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Article

Spatial Pattern and the Process of Settlement Expansion in Jiangsu Province from 1980 to 2010, Eastern China

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Abstract: Human settlement expansion has very important effects on regional population migration, economic balance and ecosystem services. Understanding the evolution of settlement expansion and regional differences is significant for regional sustainability. The results showed that in the past 30 years, the urbanization rate in Jiangsu province was lower. From 1980 to 2010, the expansion area of urban settlement was larger than that of rural settlement. Urban settlement expanded slowly from 1980 to 2005 and strongly from 2005 to 2010. Rural settlement expanded greatly from 1980 to 1995, and 37.14% of settlement was mostly on cropland. The type of urban settlement expansion from 1980 to 1995 and from 2000 to 2005 was compact expansion. Settlement expansion in the south of Jiangsu province was greater than that in the north of Jiangsu province. The spatial pattern of settlement in most cities was a cluster. In the past 30 years, urban and rural settlement expansion had significantly different impacts on the soil and water environment. Urban settlement expansion was great in the south of Jiangsu province and widened the economic and social gap between the south and north of Jiangsu province.

Keywords: settlement; expansion; spatial pattern; Jiangsu province

1. Introduction

Global changes are significant issues worldwide and presenting scholars and government managers with challenges [1–3]. Land use expansion into wild lands and intensification of land use within semi-natural anthromes lead to anthropogenic transformation of the biosphere [4–8]. From 1980, many international projects, such as International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Programme on global environmental change (IHDP), have been set up for studying global changes and their effects [9]. Land use and land cover change (LUCC) has always been recognized as a key indicator in the field of global changes [10–14]. Moreover, human settlements are an important issue of LUCC and have a high correlation with ecosystem and environment conservation [13,15–25]. The changes of settlements reflect the interaction between humans and the natural environment [11]. The human settlements of cities are a function of the natural environment, society and economy, and their suitability directly affects the production, life, environment and transportation of cites [26,27].

The human settlements in developed countries are relatively stable, while the human settlements in developing countries, especially Asia and Africa, change greatly with the development of the economy and urbanization [11]. The study of settlements mostly focused on the historical evolution of settlements [28], informal settlements [15], the spatial pattern [29–31], the dynamics [13,27,28], the resilience of settlements in coastal or mountain areas [14] and sustainable management [11,23]. Society in developing countries has faced the problem of rapid settlement growth [12,13,26,27,32–34]. Recent studies have highlighted the urban or rural settlement dynamics and the effects of human settlements on the environment and ecology based on the city, urban agglomeration, metropolitan area and natural region [10,11,13,14,19,29,35–38], while few concern regional human settlement changes, such as the administrative region. More important is the scarcity of research that analyzes the urban and rural settlements together from an integrated perspective. Therefore, further studies into the regional differences of human settlements in an administrative area from an integrated perspective are required. At the province scale, the methods for quantitatively identifying the expansion area, the spatial-temporal types of settlement expansion and the comparison of cities are important.

The settlements in Jiangsu province have a high population due to the Yellow River and Yangtze River. The urban and rural settlements in Jiangsu province have changed greatly in the past 30 years. With the increasing income of farmers, rural settlements have gradually expanded into urban settlements. Rural settlements in the south of Jiangsu province expanded greatly, because the Chinese government implemented the policy of reform and opening up, and rural enterprises grew rapidly from 1978. The rural settlements in the north of Jiangsu province expanded later than those in the south of Jiangsu province. Many farmers in the north of Jiangsu province moved and worked in the south of Jiangsu province with higher wages. The characteristics of the settlement transformation in this region were the typical for China. This paper studies the characteristics and regional differences of urban and rural settlement growth, both from the expansion area and the spatial pattern, taking a case study from

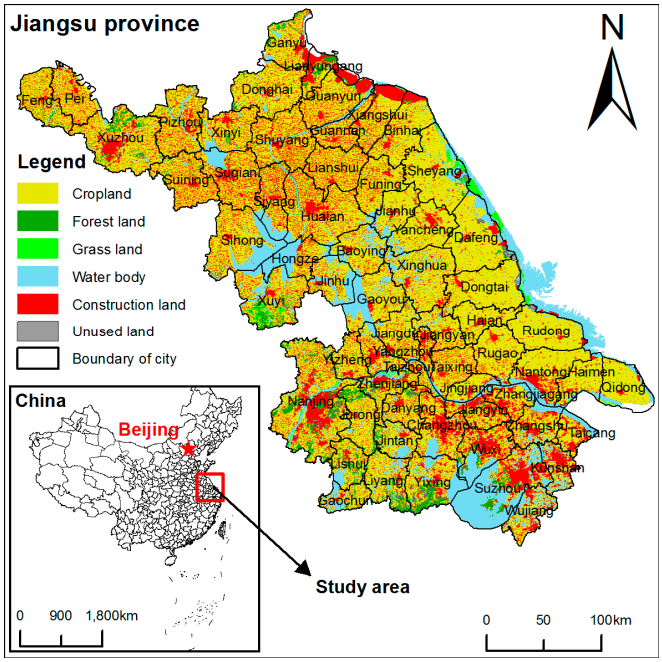
an administrative province in eastern China, where rapid settlement expansion has occurred and regional differences are dramatic. The paper aims to: (i) analyze the regional differences of human settlement expansion of the cities in Jiangsu province; (ii) compare the expansion of urban and rural settlements at regional scales; and (iii) determine the spatial patterns and regional differences of human settlements. To achieve the goals of this paper, remote sensing (RS) images and geographic information system (GIS) technology were applied to obtain and analyze the data of human settlements. The main aim is to reveal the differences in human settlement expansion and the spatial pattern of settlement expansion at an administrative region scale. This will help decision-makers of the province to consider the regional balance to form scientific strategies or policies for the sustainable development of human settlements in the study area and other similar regions.

2. Material and Methods

2.1. Study Area

Jiangsu province consists of 63 cities and counties (Figure 1), with a population of 78.69 million in 2010. The longitude and latitude of its position range from 116°18′E to 121°57′E and from 30°45′N to 35°20′N, respectively. The total area is 102.6 thousand square kilometers. The economic development level in Jiangsu province is among the top ten cities in China. The province also has a perfect location. It lies in the lower reaches of the Yangtze River and the head of the new Eurasian continental bridge. Meanwhile, the most common topography in Jiangsu is plains. The water resources are rich, such as the Yangtze River, Huai River, Jinghang Canal, Tongyu Canal, Taihu Lake, Hongze Lake, Gaoyou Lake, Luoma Lake and Huanghai coast. The climate in Jiangsu province is between the warm temperate zone and the subtropical zone. The percentages of the area of cropland, forestland, grassland, water area, settlement and unused land are 61.42%, 3.00%, 0.90%, 15.20%, 19.27% and 0.21%, respectively.

Figure 1. The location of the study area.



Jiangsu province has been divided into seven classes [39]. The first class is the south of the Yangtze River region; the second class is the Yangtze River and Huai River region; the last class is the north of the Huai River region. The first class region is classified into to two sub-regions, which are the area around Taihu Lake and the mountains and hills around Nanjing and Zhenjiang. The second class region is classified into three sub-regions, which are the area around the Yangtze River, the area around the coast and the Inner Lixiahe region. The third class is divided into two sub-regions, which are the area around the coast and Huaihe River and the area around the old Yellow River course.

2.2. Data and Methods

2.2.1. Data Collection

The settlement data of Jiangsu province for the years of 1980, 1995, 2000, 2005 and 2010 came from the National Science and Technology Infrastructure: Data Sharing Infrastructure of Earth System Science. The settlement data were digitized in the ArcGIS 10.2 Desktop (ESRI Inc., Redlands, CA, USA) software based on the TM remote sensing data (30 m × 30 m). The settlements in our paper included urban land and rural residential area. The boundaries of 63 counties were collected from the Department of Land and Resources of Jiangsu Province. The urban and rural settlements were not defined by the population, because of the large population in China, but by the scale of the built-up area in the region. The urban settlement in towns and cities is concentrated within a larger area. The rural settlement in the countryside is scattered.

2.2.2. Settlement Expansion Intensity Index (SEII)

The settlement expansion intensity index (SEII) of a spatial unit is the proportion of newly increased urban area to its total area [11,40]. It is correlated with the annual growth area and the total area of the spatial unit. The SEII is calculated using the following equation:

$$SEII_i = \frac{SLA_i^{t_2} - SLA_i^{t_1}}{TLA_i \times \Delta t} \times 100 \quad (1)$$

where $SEII_i$ stands for the settlement expansion intensity index of spatial unit i. $SLA^{t2}{}_i$ and $SLA^{t1}{}_i$ are the area of settlement at time t_2 and t_1, respectively. TLA_i is the total area within the administrative city and county boundary i and Δt is the study period.

2.2.3. Settlement Expansion Differentiation Index (SEDI)

The settlement expansion differentiation index (SEDI) is the ratio of the settlement expansion rate of a spatial unit to the settlement expansion rate of the study area [11]. The SEDI makes the expansion degrees of the spatial units comparable and detects the settlement change hotspots. We employ $SEDI_i$ as follows:

$$SEDI_i = \frac{\left|SLA_i^{t_2} - SLA_i^{t_1}\right| \times SLA^{t_1}}{\left|SLA^{t_2} - SLA^{t_1}\right| \times SLA_i^{t_1}} \quad (2)$$

where $SEDI_i$ indicates the settlement expansion differentiation index of unit i; $SLA^{t_2}{}_i$ and $SLA^{t_1}{}_i$ are the area of settlement of spatial unit i at time t_1 and t_2, respectively; and SLA^{t_2} and SLA^{t_1} indicate the total area of settlement in the study area at time t_1 and t_2, respectively.

2.2.4. Average Nearest Neighbor (ANN)

The average nearest neighbor is calculated based on the average distance from each feature to its nearest neighboring feature [41]. The average nearest neighbor index is the ratio of the observed mean distance to the expected mean distance. The expected distance is the average distance between neighbors in a hypothetical random distribution. We employ average nearest neighbor (ANN) as follows:

$$ANN = \frac{\overline{D_0}}{\overline{D_e}} = \frac{\sum_i d_i / n}{\sqrt{n/A}/2} \tag{3}$$

where D_o is the average observed mean distance; D_e is the expected mean distance; n is the number of features; d is the observed mean distance; and A is the area of spatial unit. If the index is less than one, the pattern exhibits clustering; if the index is greater than one, the trend is toward dispersion or competition.

2.2.5. Compactness of Urban Morphology

The compactness of urban morphology originates from the area and perimeter and is defined as the ratio of the radius of an idealized circle associated with the actual area of the isovist to the radius of an idealized perimeter from the actual perimeter in question [42].

$$C_i = \left(\frac{a_i}{\pi}\right) \Big/ \frac{p_i}{\pi} \tag{4}$$

where C_i is the morphology compactness of the spatial unit i; a_i is the area of the spatial unit i; and p_i is the perimeter of the spatial unit i. The compactness varies from a value of zero for a straight-line isovist with the vantage point at one of its ends to one for a circle with its vantage point at its center. The larger compactness index stands for the high compactness of the spatial morphology. Otherwise, the compactness of the spatial morphology is lower.

3. Results Analysis

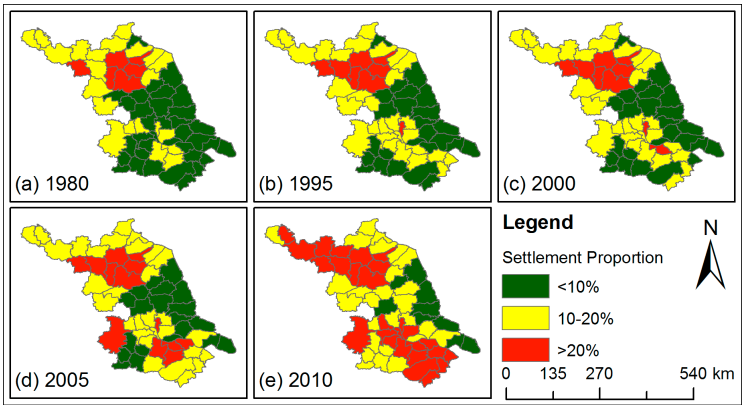
3.1. Settlement Proportion in Jiangsu Province

In Jiangsu province, the settlement area in 1980 was 11.00 thousand km^2 and expanded to 18.63 thousand km^2 in 2010. The settlement area increased greatly by 4502.51 km^2 from 2005 to 2010. From 1980 to 1995, from 1995 to 2000 and from 2000 to 2005, the area of settlement increased by 1997.76, 252.05 and 876.96 km^2, respectively. The settlement proportion in Jiangsu province increased from 10.76% to 18.22% from 1980 to 2010.

Figure 2 shows the settlement proportion in the Jiangsu province from 1980 to 2010. In 1980, the settlement proportion in Huaian and Suqian cities alone was larger than 20%. In the south of Jiangsu

province, the settlement proportion in Nanjing, Yangzhou, Wuxi and Taizhou alone was 10%–20%. The settlement proportion in other cities was lower than 10%. From 1980 to 2000, the settlement proportion of cities around the Yangtze River, such as Jiangdu, Taizhou, Jiangyan, Zhenjiang and Taixing, increased. From 2000 to 2005, the settlement proportion of cities around Taihu Lake, such as Yixing and Suzhou, increased. From 2005 to 2010, the settlement of cities, such as Xuzhou, Liyang and Jintan, around the old Yellow course region and the mountain area around Nanjing and Zhenjiang increased.

Figure 2. The settlement proportion changes from 1980 to 2010.



3.2. Urban and Rural Settlement in Jiangsu Province

In Jiangsu province, the area of rural settlement was far larger than that of urban settlement (Figure 3). In 1980, the area of rural settlement was five times the area of urban settlement. With the economic and social development of the cities, the urban and rural settlements expanded differently. In 2010, the area of rural settlement was about 1.5-times the area of urban settlement. The rural settlement expansion area from 1980 to 2010 was lower than the urban settlement expansion in all cities of Jiangsu province. The rural settlement expanded greatly from 1980 to 1995 and from 2000 to 2005. The urban settlement expanded by about 1000 km^2 from 1980 to 2005 and by about 5000 km^2 from 2005 to 2010. Only the rural settlement in Rugao, Jiangyan, Taixing, Changzhou, Zhangjiagang, Changshu, Taixing and Yixing changed greatly from 1980 to 2010 (Figure 4).

Figure 3. The rural settlement and urban settlement changes from 1980 to 2010.

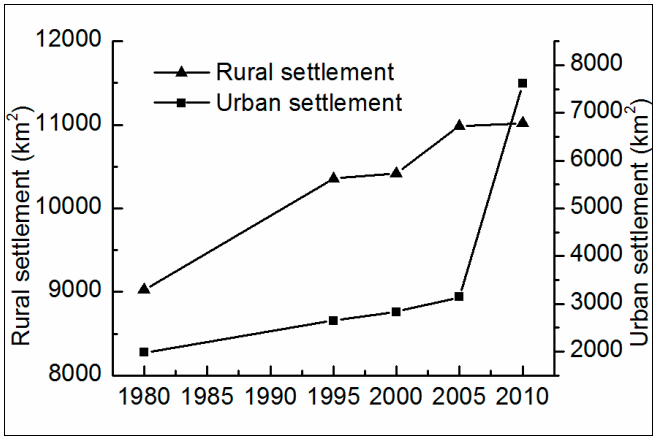
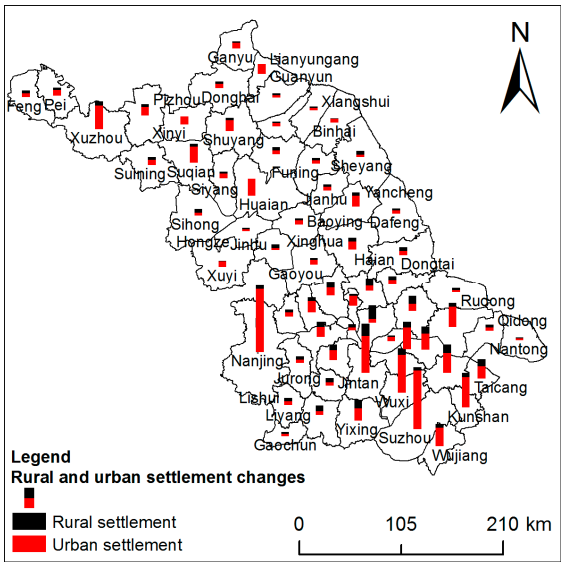


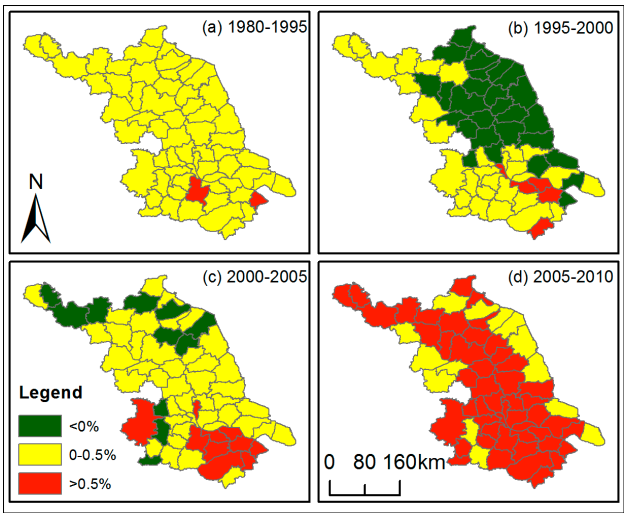
Figure 4. The differences of rural settlement and urban settlement changes from 1980 to 2010.



3.3. Settlement Expansion in the Cities of Jiangsu Province

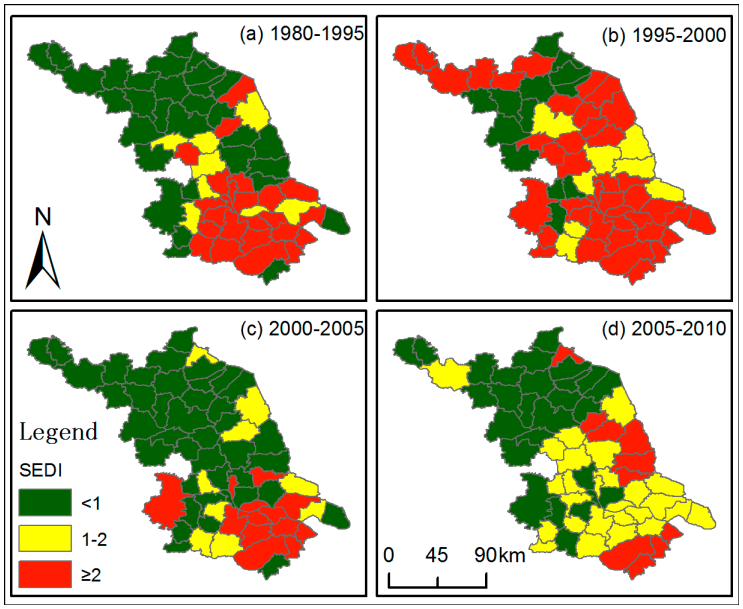
The SEII of Jiangsu Province from 1980 to 2010 is 0.25%. The SEII of Jiangsu province from 1980 to 1995, from 1995 to 2000 and from 2000 to 2005 was 0.13%, 0.05% and 0.17%, respectively. Specifically, the SEII of Jiangsu province from 2005 to 2011 was 0.88%. The SEII in different cities was different (Figure 5). From 1980 to 1995, the SEII in 61 cities was 0%–0.5%, and only in Changzhou and Taicang was it larger than 0.5%. From 1995 to 2000, the settlements of cities around the coastal area and the inner Lixiahe region decreased. From 2000 to 2005, the SEII of the cities in the north of Jiangsu province and its cities, such as Yizheng, Jurong and Gaochun, was below zero. The settlement expansion rate of cities around Taihu Lake, such as Suzhou, Wuxi, Jiangyin, Changzhou and Nanjing, increased. From 2005 to 2010, a settlement expansion rate of 77.78% of the cities in Jiangsu province was larger than 0.5%. The settlement expansion rates of cities around the coastal area, the old Yellow River course and the mountain region are less than 0.5%.

Figure 5. The settlement expansion intensity index (SEII) of different cities in different periods from 1980 to 2010.



The settlement expansion rates in different spatial units were different. The SEDI shows the ratio of the settlement expansion rate in spatial units and the annual settlement expansion rate in Jiangsu province (Figure 6). From 1980 to 1995, the settlement expansion rate of cities in the north of Jiangsu province, the mountain area and the coastal area was below the annual rate of the whole province. The rate of settlement expansion in cities around Taihu Lake and the Yangtze River was larger than the annual settlement expansion rate in Jiangsu province. From 1995 to 2000, the settlement expansion rate of cities in the south of Jiangsu province, the Lixiahe region and the coastal area was larger than the annual settlement expansion rate. From 2000 to 2010, the settlement expansion rate of cities in the north of Jiangsu province, the mountain zone and the Yangtze River Basin was lower than the average rate of settlement expansion in Jiangsu province. The settlement expansion rate of cities in the Taihu region and the coastal middle zone was larger than the average rate of settlement expansion in Jiangsu province.

Figure 6. The settlement expansion differentiation index (SEDI) of different spatial units in different periods from 1980 to 2010.



3.4. Settlement Expansion Trajectory in Jiangsu Province

Settlement expanded by occupying other landscapes, such as cropland, forestland or grassland. From 1980 to 2010, there were five settlement expansion trajectories, which were unchanged settlement, settlement from cropland, settlement from grassland, settlement from forestland and settlement from water area. From 1980 to 2010, 58.37% of settlement was from the previous settlement, and 37.40% of settlement was transferred from cropland. The percent of settlement in 2010 originating from forestland, grassland and water area was 0.65%, 0.47% and 1.08%, respectively (Table 1). The proportion of settlement transferred from cropland was different. Table 1 shows that 19.46% of settlement was changed from cropland from 2005 to 2010. The proportion of settlement from cropland from 2000 to 2005 was 6.87% and was larger than that from 1995 to 2010. The settlement from forestland, grassland and water area, occurring mostly from 2005 to 2010, was 1.64%.

Table 1. Major settlement expansion trajectory from 1980 to 2010.

Sources	Trajectory	Percent (%)
settlement	settlement→settlement→settlement→settlement→settlement	58.37
cropland	cropland→cropland→cropland→cropland→settlement	19.46
	cropland→cropland→cropland→settlement→settlement	6.87
	cropland→cropland→settlement→settlement→settlement	3.37
	cropland→settlement→settlement→settlement→settlement	7.44
	cropland→cropland→cropland→forestland→settlement	0.25
forestland	forestland→forestland→forestland→forestland→settlement	0.49
	forestland→forestland→settlement→settlement→settlement	0.17
grassland	grassland→grassland→grassland→grassland→settlement	0.32
	grassland→grassland→grassland→forestland→settlement	0.09
	grassland→grassland→grassland→settlement→settlement	0.06
water area	water area→water area→water area→water area→settlement	0.83
	water area→water area→water area→settlement→settlement	0.2
	water area→water area→water area→cropland→settlement	0.06

Figure 7 shows the settlement resources of cities in Jiangsu province in 2010. We found that in 2010, the settlement area in the north of Jiangsu province and that in the south of Jiangsu province was large. However, the resources of settlement were different. The settlement in the north of Jiangsu province was largely from unchanged settlement, while the settlement in the south of Jiangsu province was largely from cropland. In Nanjing city, half of the settlement in 2010 was from unchanged settlement and half was from cropland. The few settlements in Xuzhou and Nanjing cities were from forest, grassland and water area. Figure 8 shows the settlement area from cropland in different cities from 1980 to 2010. The settlement from cropland in the north of Jiangsu province mostly occurred from 2005 to 2010. The settlement from cropland in the south of Jiangsu province mostly occurred from 2000 to 2005. The settlement from cropland in Nanjing, Suzhou, Wuxi, Changzhou, Jiangyin, Yixing, Wujiang and Zhangjiagang occurred from 1980 to 2010. The settlement from cropland in Taicang and Kunshan cities occurred from 1980 to 2005.

Figure 7. The settlement expansion trajectories from 1980 to 2010.

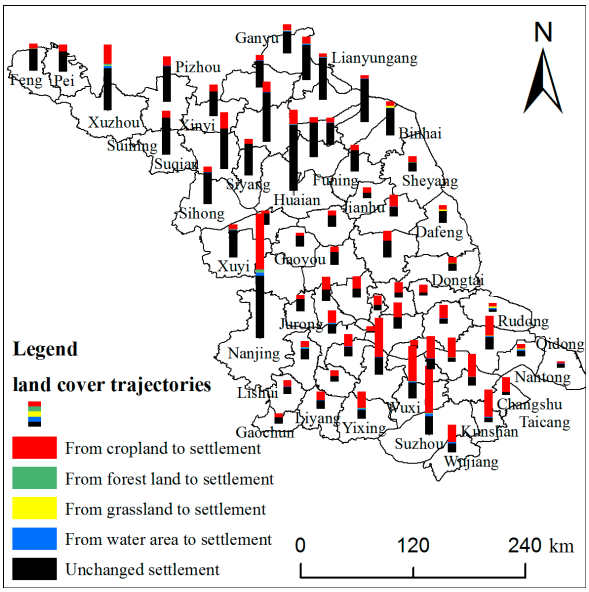
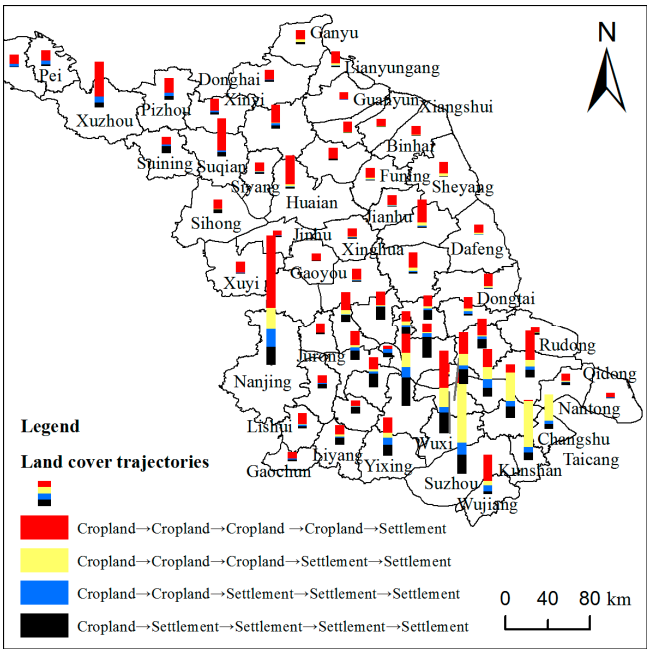


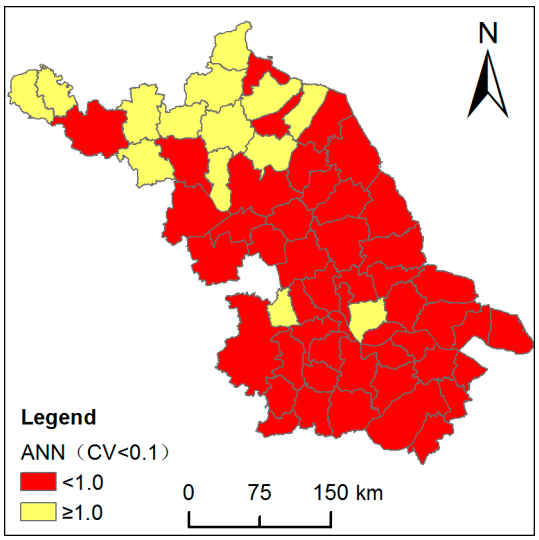
Figure 8. The cropland to settlement trajectories from 1980 to 2010.



3.5. Spatial Pattern of Settlement Expansion

Based on the ANN of different spatial units in Jiangsu province, we found that ANN in the north of Jiangsu province is larger than 1.0, and in the middle and south of Jiangsu province below 1.0 (Figure 9). The distribution of settlement in the north of Jiangsu province is random and that in the middle and south of Jiangsu province is accumulative.

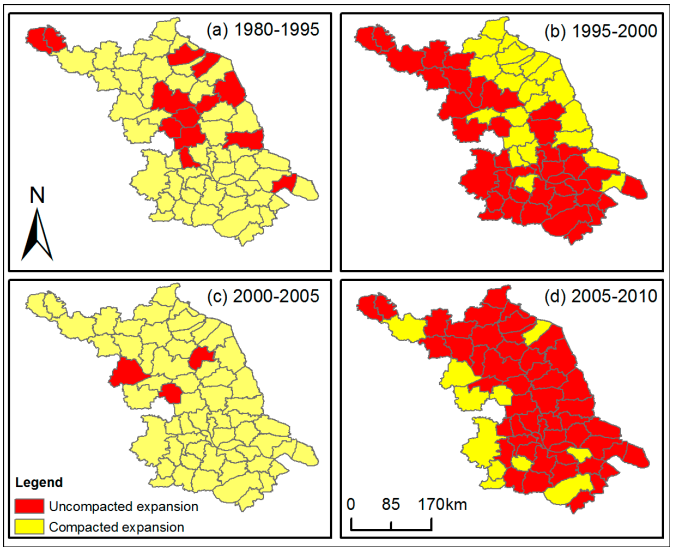
Figure 9. The average nearest neighbor (ANN) of different spatial units from 1980 to 2010.



The compactness of urban morphology in Jiangsu province changed from 0.13 to 0.12 from 1980 to 2010 (Figure 10). During 1980 and 2010, the compactness increased from 1980 to 1995 and from 2000 to 2005; the compactness decreased from 1995 to 2000 and from 2005 to 2010. Figure 7 shows the spatial pattern changes of cities in Jiangsu province from 1980 to 2010. The spatial pattern of city settlement expansion in Jiangsu province from 1980 to 1995 and from 2000 to 2005 was a compacted

type. However, the expansion of most city settlement in Jiangsu province from 1995 to 2000 and from 2005 to 2010 was an un-compacted type. From 1995 to 2000, the spatial pattern of cities in the south and west of Jiangsu province was the un-compacted type, and that in the east of Jiangsu province was the compacted type. From 2005 to 2010, the spatial pattern in the east and south of Jiangsu province was the compacted type, and that in the west of Jiangsu province was the un-compacted type.

Figure 10. The compactness ratio of the spatial units in Jiangsu province.



4. Discussion

Settlement expansion was driven by the development of the economy from 1978, which corresponded to other scholars' study [8]. Due to the Yellow River's old course in the north of Jiangsu province, the high density of the population led to a larger area of settlement. However, the population and settlement in the south of Jiangsu province was lower (Figure 7). During 1194 and 1835, the Yellow River seized the course of Huai River, and people in the north of Jiangsu province migrated into the south of Jiangsu. Ancient business in the south of Jiangsu province was flourishing. The economy in the north of Jiangsu province declined [43]. From 1980 to 2010, the settlement expansion in the south of Jiangsu province was greater than that in the north of Jiangsu province because of the reform and opening-up policy and history (Figure 2). A bunch of village and town enterprises have emerged from 1978 in the south of Jiangsu province. Rural settlement expanded greatly from 1980 to 1995 (Figure 2). Meanwhile, many croplands were transferred to settlement from 1980 to 1995 in the south of Jiangsu province (Figure 8). From 2001, China became a member of the World Trade Organization (WTO). More enterprises needed more land for economic development, and more people migrated into the south of Jiangsu province. The differences of settlement expansion in the north and south of Jiangsu province expressed the development imbalance of Jiangsu province.

Settlement in Jiangsu province expanded periodically. An (2012) indicated that the expansion of urban built-up area has a periodic characteristic due to the adjustment of the national strategy [43]. The area of settlement, the settlement expansion rate, the settlement expansion trajectory and the spatial pattern could reflect the periods of settlement expansion in Jiangsu province. The first period was from 1980 to 1995. In this period, the settlement expanded slowly and stably. From 1978, the Chinese

policy of reform and opening-up was carried out in China. China had a relatively free market economy. The rural and urban settlement expanded greatly from 1980 to 1995, and rural settlement expanded more than urban settlement (Figure 3). The settlement expansion rate in Jiangsu province had no significant differences (Figure 4). The second period was from 1995 to 2005. In this period, the settlement expansion was in the transformation period. The rural settlement changed little from 1995 to 2000 and changed greatly from 2000 to 2005. The spatial pattern of settlement expansion from 1995 to 2000 was the un-compacted type, and from 2000 to 2005, it was the compacted type. The settlement expansion rate in Jiangsu province had significant differences. In some spatial units, the area of settlement decreased from 1995 to 2005, because the Chinese government department reclaimed some settlement of a small area or obsolete settlements for cropland for national food security. The third period was from 2005 to 2010. In this period, settlement expanded greatly. The urban settlement expansion rate was higher. Rural settlement was stable. Many croplands were transferred to settlement. The settlement expansion rate in Jiangsu province had few differences.

Settlement in Jiangsu province expanded regionally. Tan (2004) indicated that the expansion of urban construction land was larger, while there were obvious regional differences [44]. Based on the area of settlement and the settlement expansion from 1980 to 2010, Jiangsu province was divided into a southern part and a northern part. The settlement expansion rate in the north of Jiangsu province is lower than that in the south of Jiangsu province (Figure 6). The settlement trajectory in the north of Jiangsu province was different from that in the south of Jiangsu province (Figure 7). Meanwhile, the settlement from cropland in the north of Jiangsu province was lower than that in the south of Jiangsu province (Figure 8). The spatial pattern of settlement in the north of Jiangsu province was random, while in the south of Jiangsu province, it was accumulative. The south of Jiangsu province consists of a mountain zone around Nanjing, Zhenjiang and Yangzhou, the south of the Yangtze River Basin, the Taihu Lake Basin and the south coastal area. The north of Jiangsu province consists of the Yellow River's old course around Xuzhou, Suqian and Huaian, the Lixiahe zone and the north coastal area. In Jiangsu province, the settlement expanded greatly, firstly in the Yangtze River Basin and Taihu Lake Basin from 1980 to 2005. Then, the settlement of Xuzhou City in the north of Jiangsu province expanded from 2005 to 2010 (Figure 2).

5. Conclusions

Settlement expansion in Jiangsu province was driven by the development of the economy after 1978. The settlement in Jiangsu province was in a stable expansion period from 1980 to 1995, in a transformation period from 1995 to 2005 and in a greater expansion period from 2005 to 2010. The settlement in Jiangsu province expanded regionally. The settlement in the south of Jiangsu province expanded more than in the north of Jiangsu province. The differences of settlement expansion had a negative effect on regional development. Settlement expansion in the south of Jiangsu province has a high negative effect on the soil and water environment. The economic development in the north of Jiangsu province demonstrated a large gap between the north and the south of Jiangsu province. The findings in this paper can suggest that the government of Jiangsu province pay attention to the differences between the north and south of Jiangsu province, as well as to the settlement history in land use planning.

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Author Contributions

Yan Xu is the designer of the research work and contributed to the experimental campaign and the paper writing. Lijie Pu contributed to the design, the results' post-processing and the discussion. Lifang Zhang contributed to the writing of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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