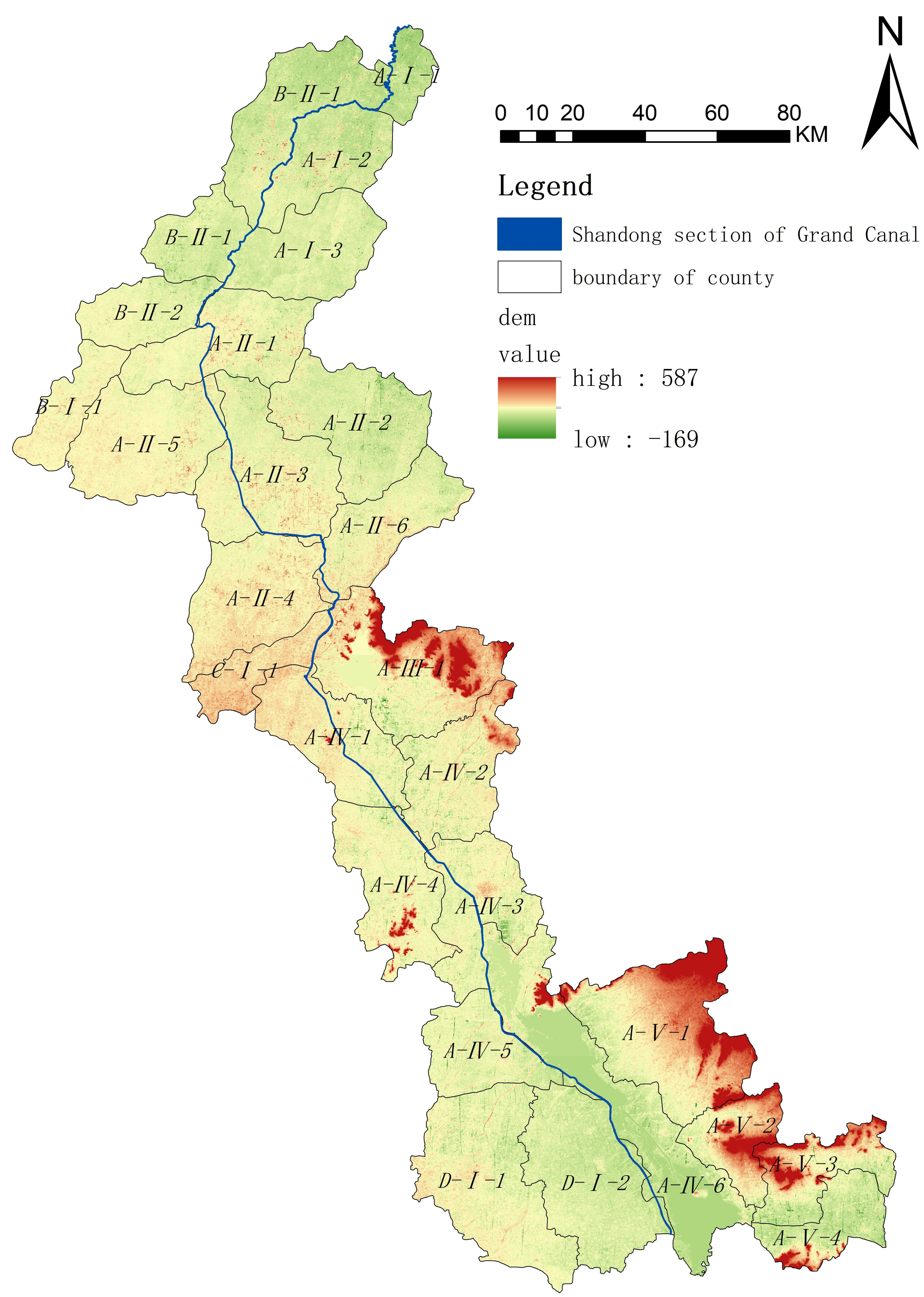


Figure 2 The Shandong section of the Grand Canal and its administrative units at all levels

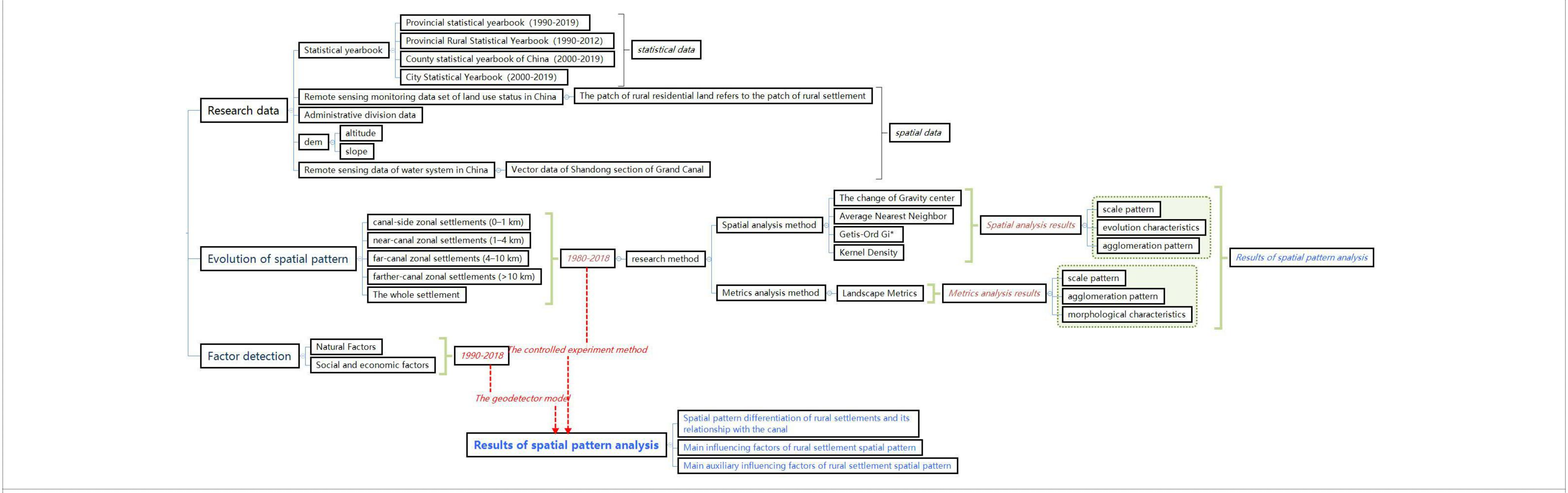


Figure 3-a Research method flow

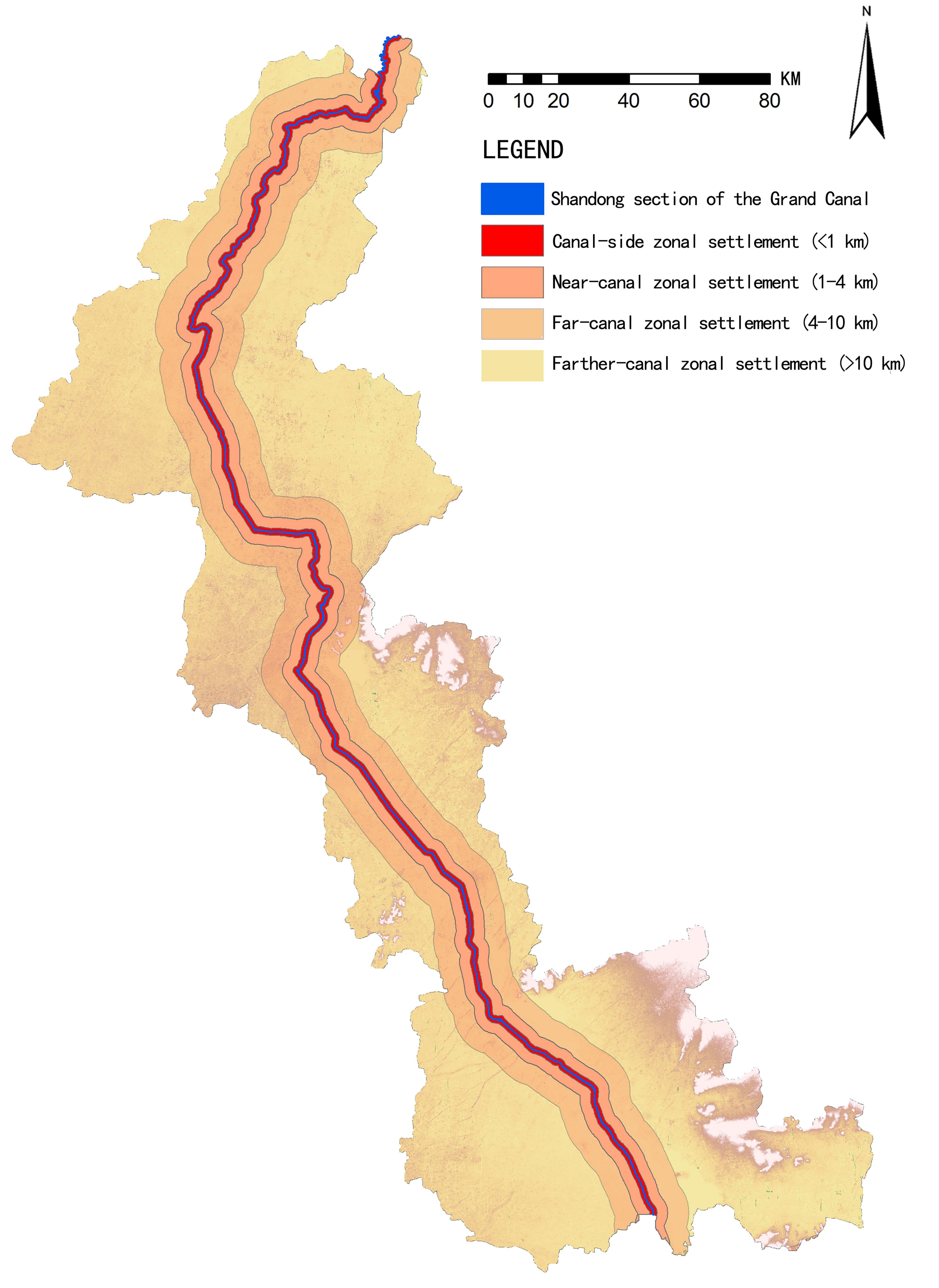


Figure 3-b Rural settlement belt along the Shandong section of the Grand Canal

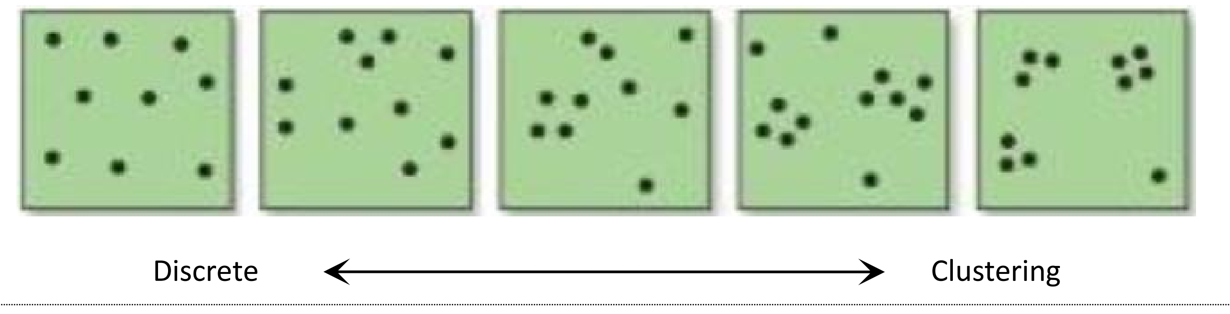


Figure 3-c Diagram of discrete clustering（From ArcMap）

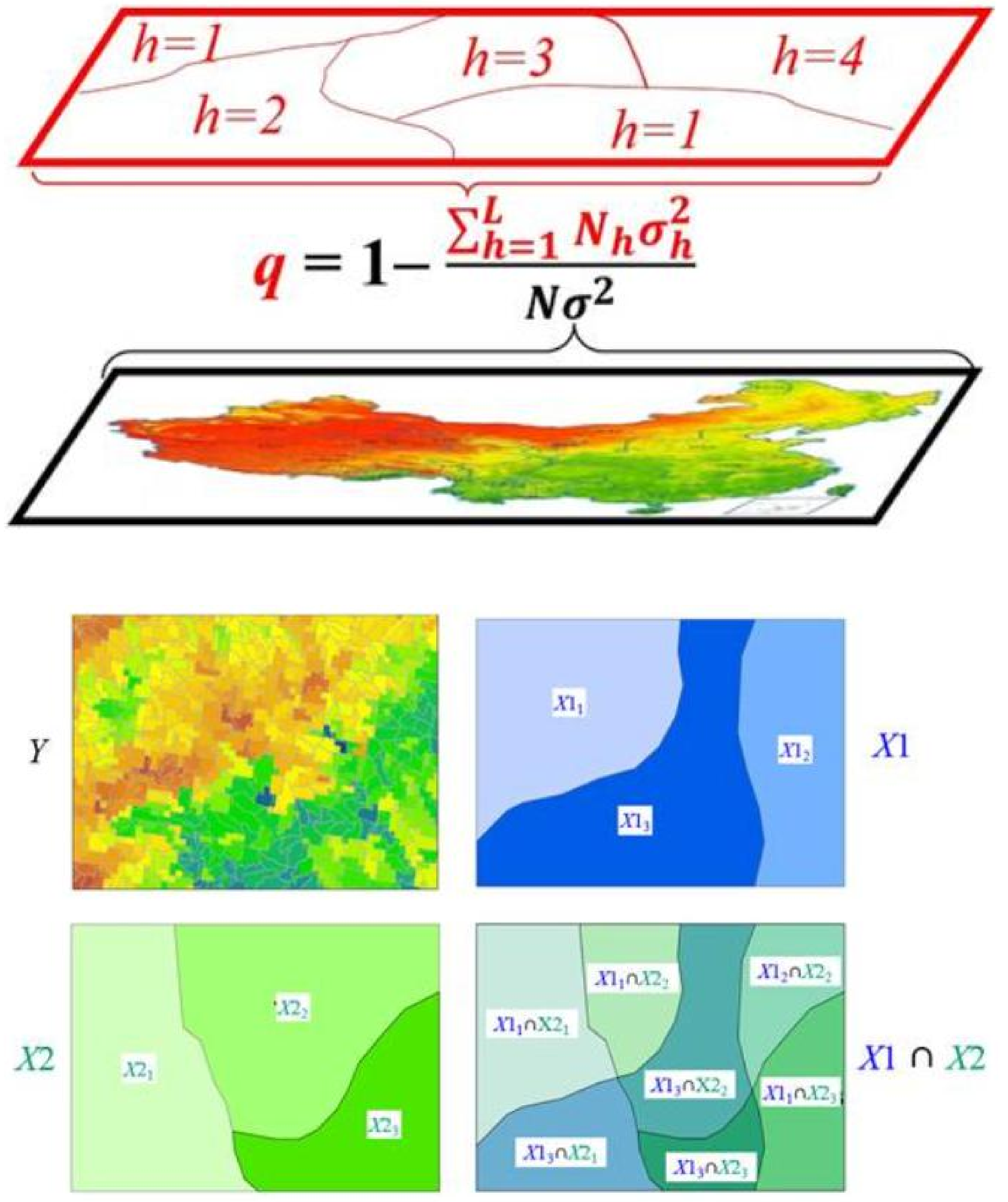


Figure 3-d Principle of Geodetector ＆ Interaction between explanatory variables X1 and X2 impacting on a response variable Y: q(Y|X1X2).（http://www.geodetector.cn/）

Figure 3 Schematic diagram of research methods

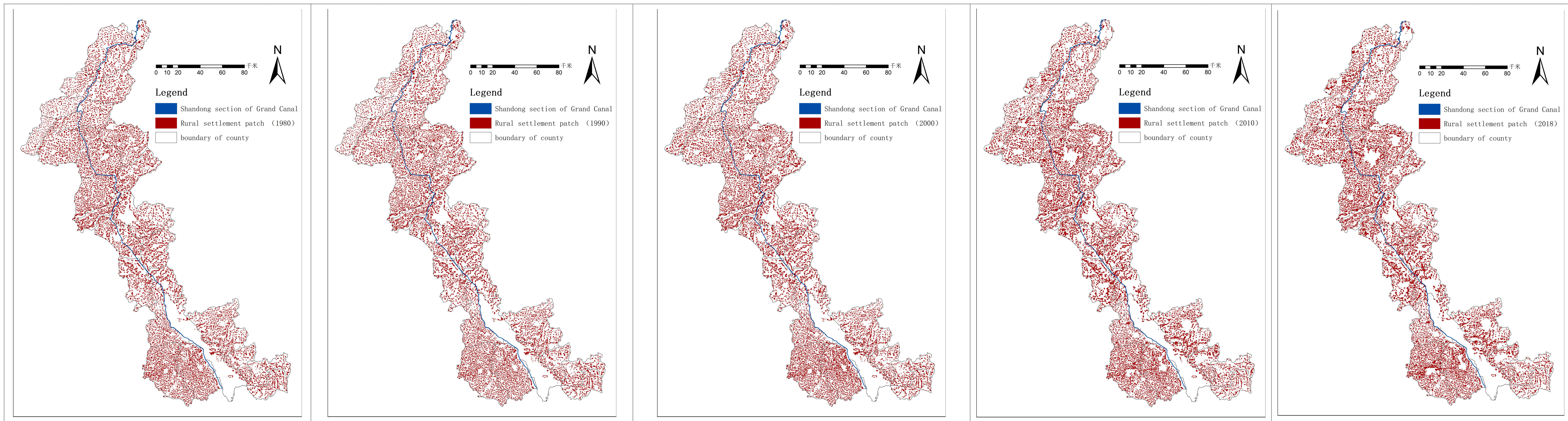
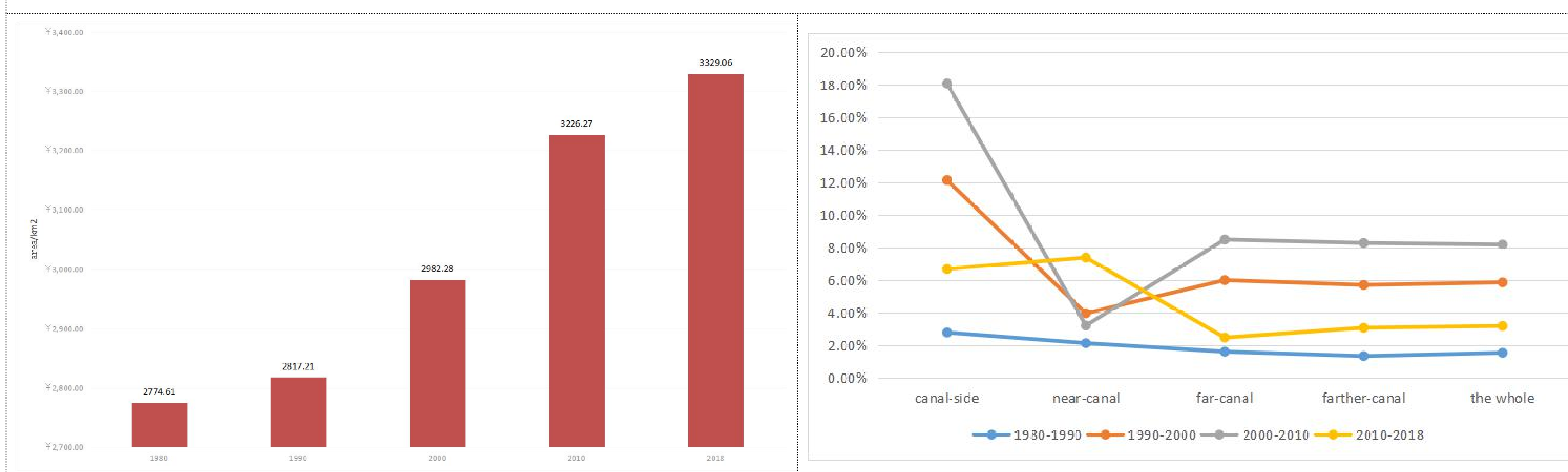


Figure 4-a Spatial pattern and dynamic change of rural settlements along the Shandong section of the Grand Canal from 1980 to 2018



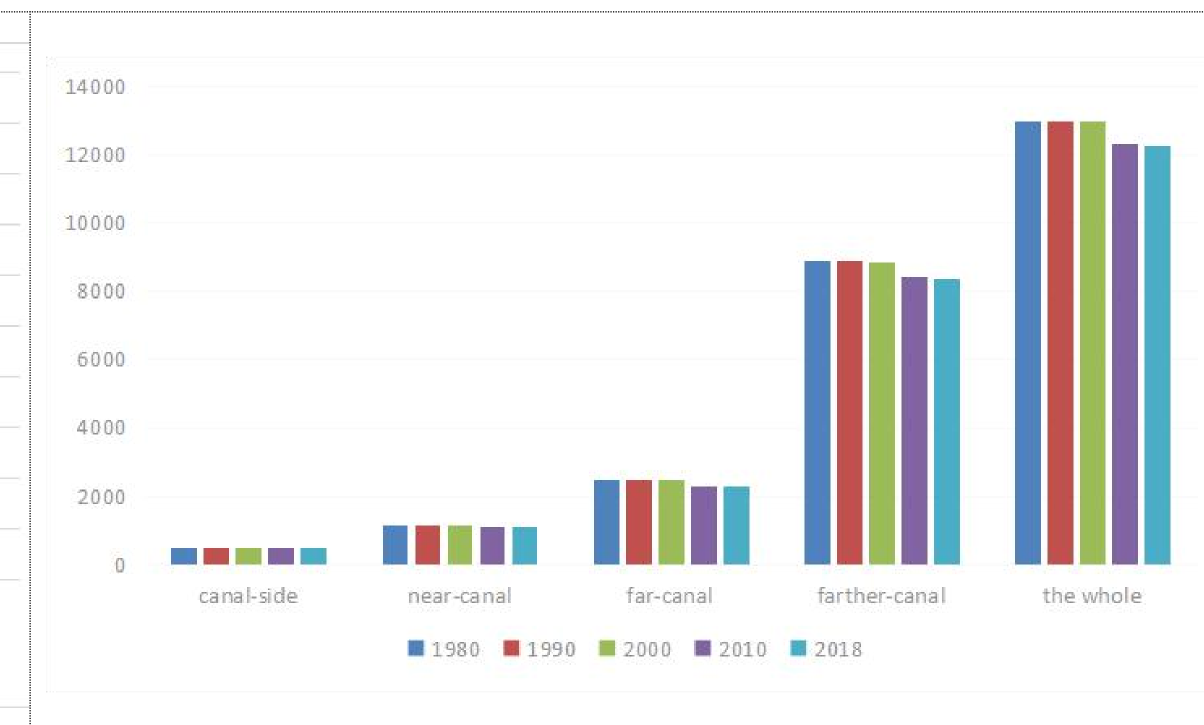


Figure 4-b Sum of total rural settlement area and its growth rate in the study area from 1980 to 2018

Figure 4-c Evolution of the number of settlement patches in different settlement zones from 1980 to 2018

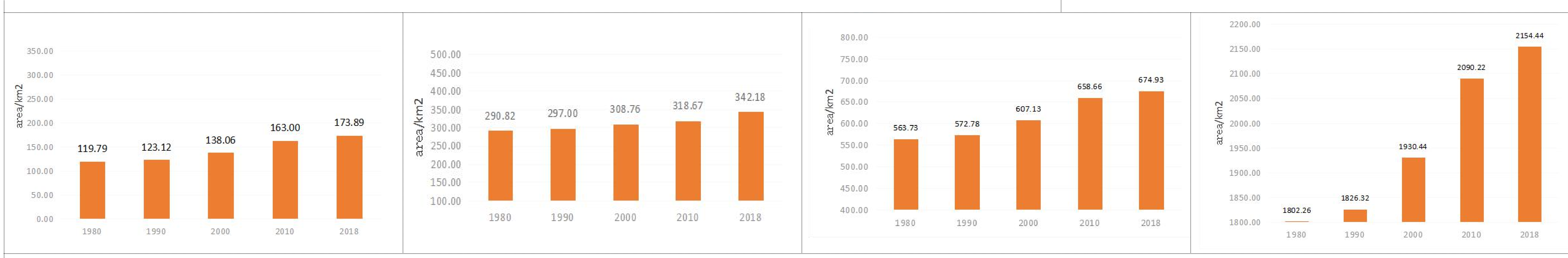


Figure 4-d The evolution of rural settlement area in each settlement belt from 1980 to 2018

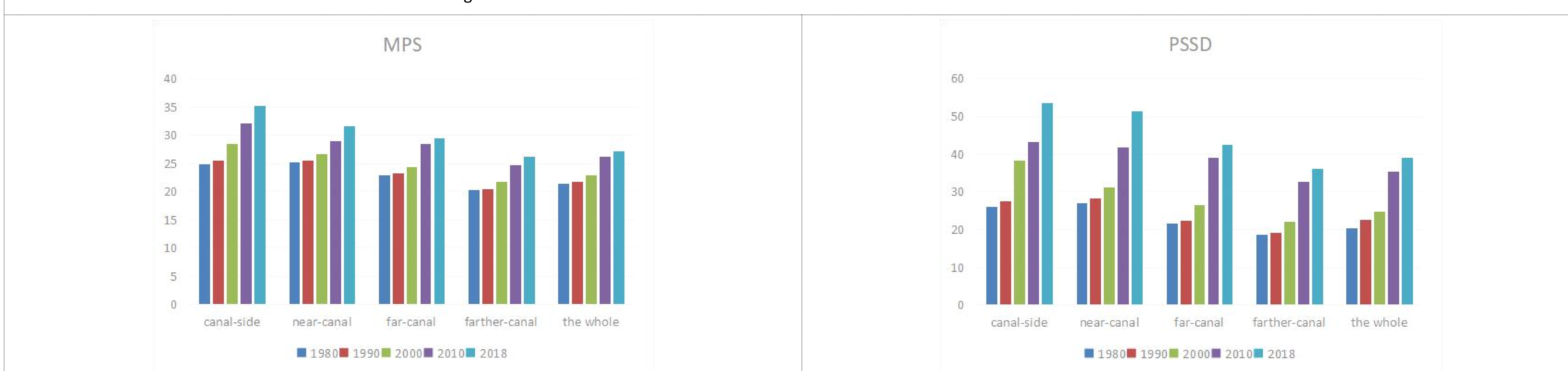
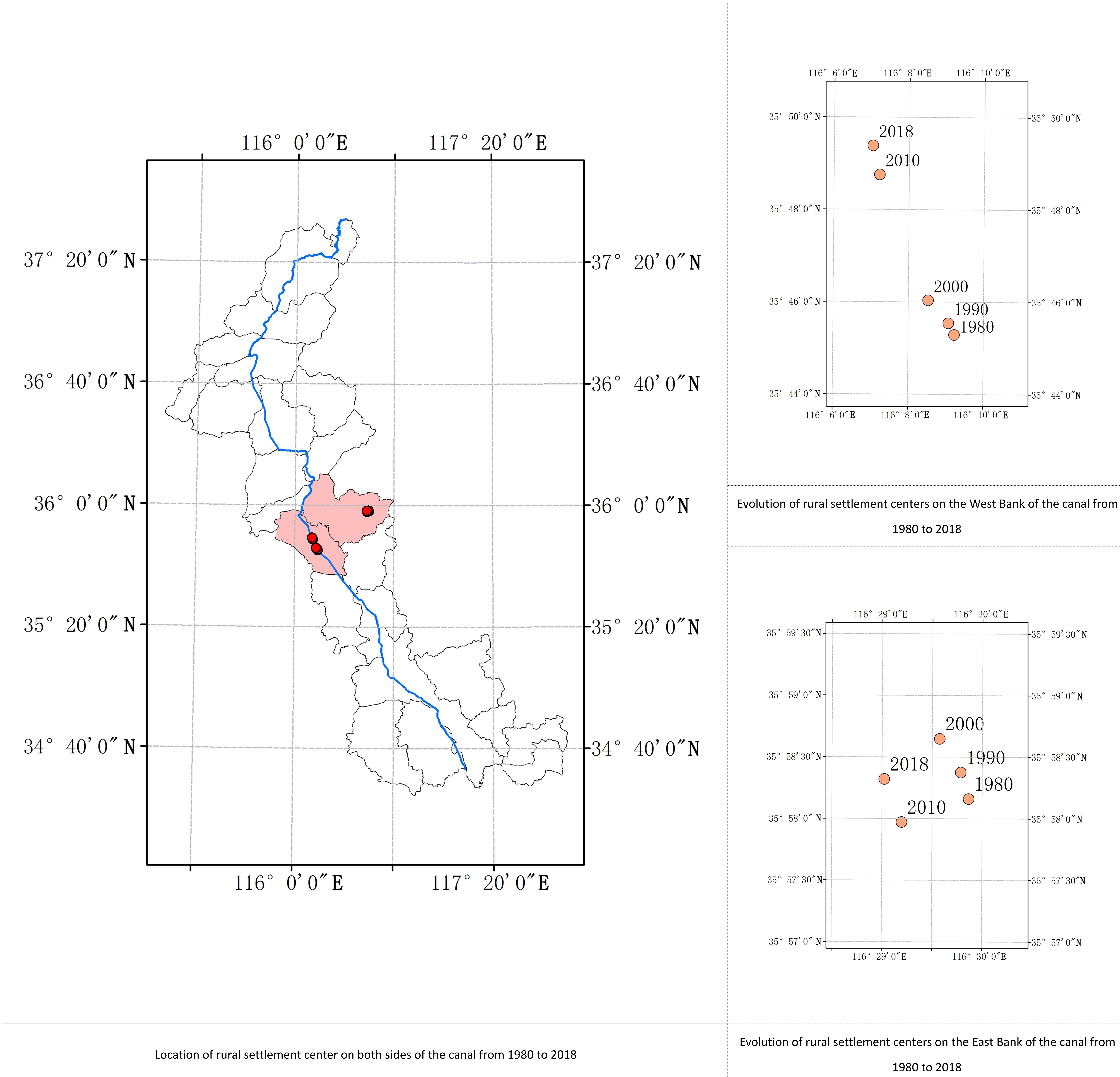


Figure 4-e Evolution of mean patch size (MPS) and patch size standard deviation (PSSD) of rural settlements in different settlement zones from 1980 to 2018

Figure 4 Spatial scale characteristics of rural settlements from 1980 to 2018



Evolution of rural settlement centers on the West Bank of the canal from 1980 to 2018

Location of rural settlement center on both sides of the canal from 1980 to 2018

Evolution of rural settlement centers on the East Bank of the canal from 1980 to 2018

Figure 5 Gravity transfer map of rural settlements on both sides of the canal from 1980 to 2018

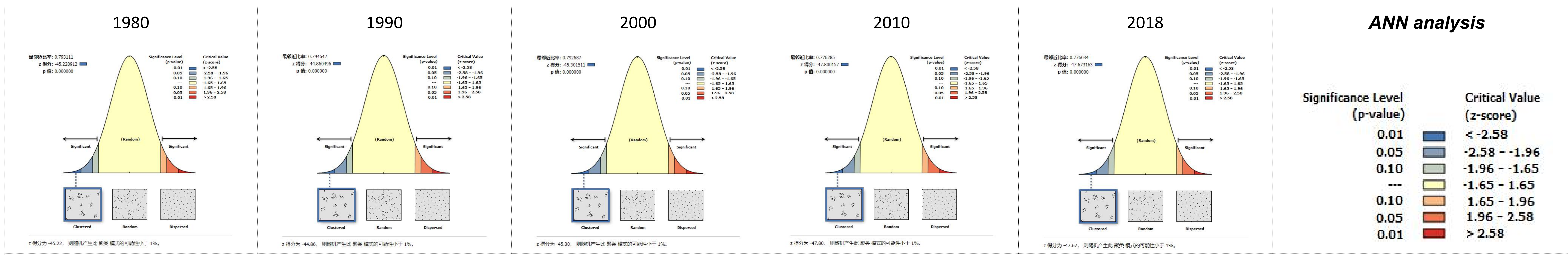


Fig.6-a Analysis on the average nearest neighbor index of rural settlements in the study area from 1980 to 2018

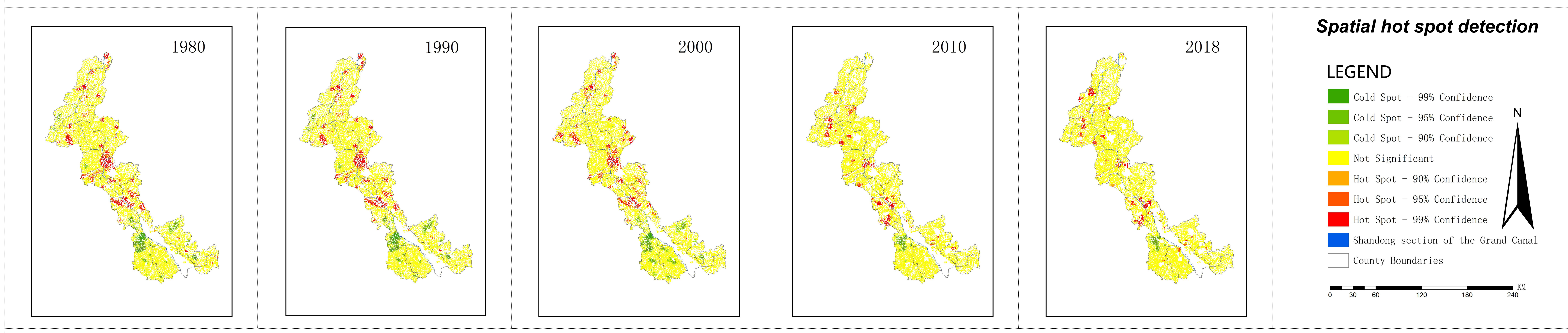


Fig.6-b Analysis of cold and hot spots of rural settlements in the study area from 1980 to 2018

1980	1990	2000	2010	2018	**Proportion statistics**
13.35%	13.24%	13.41%	11.68%	11.13%	Highest density
27.92%	27.97%	26.01%	23.48%	23.48%	higher density
36.30%	36.28%	36.69%	37.78%	37.65%	medium density
17.74%	17.80%	19.20%	21.54%	21.85%	lower density
4.69%	4.70%	4.69%	5.52%	5.88%	lowest density

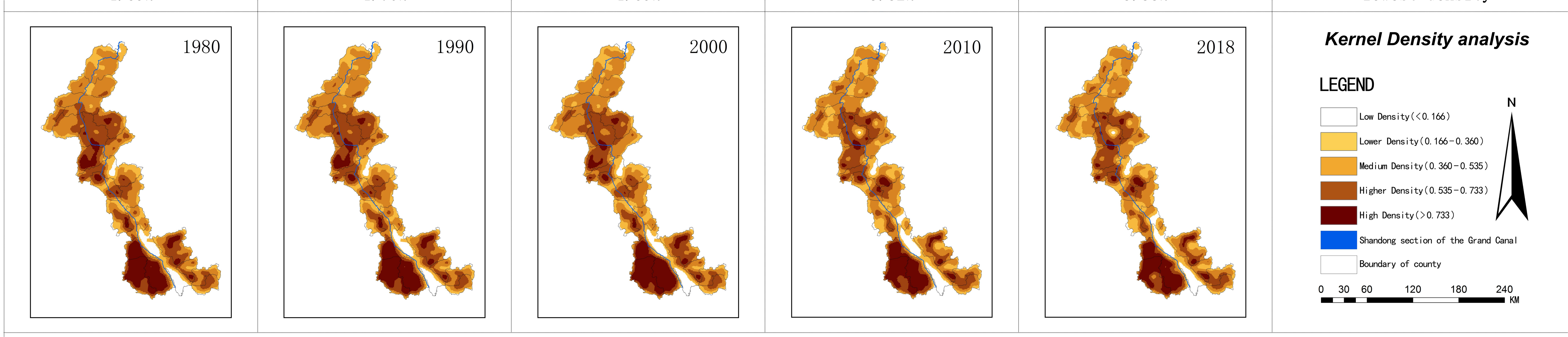


Fig.6-c Density analysis of rural settlements along the Shandong section of the Grand Canal from 1980 to 2018

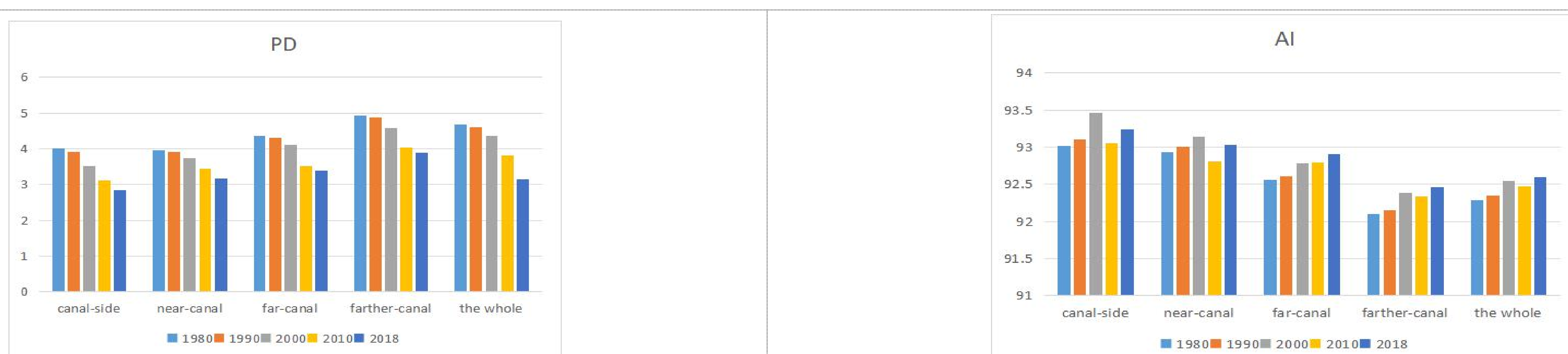
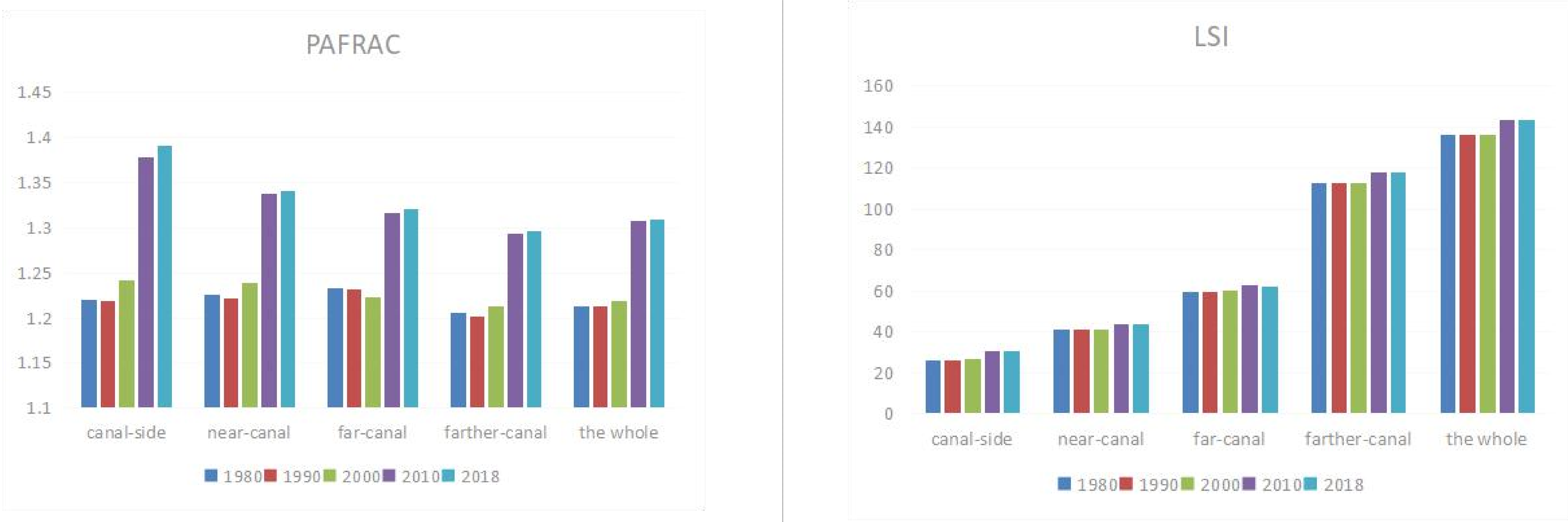


Fig.6-d Evolution of aggregation index (AI) and patch density (PD) of rural settlements in different settlement zones from 1980 to 2018

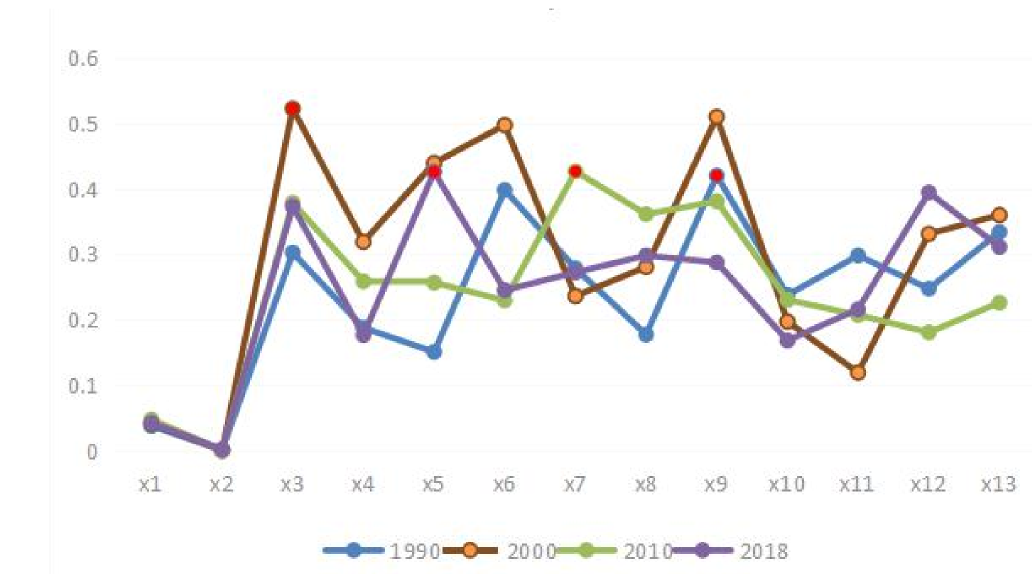
Figure 6 Spatial agglomeration characteristics of rural settlements along the Shandong section of the Grand Canal from 1980 to 2018



Evolution of landscape shape index (LSI) and perimeter area fractal dimension (PAFRAC) of rural settlements in different settlement zones from 1980 to 2018

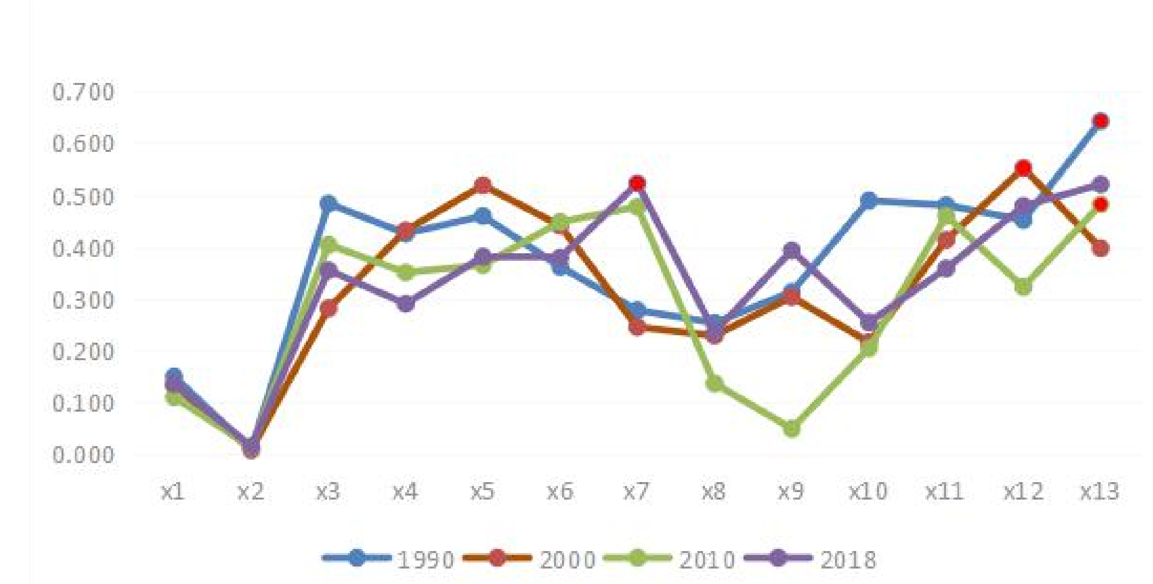
Figure 7 Rural settlement patch's landscape index zone from 1980 to 2018

The whole	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
1990	0.038	0.001	**0.302**	0.188	0.151	0.398	0.278	0.177	0.420	0.238	0.298	0.247	**0.334**
2000	0.041	0.001	0.522	0.319	0.439	**0.497**	0.236	0.280	**0.510**	0.197	0.119	0.331	0.360
2010	0.048	0.001	**0.378**	0.258	0.256	0.229	0.426	0.361	**0.381**	0.230	0.207	0.180	0.226
2018	0.042	0.002	**0.373**	0.176	0.426	0.245	0.272	0.298	0.287	0.168	0.216	**0.394**	0.311
Q average	0.042	0.001	0.394	0.235	0.318	0.342	0.303	0.279	**0.400**	0.208	0.210	0.288	0.308



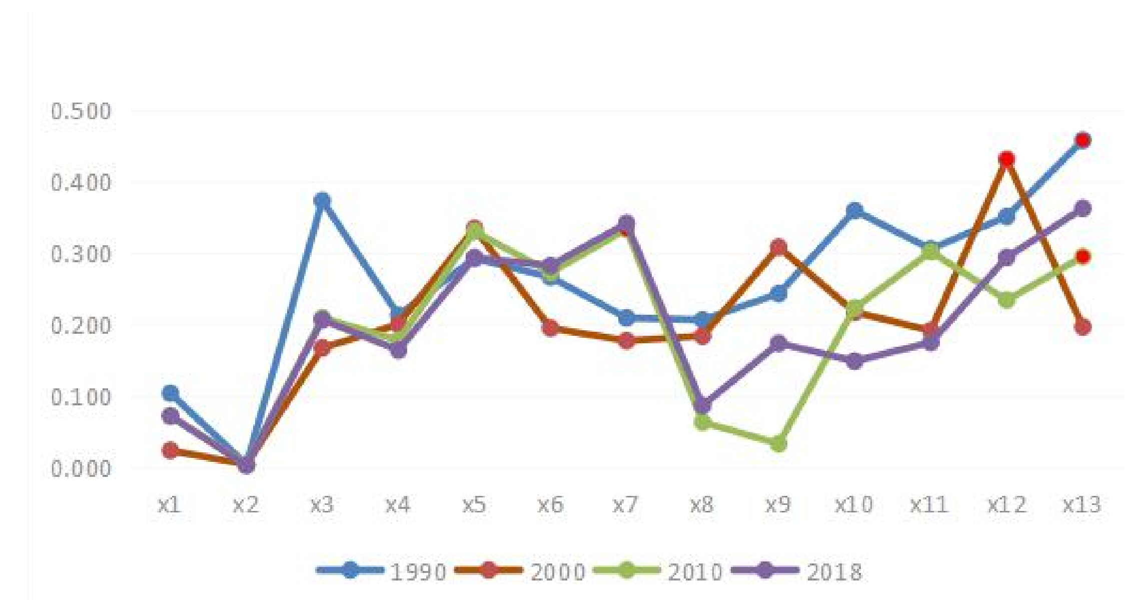
Q value trend and peak value of the whole settlements from 1990 to 2018

canal-side zonal	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
1990	0.150	0.009	**0.484**	0.426	0.460	0.362	0.278	0.254	0.313	**0.490**	0.481	0.452	0.643
2000	0.132	0.009	0.282	0.432	**0.519**	**0.441**	0.245	0.229	0.304	0.216	0.414	0.552	0.398
2010	0.111	0.014	0.404	0.351	0.365	0.448	**0.477**	0.137	0.049	0.205	**0.460**	0.323	0.482
2018	0.136	0.016	0.355	0.290	**0.381**	0.379	0.523	0.235	0.393	0.255	0.358	**0.479**	0.521
Q average	0.132	0.012	0.381	0.375	0.431	0.408	0.381	0.214	0.265	0.292	0.428	0.452	**0.511**



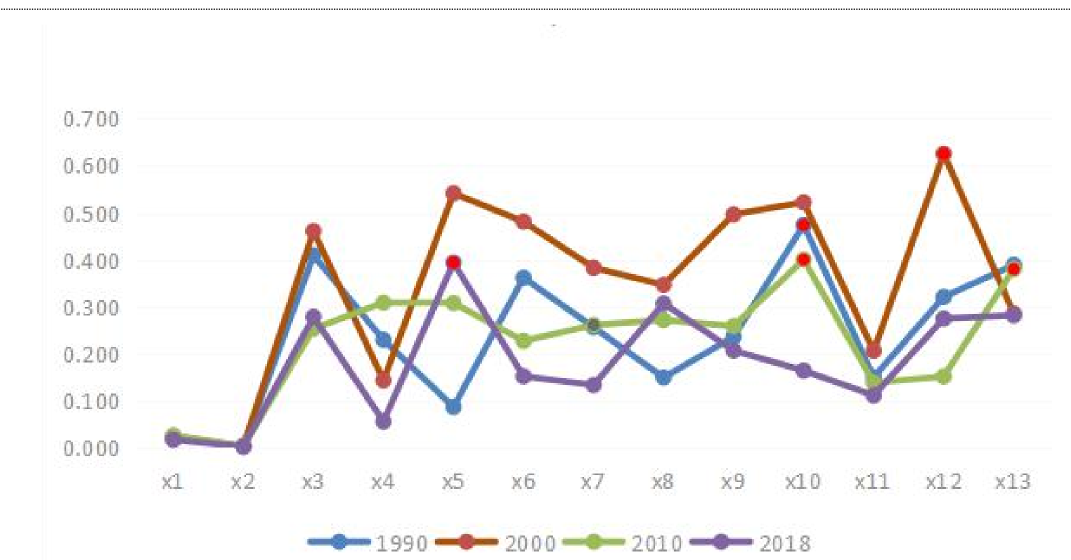
Q value trend and peak value of canal-side zonal settlements from 1990 to 2018

near-canal zonal	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
1990	0.105	0.005	0.374	0.214	0.293	0.267	0.210	0.207	0.244	**0.360**	0.306	**0.352**	0.458
2000	0.025	0.005	0.168	0.201	**0.335**	0.196	0.178	0.185	**0.309**	0.218	0.192	0.432	0.198
2010	0.073	0.005	0.210	0.179	**0.331**	0.273	0.334	0.064	**0.034**	0.224	0.302	0.235	0.296
2018	0.073	0.004	0.207	0.165	**0.295**	0.283	**0.342**	0.087	0.175	0.150	0.176	0.295	0.363
Q average	0.069	0.005	0.240	0.190	0.314	0.255	0.266	0.136	0.191	0.238	0.244	0.329	**0.329**



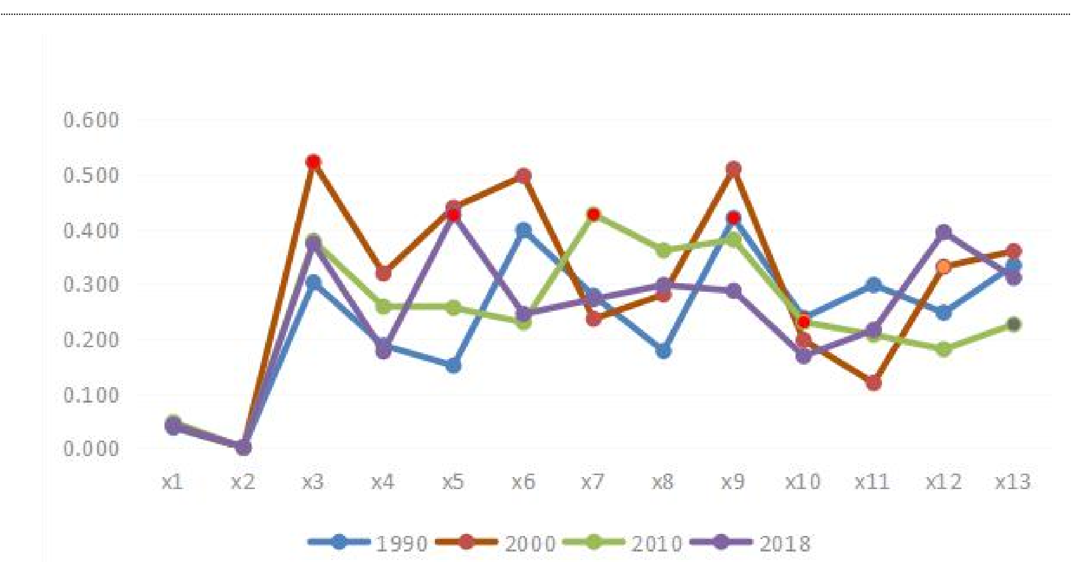
Q value trend and peak value of near-canal zonal settlements from 1990 to 2018

far-canal zonal	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
1990	0.025	0.004	**0.409**	0.230	0.087	0.362	0.257	0.150	0.236	0.474	0.150	0.321	**0.389**
2000	0.020	0.004	0.461	0.144	**0.541**	0.481	0.383	0.347	0.497	**0.522**	0.207	0.625	0.285
2010	0.027	0.004	0.254	**0.309**	0.308	0.227	0.261	0.272	0.259	0.400	0.139	0.152	**0.380**
2018	0.018	0.003	0.279	0.056	0.394	0.152	0.134	**0.307**	0.207	0.164	0.112	0.275	**0.282**
Q average	0.023	0.004	0.351	0.185	0.333	0.306	0.259	0.269	0.300	**0.390**	0.152	0.343	0.334



Q value trend and peak value of far-canal zonal settlements from 1990 to 2018

further-canal zonal	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
1990	0.038	0.001	**0.302**	0.188	0.151	**0.398**	0.278	0.177	0.420	0.238	0.298	0.247	0.334
2000	0.041	0.001	0.522	0.319	0.439	**0.497**	0.236	0.280	**0.510**	0.197	0.119	0.331	0.360
2010	0.048	0.001	**0.378**	0.258	0.256	0.229	0.426	0.361	**0.381**	0.230	0.207	0.180	0.226
2018	0.042	0.002	**0.373**	0.176	0.426	0.245	0.272	0.298	0.287	0.168	0.216	**0.394**	0.311
Q average	0.042	0.001	0.394	0.235	0.318	0.342	0.303	0.279	**0.400**	0.208	0.210	0.288	0.308



Q value trend and peak value of further-canal zonal settlements from 1990 to 2018

Figure 8 Trend and peak value of Q value in each settlement zone from 1990 to 2018

An analysis of the Spatial Evolution and Influencing Factors of Rural Settlements along the Shandong Section of the Grand Canal of China

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The authors declare that they have no conflict of interest.

Abstract

Since 1980s, the weakening of the transportation function of the Grand Canal and rapid urbanisation has generated significant changes in the spatial pattern of rural settlements along the Grand Canal. Analysing the changing characteristics of this spatial pattern, and exploring the natural, social, and economic factors influencing these changes are key to understanding the regional spatial structure and development law, and grasping the degree of influence of these factors.

This study selected approximately 13,000 rural settlements in 27 county-level units in the Shandong section of the Grand Canal, from 1980 to 2018, as the research object. The Grand Canal's distance buffer zone is divided into canal-side, near-canal, far-canal, and further-canal settlements. The correlation model with the canal is constructed through the controlled experiment. The distribution, scale and form of the settlement are analysed quantitatively by applying the change of gravity centre model (CGC), average nearest neighbour analysis (ANN), landscape metrics (LM), and other methods. The quantitative analysis of geographic detectors in spatial pattern differentiation factors shows the relative importance and interaction within them.

This study indicates that the spatial distribution shows 'large dispersion and small concentration' and 'small-scale agglomeration' characteristics. The larger the scale of the settlement expands, the more the number of settlements decreases. The closer the settlement nears the river, the more complex the shape clusters. The total output value of agriculture, forestry, animal husbandry, fisheries, the total power of agricultural machinery, and the effective irrigation area are the main influencing factors. The grain area and the per capita disposable income of rural residents are the main auxiliary influencing factors.

Keywords: rural settlements; spatial evolution; impact factors; quantitative methods; Shandong section of the Grand Canal

1. Introduction

Since the Reform and Opening, the social economy has developed rapidly, and people's living standards have improved. With rapid urbanisation, there was a noticeable difference in the spatial distribution between urban and rural structures (Zhang et al., 2019; Tian et al., 2016). The development of rural areas was showing slow growth under the double pressure of urban development expansion and its development limit (Bao & Fang, 2012). The distribution and form of rural settlements have also changed dramatically (Tu et al., 2017). Since 2010, rural development has been gradually emphasised by introducing China's new urbanisation and rural revitalisation strategy. Achieving efficient and sustainable rural development, especially the development of rural settlements in specific areas, has become a new research focus.

As a world cultural heritage, the Grand Canal is the crystallization of the wisdom of ancient Chinese civilisation. As the main waterway running from north to south, it has driven the rise and prosperity of settlements along the route in Chinese history (Zhang et al., 2020). However, with the completion of China's first railroad from north to south in the 1980s, the transport function of the canal was primary replaced, leading to the lagging development of the canal and the settlements along its route. As a unique part of China's cultural landscape, the government attaches great importance to the development of the canal and the settlements and has promulgated the Outline for the Protection and Utilization of the Grand Canal Culture (2019). Shandong Province has put forward documents accordingly, such as the Implementation Plan for the Protection, Heritage and Utilization of the Grand Canal Culture in Shandong Province (2020). Also, the study of the settlements along the canal is highly valued, particularly regarding the rural settlements. As a rural population settlement influenced by the natural environment, social economy, and policies, it has been given a special canal imprint under the unique geographical location, bearing the social production life of rural residents (Long et al., 2019). The evolution and development of their spatial patterns have witnessed human-land relations along the canal and the formation of their heterogeneity since the Reform and Opening. The evolution and development have also explored the characteristics of rural settlements' location, scale, distribution, morphology, and other differentiations, and their influencing factors and mechanisms. Through the research, fully understanding the dynamic evolution of the countryside for the merging points, village relocation and other relocating issues in the future, and issues of resource sharing public facilities allocation are possible. It helps to identify the dominant and auxiliary factors affecting the development of villages. It also helps to find the optimal entry point for industrial layout, structure optimization and spatial layout in village planning. It is of great theoretical value and practical significance to maximize the input-benefit ratio of rural development, optimize the spatial pattern of rural settlements, promote sustainable rural development, and revive canal settlements (Liu et al., 2014).

Hence, the authors selected 27 county-level rural settlements in the Shandong section of the Grand Canal as the research object. The authors innovatively made divisions according to four levels: canal-side zonal settlement (<1 km), near-canal zonal settlement (1-4 km), far-canal zonal settlement (4-10 km), and further-canal zonal settlement (>10 km). Based on land use data and socioeconomic data in 1980, 1990, 2000, 2010, and 2018, the authors applied the CGC model, kernel density, ANN analysis, Getis Ord Gi*, and land metrics to analyse the settlement patches in rural areas quantitatively. Based on the quantitative analysis, the authors studied the spatial characteristics of settlements' size, distribution, and morphology. The paper also analysed the dominant and auxiliary factors influencing differentiation from both natural and socioeconomic perspectives. The study has provided theoretical references for the development of rural settlements along the canal, including:

1) Defining the characteristics of scale and the regular pattern of focus-shift, that becomes a guiding role in the degree control and migration site selection in village planning;
2) Defining the characteristics of distribution, which provides references for sharing resources and managing public facilities in regional planning;
3) Clarifying the characteristics of morphology, that assists to find the development direction of rural settlements along the canal according to local conditions.

2. Literature Review

In recent years, many scholars have studied the distribution and evolution of the settlements along the Grand Canal and the rural settlements in China, which have made rich achievements. Many have further explored the spatial pattern and morphology of the canal's settlements, primarily relying on historical excavation and spatial characterization methods. In the overall spatial pattern of canals, a three-level structure of city-town-village is commonly seen. However, there are regional adaptations and differences in spatial layout, morphological patterns, functional characteristics, and cultural attributes of settlements along the Grand Canal (Wen et al., 2020). Since 1984, urban settlement distribution has tended to be discrete and dispersed (Shi & Huang, 2019). Since the Reform and Opening, the spatial pattern of towns along the canal has changed from closed and monotonous to open and diversified (Niu, 2012). Villages along the canal are distributed in a regular and skewed matrix with natural distribution (Zhang & Tang, 2018), mainly influenced by natural geographical location, socioeconomic policies, and canal functions (Li, 2007; Zhang, 2019). However, under the influence of towns and roads, the rural settlements, as essential elements of the Grand Canal, are mainly driven by agricultural production and road networks, indicating that rural settlement has changed from natural to sudden growth (Wen, 2019; Zhao et al., 2021).

Studies on rural settlements originated and focused on qualitative research in Europe. Since the revolution of econometric geography in the West, scholars have applied the cellular automation (CA) model, Voronoi diagram, binary model, and fractal theory to quantitative studies of the spatial evolutionary trends of rural settlements and their influencing factors. Researchers urgently requested spatial data in the fields, especially for applying probability, computational geometry, and geographic information science, that could establish standardisation and be more objective than qualitative analysis (Atsuyuki et al., 2000; Duyckaerts & Godefroy, 2000). Studies on rural settlements in China have been more fruitful in recent years (Tan et al., 2021; Yang et al., 2020). The evolution of Chinese rural settlements follows a life cycle of formation, development, stabilization, decline, and revival (An et al., 2015). The scale, pattern and morphology of rural settlements reflect the evolution of nature, socioeconomic policy changes, and human-land relations in current society (Yao & Xie, 2016). Furthermore, the studies have found that the distribution pattern of Chinese villages is the result of the interaction of environmental, geographical, social, and economic factors (Zhou et al., 2020), with rapid population growth and accelerated economic growth being the main reasons for changes in rural settlements. The continuation of the rural land system and changes in family structure have also influenced the evolution of rural settlements (Song & Li, 2020; Li & Song, 2020).

In the research regarding the evolution of rural settlements' spatial pattern and its influencing factors, a large number of scholars have used spatial analysis methods, geographically weighted regression models, and geographic detectors to investigate rural settlements in suburban counties (Liu, 2020); traditional settlements in Youshui Basin (Du & Guo, 2020);

rural settlements in Hexi, Gansu (Li, 2020); rural settlements in wetland landscapes (Li & Peng, 2020); rural settlements on urban islands (Cui & Yan, 2020); rural settlements in the poverty belt of Beijing, Tianjin and Hebei (Tao et al., 2020); rural valley settlements (Xu & Zhao, 2020); rural settlements in near urban areas (Chen, 2020), Dingziwan area in Jiaodong (Zhang, 2020); villages in poor areas in southwest China (Yao et al., 2020); oasis villages in Xinjiang (Lin et al., 2020); and various other types of rural settlements in terms of size, density and shape. Scholars have analysed the evolution of size, density and shape, and the relationship between their evolution and indicators such as slope elevation, agricultural technology, non-agricultural population, industrial output value, and net income per capita. Researchers have found that the natural environment (Chen, 2020), socioeconomic, and cultural factors (Gulizre et al., 2020) influence the evolutionary diversity of rural settlements. However, the dominant factors have significant regional differences (Long et al., 2019). For example, the spatial distribution of rural settlements in Xinjiang Oasis is influenced by road accessibility at the townscape and county level, the road's slope, the distance to rivers, temperature, elevation, but insignificantly by social and economic factors. Land relief, average annual temperature, and average annual precipitation are the main natural forces within the Loess Plateau region. Equally, food production, total population, and proportion of the rural population are the critical humanistic driving forces.

In summary, due to the significant differences in the evolutionary characteristics of rural settlements among geographical types and their dominant factors, only a few quantitative studies on the Grand Canal have a geographical variety of an artificial river. The bottom-most research is on the evolutionary characteristics of rural settlements and their main driving factors for this particular geographical type along the Grand Canal. Therefore, this paper selected all rural settlements in the 27 county-level units through which the Shandong section of the Grand Canal flows as research objects, and studied the spatial distribution of rural settlements along the Shandong section of the canal and their evolutionary characteristics, and analysed the factors using geographic detectors. The economic development level in the east and west of Shandong Province is different. The area that the Shandong section flows through is significantly impacted by the railroad, a specific area of backward development and more representative of the evolutionary characteristics of rural settlements in this geographical type. Driven by the canal planning and development policy of Shandong Province, the study of the pattern characteristics and the dominant factors of divergence in this region is more typical, and the results are of more practical significance. The study also provides a theoretical reference for the development and protection of rural settlements along the canal, expands the application of rural settlement research and enriches the theoretical system.

3. Research Overview

3.1 Demarcating the Shandong section of the Grand Canal

China's Grand Canal (building in 486 BC) is the world's longest, oldest, and largest canal. It stretches over 2,700 km and spans more than ten latitudes of Earth (Figure 1-a). In ancient China, it was the main north-south traffic artery. In the Yuan dynasty, the excavation of the canal's Shandong section laid the foundation for and supported the establishment of Beijing as the political centre. After the Ming and Qing dynasties, a specific canal transport management organisation was established for the Grand Canal's Shandong section. The geographical and social environments changed since the canal was connected. The flow of canal goods and people have done much to promote commercial and handicraft industrial development along the canal, bringing prosperity to the cities on that route.

However, a massive change in the waterway caused a water shortage in 1855, seriously affecting the regular operation of water transport. The delayed canal dredging disrupted grain transport towards the end of the Qing dynasty, and the associated management agencies and personnel also disappeared due to diplomatic difficulties. In addition to some sections of the canal, it also began to dry up. However, with its rich historical connotation, crucial geographical location, and unique human, the Grand Canal still occupies a significant position on China's regional cultural map (Zhang, 2019).

This research aims to intercept Decheng District, Dezhou City at the northern end of the Shandong section of the Grand Canal, and Weishan County, Jining City at the south end. This section of the Grand Canal is approximately 643 km in length, accounting for approximately one-fourth of the total length of each section of the Grand Canal River (Figure 1-b & c).

Figure 1 Location map of China Grand Canal and its Shandong section

3.2 Defining rural settlement

This study covers 27 county-level units in the provinces of Shandong, Hebei, Henan, and Jiangsu in the region of the Shandong section of the Grand Canal River. The geographical position is between 34 ° 75'N and 36 ° 51'N, and 116 ° 34'E and 117 ° 58'E; the east-west span is about 250 km; the south-north span is about 350 km, and the average altitude is about 316 m (Figure 2).

The study area is in a temperate monsoon climate, the terrain consists mainly of flat plains, and there are a few mountains on the east side. By the end of 2018, the study area's total population was 20.058 million, 49.06% of which represented the rural population, exceeding the national portion of 41.48% rural population. It shows that rural settlements are still an important aspect of survival and development in the region. The study area's total gross domestic product (GDP) is 7662.34 billion yuan, and the per capita GDP is 56253 yuan, which is lower than that of Shandong province, with a per capita GDP of 76,267 yuan (Shandong, 2020).

Figure 2 The Shandong section of the Grand Canal and its administrative units at all levels

4. Methodology

4.1 Data sources and research methods

This research (Figure 3-a) uses CGC, KN, ANN, Getis-Ord GI*, and LM to express the spatial pattern of rural settlements from four aspects: spatial scale characteristics, Spatial Gravity Centre evolution characteristics, spatial agglomeration characteristics and patch shape characteristics (Li, 2020; Yang et al., 2020; Tan et al., 2021). Based on the analysis results of each sample year from 1980 to 2018, the evolution of spatial pattern was summarised. 13 statistical factors in the study data were detected via single-factor and interactive detection, and the main influencing factors and main auxiliary influencing factors were also identified. Finally, the spatial pattern of rural settlements and the relationship between influence factors and the canal were obtained by cross-referencing the analysis results.

4.2 Data source and data processing

Data sources include:

(1) China Land Use/land cover remote sensing monitoring database (1980-2018) extracted the rural residential area land patches. The data set is provided by Data Centre for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) (http://www.resdc.cn).

(2) Socioeconomic data were obtained from Shandong, Hebei, Jiangsu and Henan statistical yearbooks and rural statistical yearbooks (1990-2019), the China County Statistical Yearbook (2000-2019), and the Dezhou City, Liaocheng City, Tai'an City, Jining City, and Zaozhuang City Statistical Yearbook (2000-2019).

(3) Administrative division data and county Digital Elevation Model (DEM).

(4) Data for the Shandong section of the China Grand Canal were obtained from the Chinese water system, combined with manual translation and remote sensing data.

4.3 Methodology

4.3.1 The controlled experiment method

By setting up the experimental and control groups, this study used the distance from the Grand Canal as the only variable. As mentioned above, the settlements are divided into canal-side zonal settlements (0–1 km), near-canal zonal settlements (1–4 km), far-canal zonal settlements (4–10 km), and further-canal zonal settlements (>10 km) (Shandong, 2020) (Figure 3-b). The correlation model between spatial patterns and canal distance was constructed by cross-referencing.

4.3.2 The CGC model

This study uses the CGC of the rural settlement patch to calculate the distribution centre of gravity of the rural settlements in the studied area, showing the temporal and spatial changes in the corresponding area's centre of gravity (Li, 2020).

$$X = \frac{\sum_{i=1}^{n} X_i a_i}{\sum_{i=1}^{n} a_i}, Y = \frac{\sum_{i=1}^{n} Y_i a_i}{\sum_{i=1}^{n} a_i}$$

X and **Y** are the longitude and latitude of the centre of gravity of the rural settlement patch in the study area in the data year. $\mathbf{X_i}$ and $\mathbf{Y_i}$ are the longitude and latitude of the rural settlement patch **n**, respectively, and $\mathbf{a_i}$ is the patch's area.

4.3.3 Kernel density analysis

Kernel density analysis expresses the continuity of discrete spatial data and analyse the settlements' spatial distribution density (Tan et al., 2021). Thus, it directly reflects regional differences in the distribution of rural settlements in different regions.

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

m is the number of observations, **h** is the smoothing parameter or bandwidth (**h** > 0), **K** is the kernel function, and (**x** - $\mathbf{x_i}$) is the distance between the estimated point **x** and the event point $\mathbf{x_i}$.

4.3.4 ANN analysis

ANN measures the distance between each feature's centroid and the centroid of its nearest neighbours and then calculates the average of all the nearest neighbours. The analysis results include the following five parameters: nearest neighbour index, expected average distance, average observation distance, Z-score, and P-value. The Z-score and P-value results are measures of statistical significance. ‘Nearest neighbour index’ is the ratio of ‘average observation distance’ to ‘expected average distance’. If the nearest neighbour index is less than 1, the pattern is clustered; if the index is greater than 1, the pattern tends to be discrete or competitive (Figure 3-c). Thus, ANN analysis can provide an index of a data’s specific degree of aggregation (Li, 2020).

4.3.5 Spatial hot spot detection

Spatial hot spot detection uses the Getis-Ord Gi* statistics in ArcGIS 10 to identify statistically significant hot and cold spots. It is used to test whether there are statistically significant high and low values in some areas (Zhang et al., 2019; Tan et al., 2021). The area visualisation method can be used to identify hot spots and cold spots.

$$G_i^*(d) = \sum_{j=1}^{n} w_{ij}(d)x_i / \sum_{j=1}^{n} x_j$$

Where $\mathbf{w_{ij}(d)}$ is the spatial weight defined by the distance rule, **and** $\mathbf{x_i}$ and $\mathbf{x_j}$ are the variable values of the **i** and **j** regions, respectively.

4.3.6 Landscape metrics

This study uses Fragstats4.2 to calculate various indices and selects the average patch area according to three levels of scale, agglomeration, and shape characteristics of the rural settlement space (Li, 2020). The mean patch size (MPS) and patch size standard deviation (PSSD) were selected to quantify the scale characteristics of rural settlements, whereas the aggregation index (AI) and patch density (PD) quantified their agglomeration characteristics. The Landscape shape index (LSI) and perimeter area fractal dimension (PAFRAC) quantified the shape characteristics. The main calculation formulae are as follows：

$$MPS = \frac{\sum_{i=1 a_i}^{n}}{N}$$

$$PSSD = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left(a_i - \frac{\sum_{i=1}^{n} a_i}{N}\right)^2}$$

$$AI = \left[\frac{g_{ii}}{\max \rightarrow g_{ii}}\right](100)$$

$$PD = N/A$$

$$LSI = \frac{0.25\sum_{i=1}^{n} p_i}{\sqrt{A}}$$

$$PAFRAC = \frac{2}{\frac{\left[N\sum_{i=1}^{n}\left(\ln p_i \times \ln a_i\right)\right]-\left[\left(\sum_{i=1}^{n}\ln p_i\right)\times\left(\sum_{i=1}^{n}\ln a_i\right)\right]}{\left(N\sum_{i=1}^{n}\ln p_i^2\right)-\left(\sum_{i=1}^{n}\ln p_i\right)^2}}$$

4.3.7 The geodetector model

Geographic detectors can test the spatial heterogeneity of a single variable; they can also detect the possible interaction and linear relationship between two variables by testing the coupling of their spatial distribution (Yang et al., 2020) (Figure 3-d).

In this study, factor and interaction detectors were used to explore the impact of different influencing factors on the development of and changes in rural settlements along the Shandong section of the Grand Canal.

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

N and **σ²** represent the number of units in the study area and the variance of **Y**, respectively; the value of the detection result **q** is strictly within [0, 1]. Thus, if **Y** is stratified by itself, then **q** = 0, meaning there is no heterogeneity in **Y**; **q** = 1 means that **Y** is perfectly heterogeneous.

Figure 3 Schematic diagram of research methods

5. The spatial pattern of rural settlements and its evolution characteristics

5.1 Rural settlement spatial scale characteristics

5.1.1 The spatial scale pattern

The settlement patch's total area has increased annually from 2774.61 km^2 to 3329.06 km^2 (Figure 4-a), but the number of patches has decreased from 12986 to 12239. The patch area increase rate was 8.18%, which was the most significant from 2000 to 2010 (Figure 4-b), and the number of patches also decreased considerably (Figure 4-c). The distance between the rural settlement patch and the canal is inversely proportional to the settlement patch area's rate increase. The further the distance between the rural settlement patch and the canal, the higher the settlement patch's area increase rate (Figure 4-d).

The results show that the rural settlement spatial scale is in continuous expansion at various expansion rates. Change in the scale of rural settlements is mainly dominated by border expansion. The most significant expansion occurred in 2000-2010, mainly due to policy reasons (Shandong, 2010). The closer the rural settlement is to the canal, the faster the rate at which the settlement space scale increases and the greater the degree of settlement amalgamation.

5.1.2 Landscape metrics

MPS can indicate the degree of landscape fragmentation. The PSSD demonstrates the difference in the scale of rural settlements.

MPS values from 1980 to 2018 showed an overall upward trend and a negative correlation with the distance from the canal. PSSD values also showed an overall upward trend. From 1980 to 1990, the variation in each settlement zone was relatively smooth. From 1990, the PSSD values for canal-side zonal settlement increased first, and the overall value increased from 1990 to 2010. After 2010, all others slowed down, except for canal-side zonal settlement (Figure 4-e).

The results show that from 1980 to 2018, the fragmentation of rural settlement patches decreased annually. The overall rural settlement scale highlights the difference in development, and the difference as it pertains to the rural settlement area is evident year by year. The closer the rural settlements are to the canal, the earlier and more apparent the differentiation. In short, from 1980 to 2018, the rural settlement patches in the study area showed a partial merger trend, and the closer to the canal, the more evident that trend.

Figure 4 Spatial scale characteristics of rural settlements from 1980 to 2018

5.2 Rural settlement spatial Gravity Centre evolution characteristics

5.2.1 The CGC model

Based on the data set of rural settlements along the Grand Canal from 1990 to 2018, the longitude and latitude coordinates of each rural settlement polygon's centroid were calculated using ArcGIS 10.8. The centre of gravity coordinates of rural settlements in each data year was calculated using Excel statistical analysis. The results (Figure 5) show that the centre of gravity on both sides of the canal was relatively concentrated. During the period 1990-2018, there was a slight shift. The regional centre of gravity on the west side of the canal moved slightly parallel to the canal. The migration of the centre of gravity of the rural settlements on the canal's east side can be divided into three phases:

(1) 1980-2000, when the centre of gravity moved slightly to the northwest, the moving speed was uniform;

(2) 2000-2010, when it moved significantly to the southwest; and

(3) 2010-2018, when it moved to the northwest, the whole track took on a Z-shape.

In most years, the migration approached the canal, demonstrating the Grand Canal's attraction to the migration of rural settlements along its two banks from 1980 to 2018.

Figure 5 Gravity transfer map of rural settlements on both sides of the canal from 1980 to 2018

5.3 Rural settlement spatial agglomeration characteristics

5.3.1 ANN analysis

An ANN can represent the spatial clustering of rural settlements. The ANN values of the five samples in the villages along the canal were all less than 1(0.7760-0.7926), and the Z-scores of the high/low cluster were all negative (-47.80 − -44.86). The results show that the spatial distribution pattern has hardly changed from 1980 to 2018, revealing a low clustering pattern (Figure 6-a).

5.3.2 Hot spot analysis

The hot spots and cold spots of the scale distribution of rural settlements from 1980 to 2018 were obtained by considering the rural settlement patch area as the statistical attribute. The results show obvious regional differentiation in the distribution of cold and hot spots in rural settlements along the canal. The hot spots are more evident in some areas than others, with cold spots relatively concentrated in southern areas. By 2010, the number of hot spots on the north and east sides of the study area had decreased, and the cold spots on the south side had also decreased. These results show that the area of corresponding cold and hot spots has been reduced, and the scale of settlement patches tends to be different (Figure 6-b).

5.3.3 Kernel density analysis

The kernel density analysis and search radius of the rural settlements along the canal were set to 30 km, the kernel density maps of rural settlements in 1980, 1990, 2000, 2010, and 2018 were drawn. The higher the kernel density, the more settlement patches are distributed. Kernel density is classified into five levels, namely lowest, lower, medium, higher, and highest density, according to its value. The results show that from 1980 to 2018, the proportions of highest-density and higher-density areas concerning rural settlement density decreased, and the proportions of lowest-density and lower-density areas increased (Table 6-c). In terms of geographic space, results show a development trend involving one central core and multiple sub-cores. The single central core is distributed in the southwest of the study area (Yutai County, Feng County, and Pei County). Multiple sub-cores are distributed in groups, and the settlement's spatial pattern changes dynamically.

In short, from 1980 to 2018, the highest-density areas were mainly distributed around lakes and along rivers, and the settlements' overall kernel density showed a downward trend. This phenomenon aligns with the rapid urbanisation and industrialisation of rural settlements due to China's reform and opening up.

5.3.4 Landscape metrics

AI measures the aggregation index of rural settlements by the length of the patch's standard common edge, and the larger the value, the higher the spatial connectivity of rural settlement patches. Thus, PD represents the number of rural settlements per unit area.

From 1980 to 2018 (Figure 6-d), PD values showed a decreasing trend year by year and were most evident from 2000 to 2010. In the same sample year, the PD values of the canal-side and near-canal zonal settlements showed little change, whereas the PD values of the far-canal and farther-canal zonal settlements increased. From 1980 to 2018 (Figure 6-e), AI values were negatively correlated with the distance from the canal. The results show that the number of patches per unit area of rural settlements in the study area decreases annually, and the density of rural settlements tends to be sparse.

Figure 6 Spatial agglomeration characteristics of rural settlements along the Shandong section of the Grand Canal from 1980 to 2018

5.4 Rural settlement patch shape characteristics

5.4.1 Landscape metrics

LSI can reflect individual patches' shape information as well as dispersion or aggregation information among patches. PAFRAC values range from 1 to 2. The closer the value is to 1, the greater the degree of human intervention and the more exact and more regular the shape of the patch.

From 1980 to 2018 (Figure 7-a), the LSI values were positively correlated with the distance from the canal. From 1980 to 2000, the changes in PAFRAC values were relatively smooth. From 2000 to 2010, the changes in PAFRAC values increased significantly and then tended to be smooth again, and the overall value was negatively correlated with the distance from the canal.

The closer the rural settlement to the canal, the lower and more concentrated the degree of settlement boundary meander. The rural settlement boundary meander degree increased and was more dispersed 10 km away from the canal (Figure 7-b). The closer the village settlement to the canal, the more complicated the shape due to its long history. The construction of the canal and the railway's geographical location also led to less human intervention.

Figure 7 Rural settlement patch's landscape index zone from 1980 to 2018

6. The identification and quantitative analysis of the differentiation factors

6.1 Identifying the influencing factors

The evolution of rural settlements is affected by multiple factors. It can be summarised into natural factors and socioeconomic factors (Wang & Hu, 2012; Zhou & Liu, 2020). Based on the above analysis, the availability of data, the integrity of the time series, and the independence and integrity of each index were considered, and 1990, 2000, 2010, and 2018 were selected as sample years for impact detection, and refer to related literature and selected 13 detection factors (Table 1) (Kay, 2015; Cao et al., 2019; Yang et al., 2020; Li, 2020; Tan et al., 2021). This paper explores different factors' influence on the rural settlement space along the Grand Canal in Shandong province and clarifies the canal's influence on rural settlement space through a comparative analysis of each settlement zone.

Table 1 Statistical table of influencing factors and variable codes of rural settlement detection

6.2 Geodetector quantitative analysis

From the above, due to the adaptability of spatial pattern characteristics detection and the representativeness of Canal Regional type detection, the gathering characteristics of canals have the most spatial attributes and are most closely related to canals. Therefore, the dependent variable Y is the spatial attribute data of rural settlements, and the independent variable X is the exploration influencing factor data. Obtain spatial data consistency, each village settlement unit's centroid was extracted using ArcGIS 10.8 software, and each centroid's attribute value was obtained via sampling; the exact matching of X and Y data in space was realised (Wang & Xu, 2017; Cao et al., 2019). This study aims to determine the main influencing and auxiliary influencing factors of the spatial pattern of rural settlements and their correlation characteristics with the canal.

6.2.1 Single-factor detection

For the rural settlement patches in the whole settlement in the study area, the factor detection results show that, in short, economic and industrial factors have a more noticeable impact on rural settlements, followed by policy and living standards. On the contrary, the impact of natural environmental factors was the smallest (Figure 8-a).

For the rural settlement patches in the canal-side zonal settlement in the study area, the factor detection results show (Figure 8-b) the influence of science and technology facilities on rural settlements is obvious; economic and industrial factors are the second most, and environmental factors are the least influential.

For the rural settlement patches in the near-canal zonal settlement (Figure 8-c), the factor detection results show that agriculture, forestry, animal husbandry, and fishery were the dominant factors affecting the individual scale of rural settlement. In short, the influence of the living standard factor on the rural settlement is evident, followed by the economic industry factor, while the environmental factor exerts a minor influence.

For the rural settlement patches in the far-canal zonal settlement, the factor detection results show (Figure 8-d) that living standards factors have more obvious impacts on rural settlements, followed by economic and industrial factors. In contrast, natural environmental factors exerted the weakest influence.

For the rural settlement patches in the further-canal zonal settlement, the results of factor detection show (Figure 8-e) that the influence of policy factors on rural settlements is evident, followed by economic and industrial factors. In contrast, environmental factors were found to be the least influential.

The results show that agricultural production is the main factor for rural settlement areas along the Shandong section of the Grand Canal. Rural scientific and technological facilities and financial industries are the fundamental driving forces affecting the formation of rural settlement patch spatial pattern characteristics. In addition, policy expenditure and people's living standards significantly influence the rural settlement spatial pattern formation, while environmental factors exerted the slightest effect. This study shows that the closer the proximity to the canal, the higher the dependency on primitive agricultural production, and the more significant the improvement of rural scientific and technological facilities.

Figure 8 Trend and peak value of Q value in each settlement zone from 1990 to 2018.

6.2.2 Interaction factor detection

In this study, the maximum values of the interaction Q for the whole settlement and each canal settlement zone from 1990 to 2018 were calculated, and the most potent combination of influencing factors was found. By comparing the interaction results of different influencing factor combinations, auxiliary influencing factors of rural settlement spatial patterns can be obtained. For example, the occurrence frequency of the statistical factor X is shown in Table 2. The statistical results showed that rural residents' grain area and per capita disposable income did not play a prominent role in single-factor detection, but the interaction effect is noticeable, and they are the best additional factors.

Table. 2 Statistical table of Q maximum value and frequency of interaction factors in settlement zones from 1990 to 2018

7. Conclusions and discussions

7.1 Conclusions

This research uses the CGC model, kernel density analysis, ANN analysis, spatial hot spot detection, LM, and the geodetector to examine the rural settlement space and its succession along the Shandong section of the Grand Canal from 1980 to 2018. The scale pattern, Gravity Centre evolution characteristics, agglomeration pattern, and morphological characteristics of the rural settlement patch and their correlation with canal settlement were determined. In this paper, we identified the correlation factors and detected their single-factor and multi-factor interaction strength on the settlement distribution characteristics, as follows:

7.1.1 The rural settlement spatial pattern

(1) Rural settlement scale characteristics: The spatial scale of rural settlements along the Shandong section of the Grand Canal gradually expanded from 1980 to 2018, and rural settlement fragmentation decreased annually. The overall patch area appeared to follow an increasing trend while the number decreased. Some scholars found that the rapid increase of rural population and the acceleration of economic growth were the main reasons for the continuous increase of the scale of rural settlements, and the transformation from rural settlements to urban land was the main reason for the decrease in the number of rural settlements (Song, 2020; Li, 2020). Due to the announcement of the Shandong Rural Poverty Alleviation and Development Plan (2001-2010), the scale of rural settlements expanded significantly in that period.

The closer the rural settlements are to the canal, the more pronounced the settlement area's growth rate and the higher the incidence of settlement mergers. The Grand Canal attracted the migration of rural settlements along its two banks from 1980 to 2018. Therefore, it is imperative for village planning to clarify the scale characteristics and the law of gravity centre migration.

(2) Agglomeration characteristics of rural settlements: The spatial distribution characteristics along the Grand Canal showed an agglomeration pattern from 1980 to 2018, which was a significant low-cluster. The proportions of higher-density and highest-density areas in the overall settlements decreased: The highest-density areas were from 13.35% to 11.13%; higher-density areas were from 27.92% to 23.48%. The lower-density and lowest-density areas increased: The lowest-density areas were from 4.69% to 5.88%; the lower-density areas were from 17.74% to 21.85%. The dense rural settlements are primarily distributed around lakes and rivers. The overall situation is 'largely dispersed, small concentrated'. The spatial pattern is manifested in the development trend of one central core and multiple sub-cores. This phenomenon is related to the decline and disappearance of rural areas caused by rapid urbanisation and industrialization since the reform and opening up.

The further the rural settlements are from the canal and the greater the number of villages per unit area, the more obvious the growth rate, and the settlements' overall connectivity increases year by year; the closer the settlements are to the canal, the higher the connectivity. The apparent distribution characteristics can provide a reference for resource sharing and public facilities layout in regional planning.

(3) From 1980 to 2018, the overall boundary tortuosity and shape complexity of rural settlement patches increased. Between 2000 and 2010, the integration of rural settlements is the most obvious, and the degree of tortuosity and complexity increased significantly.

The closer the patch is to the canal, the more concentrated the distribution, but the more complex the shape. Greater proximity to the canal means a longer settlement formation history. Moreover, canal construction and railway construction overlap geographically, in the absence of influence from the railway and other factors caused by minimal human intervention. Clarifying its morphological characteristics will help to find the development direction for rural settlements along the canal according to local conditions. For example, a village with a well-preserved historical form gives full play to its historical advantages by opting for a suitable development plan.

7.1.2 Differentiation factors

(1) Some scholars have proposed that human and social factors such as population size, agricultural conditions, industrial structure, economic development level, and policy system are also the main driving forces for rural settlements' development and spatial evolution (Gulizre et al., 2020). Rural settlement areas along the Shandong section of the Grand Canal are dominated by agricultural production. Rural technological facilities and financial industries have the most significant impact on rural settlement patches. In addition, policy expenditures and people's living standards have a greater impact on the spatial pattern of rural settlements, while environmental factors have the most negligible impact. The closer the proximity to the canal, the more dependent settlements are on primitive agricultural production and improvements in rural science and technology facilities. Clarify the leading factors and find the optimal focus for the planning and designation of the spatial industrial layout, such as the development of modern agriculture in the canal settlements in this article to promote rural development.

(2) Double-factor effects are more substantial than single-factor effects. Rural residents' food area and per capita disposable income are the auxiliary influencing factors for the spatial differentiation of rural settlements. These factors can significantly enhance the impact of index factors on the spatial pattern evolution of rural settlements. In addition, the rural working population, the total output value of agriculture, forestry, animal husbandry and fishery, general public budget expenditures, and an adequate irrigation area also have a particular supporting role. Clarify the auxiliary influence factors, find the optimal auxiliary development point, and promote the development of the settlement at multiple aspects.

7.2 Discussions

This study adopts various analysis methods to study the spatial-temporal characteristics and influencing factors of rural settlements along the Grand Canal. Compared with the existing research, it creatively divides the settlements along the grand canal into different regions. It constructs the distance correlation model with the canal and makes multiple comparisons regarding time and space to explore the spatial-temporal evolution characteristics and its leading factors of the area along the Grand Canal.

The changes are related to the transformation of rural areas to urban areas in the context of urbanisation and industrialisation after China's Reform and Opening (Tian et al., 2016; Bao & Fang, 2012). Then, the impact of village relocation and Poverty Alleviation Policies in Shandong Province (Shandong, 2010) and the overlapping of the Grand Canal and railway construction lead to the relatively backward development of the canal region. Meanwhile, the summary of characteristics and study of influential factors provide a particular reference value for the government to develop the Grand Canal settlement and sustainable rural development.

However, the research is still preliminary, only following the natural environment and socio-economic factors mentioned many times in the relevant studies. Moreover, the historical and cultural factors of the grand canal are represented and have not been quantified that need further discussion in the future. Future research needs a longer historical review to summarise the characteristics of rural settlement succession and make an appropriate prediction. Finally, the authors suggest that this study should be introduced to the specific villages along the canal, combined with the specific situation. Furthermore, it should be adopted in other canal sections to promote determination of spatial industrial structure layout, grasp the direction of relocation of villages, merging points and migration, clarify the layout of resources sharing and public facilities allocation, to prove further the significance and external effectiveness of this study in practice.

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Data Availability Statement

The date that support the findings of this study are available from the corresponding author upon request.

Tables

Table 1 Statistical table of influencing factors and variable codes of rural settlement detection

Factor class		Variable code	Variables	Variables explanation	Date attributes	references
natural environment	natural	X1	altitude	The vertical distance of a point above sea level	spatial data	(Yang et al., 2020) (Zhang, 2020)
		X2	slope	The degree of steepness and slowness of surface units	spatial data	(Gulizre et al., 2020) (Yao et al,2020)
socioeconomic	population	X3	Rural working population	Number of rural employees	statistical data	(Li, 2020) (Gulizre et al., 2020)
	industry	X4	gross industrial output value	Sum of industrial output value	statistical data	(Yao et al.,2020) (Yang et al., 2020)
		X5	Total output value of agriculture, forestry, animal husbandry and fishery	The sum of output value of agriculture, forestry, animal husbandry and fishery	statistical data	(Li, 2020) (Tan et al.,2021)

		X6	Grain area	Land area for grain crops	statistical data	(Li, 2020) (Gulizre et al., 2020)
		X7	grain yield	Production of food crops	statistical data	(Yao et al.,2020) (Zhang et al.,2019)
	policy	X8	General public budget revenue	Government revenue	statistical data	(Gulizre et al., 2020) (Yang et al., 2020)
		X9	General public budget expenditure	Government expenditure	statistical data	(Yao et al.,2020) (Gulizre et al., 2020)
	living standard	X10	Balance of savings deposits of urban and rural residents	The sum of urban residents' savings and farmers' personal savings	statistical data	(Zhang et al.,2019) (Tan et al.,2021)
		X11	Per capita disposable income of rural residents	The total income of rural residents from various channels in that year	statistical data	(Tan et al.,2021) (Zhang et al.,2019)
	Science and technology facilities	X12	Total power of agricultural machinery	The total power of various agricultural power machinery	statistical data	(Yao et al,2020) (Tan et al.,2021)
		X13	Effective irrigation area	Irrigated farmland area	statistical data	(Zhang et al.,2019)

Table. 2 Statistical table of Q maximum value and frequency of interaction factors in settlement zones from 1990 to 2018

qmax	canal-side zonal settlements		near-canal zonal settlements		far-canal zonal settlements		farther-canal zonal settlements		The whole settlements	
1990	x3∩x6	EB	x3∩x6	EB	x3∩x6	EB	x6∩x13	EB	x3∩x6	EB
	0.7244		0.6002		0.6709		0.5415		0.5179	
2000	x9∩x12	EB	x9∩x12	EB	x9∩x12	EB	x11∩x12	EN	x5∩x9	EB
	0.7125		0.5746		0.7401		0.6161		0.5917	
2010	x6∩x12	EB	x6∩x12	EB	x7∩x12	EN	x4∩x6	EN	x4∩x6	EN
	0.6826		0.5607		0.6586		0.5573		0.5113	
2018	x5∩x13	EB	x5∩x13	EB	x11∩x12	EN	x12∩x13	EB	x5∩x13	EB
	0.6987		0.5697		0.6563		0.5396		0.5025	

EN(Enhance,nonlinear) EB(Enhance,bi-)

Factor X	X3	X4	X5	X6	X7	X9	X11	X12	X13
frequency	4	2	4	9	1	4	2	9	4

Figure legends

Figure 1 Location map of China Grand Canal and its Shandong section; (a) The location of the Grand Canal in China and Shandong Province; (b) Schematic diagram of each section of the Grand Canal of China; (c) Shandong section of Grand Canal.

Figure 2 The Shandong section of the Grand Canal and its administrative units at all levels;

Figure 3 Schematic diagram of research methods; (a) Research method flow; (b) Rural settlement belt along the Shandong section of the Grand Canal; (c) Diagram of discrete clustering; (d) Principle of Geodetector ＆ Interaction between explanatory variables X1 and X2 impacting on a response variable Y: q(Y|X1X2).（http://www.geodetector.cn/）.

Figure 4 Spatial scale characteristics of rural settlements from 1980 to 2018; (a) Spatial pattern and dynamic change of rural settlements along the Shandong section of the Grand Canal from 1980 to 2018; (b) Sum of total rural settlement area and its growth rate in the study area from 1980 to 2018; (c) Evolution of the number of settlement patches in different settlement zones from 1980 to 2018; (d) The evolution of rural settlement area in each settlement belt from 1980 to 2018; (e) Evolution of mean patch size (MPS) and patch size standard deviation (PSSD) of rural settlements in different settlement zones from 1980 to 2018.

Figure 5 Gravity transfer map of rural settlements on both sides of the canal from 1980 to 2018;

Figure 6 Spatial agglomeration characteristics of rural settlements along the Shandong section of the Grand Canal from 1980 to 2018; (a) Analysis on the average nearest neighbor index of rural settlements in the study area from 1980 to 2018; (b) Analysis of cold and hot spots of rural settlements in the study area from 1980 to 2018; (c) Density analysis of rural settlements along the Shandong section of the Grand Canal from 1980 to 2018; (d) Evolution of aggregation index (AI) and patch density (PD) of rural settlements in different settlement zones from 1980 to 2018.

Figure 7 Rural settlement patch's landscape index zone from 1980 to 2018;

Figure 8 Trend and peak value of Q value in each settlement zone from 1990 to 2018;