


Article

Research on Population-Land-Industry Relationship Pattern in Underdeveloped Regions: Gansu Province of Western China as an Example

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Abstract: Urbanization is a three-dimensional process including population, spatial, and economic changes. The coordination among the three dimensions is the key to sustainable urban development. Here, a population-land-industry index system of urbanization is constructed, and the degree of coupling and mutual feedback among population urbanization, land urbanization, and industrial urbanization are analyzed. The urbanization patterns and their spatiotemporal variation are identified. The results show that: (1) Population and land urbanization proceeded slowly in Gansu Province and their trends were similar, whereas industry urbanization proceeded faster than the two. From a spatial perspective, population, land, and industrial urbanization levels (PU_i , LU_i , and IU_i) decreased from southwest to northeast. The coupling degree of population, land, and industrial urbanization increased from 1998 to 2016 and showed significant spatial variation, decreasing from northwest to southeast. (2) Population, land, and industry all play a role in urbanization. PU_i was significantly and positively correlated with LU_i . However, there was no significant correlation between IU_i and PU_i and between IU_i and LU_i . The improvement of PU_i , LU_i , and IU_i effectively promoted the coupling degree of population, land, and industrial urbanization. (3) Seven urbanization patterns were identified in Gansu Province and evaluation units with the same urbanization pattern tended to be spatially close to each other. $IU_i > PU_i > LU_i$ (IX), $IU_i > LU_i > PU_i$ (X) and $IU_i > PU_i = LU_i$ (XI) were the dominant urbanization patterns. There was crisscross distribution of various urbanization patterns and, thus, it was not easy to observe the agglomeration center of certain urbanization pattern. (4) The urbanization pattern of the same evaluation unit changed with time. This change was mainly reflected in the change of relationship between population and land urbanization. Urbanization pattern changed more significantly in 2008–2016 than in 1998–2008. The changes were dominant by IX→XI, X→XI, XI→IX, and XI→X.

Keywords: underdeveloped regions; coupling degree; mutual feedback; urbanization pattern; transition matrix; Gansu Province of China

1. Introduction

Urbanization is a global phenomenon of socioeconomic transformation. With the acceleration of economic globalization, global urbanization and urban systems are undergoing important transformation and reconstruction. The urbanization of developed countries has basically reached a mature stage, and the focus of research has thus shifted to urbanization in developing countries. China's unique urbanization pattern has especially attracted extensive attention [1–3]. Since the 21st century, China has been experiencing rapid urbanization and industrialization. Although remarkable achievements have been made, the drawbacks of traditional urbanization pattern with the goal of

quantity growth have become increasingly apparent [4,5]. These drawbacks include waste of land resources, lack of urban functions, social disharmony, population urbanization lagging behind land urbanization, widening urban-rural gap, short settlement period, etc. The most severe problem is the poor quality of urbanization, especially the incoordination between land and population urbanization [6,7]. This is an important issue that is related to the sustainable development of human society and is a comprehensive research field that requires extensive and in-depth investigation. Friedmann pointed out that urbanization is a complex multidimensional process involving social space [8].

Chinese scholars pointed out that the growth of urbanization in China is characterized by incoordination, and specifically, land urbanization is proceeding faster than population urbanization [9]. In China, local governments often focus too much on urban spatial expansion or population agglomeration. It is also their custom to ignore the comprehensive development of land resources and fail to guide the urbanization of farmers. In this background, the coordinated growth of population urbanization and land urbanization has gradually become a hot research topic [10–12]. Most related research focuses on the influencing factors of coordination in urbanization [13], the causes of coordination in urbanization, and coordination in different types of urbanization [5,14,15]. Moreover, the definition of urban and rural areas is still controversial, causing difficulties in the differentiation of urban and rural populations [16]. International scholars generally define cities and villages through multiple indicators, such as population size and density, land use scale and density, and commuting time, and then judge the level of urbanization [17–19]. In China, scholars generally measure the comprehensive urbanization level of a region by weighted summation of multiple indicators. The key to this method is to construct a comprehensive indicator system that reflects the characteristics of urbanization in a region and then calculate the urbanization level based on the established indicator system. The multidimensional characteristics of the comprehensive indicator system overcomes the defect that single indicator method cannot reflect the rich connotation of urbanization. Indicator selection mainly considers population, economy, society, landscape, or environment, and is in accordance with the specific connotation of urbanization (e.g., population-land urbanization, population-land-industry urbanization, population-economy-land-society urbanization, etc.). On this basis, the calculated comprehensive urbanization level is able to reflect the connotation of urbanization.

Due to historical or practical reasons, there are still many problems remaining unsolved. The most prominent one is that they ignore something important. Researchers analyze urbanization from multiple dimensions, but they neglect a series of changes in economic development, social structure, and lifestyle during urbanization [7,20–22]. They also do not notice the structural relationships between dimensions and the evolution patterns of various dimensions [23]. Notably, there is little research on the time-series evolution of urbanization pattern, which is not conducive to revealing the rules of regional urbanization. On this basis, this paper focused on the three most important factors influencing urbanization: Population, land, and industry. Population agglomeration, urbanization of industry, and urbanization of land use should match with each other [24]. In other words, each of the three dimensions should adapt to and coordinate with each other. During rapid urbanization, the transfer of rural population to cities leads to the increase of demand for urban construction land, which then promotes the conversion of rural lands to urban uses. Land is the basic carrier of industrial development. Its various functions support continuous industrial development and lead to the accumulation of production factors in nonagricultural sector [24]. The coordination among them is conducive to promoting the development of coordination and sustainable of the three major systems of economy, society, and environment, as well as the regional economy and population, resources, environment, society, and internal strata [25–27]. It means the realization of effective nonagricultural transformation of population livelihood, coordinated development of land urbanization and population urbanization, and coordinated transformation of land urbanization and industrial transformation. A schematic illustrating the relationship among the three dimensions of urbanization and their coordination is presented (Figure 1) [28].

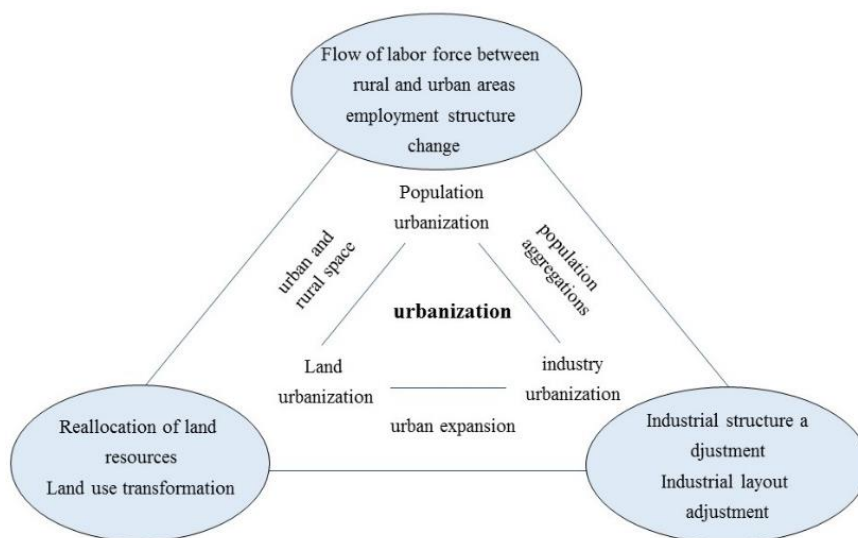


Figure 1. Mechanism of population-land-industry urbanization.

The Gansu Province, with poor economic development and low per capita income, is a typical underdeveloped region of China. In the process of urbanization, it faces problems such as low-level of urbanization, incomplete modern urban systems, uncoordinated urban-rural development, and excessive urbanization of agricultural lands. These problems are obstacles to the sustainable development of cities and can influence national economic construction, social stability, and security. Urban sustainable development is the process of achieving urban sustainability. Sustainable urbanization is a dynamic process that considers the various environmental, social, economic, and governance factors [29,30]. It emphasizes the simultaneous development of economy, society, and environment in the process of urbanization, as well as coordination between cities, between cities and rural areas, and between population, lands, and industries in development. The goal is to effectively manage and solve problems in urban space, such as ecological environmental protection, rational utilization of resources, personal welfare, and the satisfaction of basic human needs, to realize the comprehensive progress of urban society and the sustainable, stable, and coordinated development of the entire urban and rural regional system [31,32]. Taking the Gansu Province as the research object, we constructed a comprehensive evaluation index system for urbanization and used the coupling degree and Pearson models to analyze. The coordination and mutual feedback among the three dimensions (population, land, and industry) of urbanization as well as the time-series evolution of urbanization pattern are analyzed concretely in this paper. This paper attempts to use qualitative and quantitative methods in combination to reveal the coupling degree of population, land, and industrial urbanization in the Gansu Province and further understand the interaction between various elements in the process of urbanization. The results can provide useful information for solving the incoordination in urbanization process and achieving scientific development of cities.

2. Overview of Study Region

Gansu Province is located in inland western China and specifically at the intersection of China's northwest arid region, Qinghai-Tibet alpine region, and eastern monsoon region. It is thus the only province in China that has three natural geographical regions. The whole province is between 92°13' E and 108°46' E and between 32°31' N and 42°57' N (Figure 2). The total area of the province is 42.58×10^4 km², accounting for 4.72% of total area of China. The terrain tilts from southwest to northeast, and the areas of mountains and plateaus account for about 70% of the total land area of Gansu Province. Since the Gansu Province is located in inland China, it is difficult for warm and humid air currents from oceans to reach this region, precipitation is infrequent, and the climate in most regions is dry. Overall, the province has a continental temperate monsoon climate. The rivers in

the Gansu Province include both exoreic rivers (Yangtze River and Yellow River) and inland rivers. The drainage basin areas of these rivers account for 8%, 32%, and 60% of the total area of the Gansu Province, respectively.

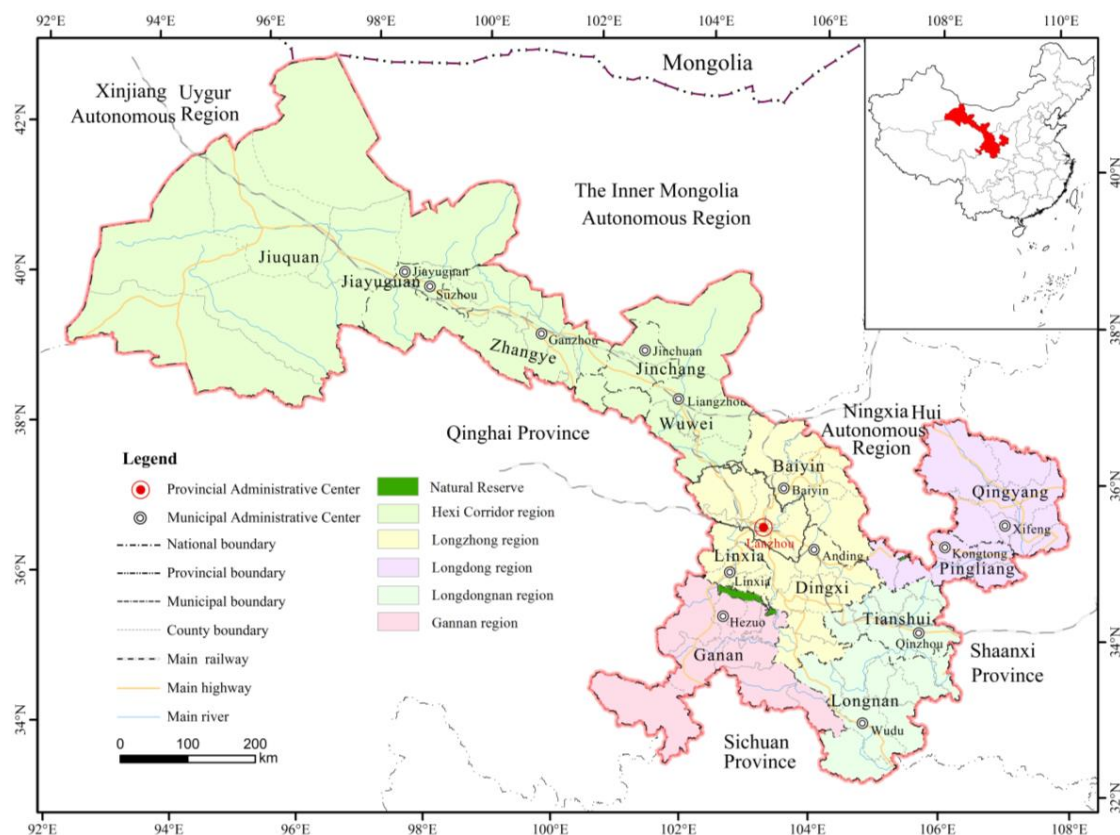


Figure 2. Location map of the Gansu Province.

The Gansu Province has jurisdiction over 14 cities (or prefectures) and 87 counties (or county-level cities and districts). It can be divided into five regions: Hexi Corridor region (Jiuquan city, Jiayuguan city, Zhangye city, Jinchang city, and Wuwei city), Longzhong region (Lanzhou city, Dingxi city, Baiyin city, and Linxia prefecture), Longdong region (Pingliang city and Qingyang city), Longdongnan region (Tianshui city and Longnan city), and Gannan region (Ganan prefecture). In 2017, the total population of Gansu Province reached 26.2571 million, among which the urban population reached 12.1807 million, accounting for 46.39% of permanent resident population. Many economic indicators of the Gansu Province are poorer than those of other provinces of China. In 2017, the GDP of Gansu Province was 767.7 billion Yuan and per capita GDP was 29,326 Yuan, both showing an increasing trend. The population of Gansu Province accounted for 1.89% of total population of the country, whereas its GDP accounted for only 0.93% of that of the country. The Gansu Province's social fixed asset investment accounted for 0.89% of that of the country, and general public budget revenue accounted for only 0.48% of that of the country. Gross agricultural product and the yields of main agricultural products both accounted for about 2.0% of those of the country. Gansu's GDP accounts for only about 30% of Shanghai and Liaoning's, and about 10% of Guangdong and Jiangsu's. The gap is widening. Among the 12 provinces (municipalities and autonomous regions) in western China, the Gansu Province is only ranked eighth in terms of GDP. Its further development is limited by market, capital, technology, ecology, environment, and human resources. In 2017, the per capita disposable income of urban residents in Gansu Province was 27,763.4 Yuan, and the per capita net income of farmers in Gansu Province was 8076.1 Yuan. In 2011–2017, the annual average growth rates of both exceeded 11%. The per capita consumption expenditure of urban residents in Gansu Province was 20,659.4 Yuan, which was 2.66 times of that of rural residents. The Engel's coefficient of

residents in Gansu Province was 29.6%, and the difference in the coefficient between urban and rural areas was small. The incidence of poverty was 9.7%.

3. Research Methods and Data Sources

3.1. Research Methods

3.1.1. Constructing an Index System of Population-Land-Industry Urbanization

According to existing research and considering the availability and quantifiability of data, we selected three indices to evaluate urbanization rural transformation degree at a county scale in Gansu Province. The three indices included population urbanization rate, land urbanization rate, and industrial urbanization rate [28]. The calculation procedures are as follows:

$$PU_i = UP_i / TP_i \quad (1)$$

$$LU_i = \frac{UL_i + IL_i}{UL_i + IL_i + RL_i} \quad (2)$$

$$IU_i = \frac{GDP_i - PGDP_i}{GDP_i} \quad (3)$$

where PU_i is the population urbanization rate of the i th county. Increase in PU_i reflects the transfer of rural population to urban areas, which leads to increasing share of urban population in total population. UP_i is the permanent urban population at year end in i th county. TP_i is the total permanent population at year-end in i th county. LU_i is the land urbanization rate of the i th county. UL_i is the area of urban construction lands (including urban lands used for residential, commercial, industrial, warehousing, institution, school, and other purposes) in the i th county. RL_i is the area of rural construction lands (including rural lands used for residential, industrial, warehousing, institution, school, and other purposes) in the i th county. IL_i is the area of industrial and mining lands (including lands used for industrial and mining purposes) in the i th county [33]. IU_i is the industrial urbanization rate of the i th county. Increase in IU_i reflects the flow of production factors from rural areas to urban areas, which leads to the change and development of industrial structure with socio-economic development. GDP_i is the GDP of the i th county. $PGDP_i$ is the primary sector GDP of the i th county.

3.1.2. Constructing a Model for Evaluating Coordination of Population-Land-Industry Urbanization

In order to objectively and scientifically determine the coordination of population, land, and industrial urbanization, the concept of capacitive coupling and capacitive coupling coefficient model in physics were used for measurement [34].

$$C_i = \left[\frac{PU_i \times LU_i \times IU_i}{\left(\frac{PU_i + LU_i + IU_i}{3} \right)^3} \right]^{\frac{1}{3}} \quad (4)$$

where C_i is the coupling degree of population, land, and industrial urbanization in the i th county. The coupling degree C_i ranges between 0 and 1, and the larger the value, the better the coordination of the three dimensions. The coupling degree reaches a maximum value of 1 only when $PU_i = LU_i = IU_i$. This approach is based on existing results [35,36] and the actual situation of the study region. According to the calculation results of coupling degree, the relationship among the three dimensions of urbanization can be classified into four stages: Low-coupling stage ($C_i \leq 0.3$), antagonistic stage ($0.3 < C_i \leq 0.6$), run-in stage ($0.6 < C_i \leq 0.8$), and high-coupling stage ($0.8 < C_i \leq 1$).

3.1.3. Local Spatial Autocorrelation

Spatial autocorrelation is a spatial statistical method that analyzes the degree to which a variable is correlated with itself through space. Here, Getis-Ord G_i^* was used to identify the spatial agglomeration characteristics (or hotspots and coldspots) of PU_i , LU_i and IU_i .

$$G_i^* = \frac{\sum_j^n W_{ij}x_j}{\sum_{i=1}^n x_i} \quad (5)$$

where x_i is the observed value of i th county; W_{ij} is the spatial weight matrix (1 for spatial neighbor and 0 for nonadjacent region). If $G_i^* > 0$, then it indicates high-high agglomeration, i.e., a hotspot region; if $G_i^* < 0$, then it indicates low-low agglomeration, i.e., a coldspot region; if $G_i^* = 0$, then it indicates high-low agglomeration.

3.1.4. Pearson Correlation Analysis

C_i were taken as dependent variables (Y), and PU_i , LU_i , and IU_i were taken as independent variables (X). Then, Pearson correlation coefficient method was used to analyze the statistical relationship between the independent and dependent variables. A two-tailed test was performed at 0.05 and 0.01 significance levels to determine the influence of various factors on C_i .

$$C(Y_i, X_j) = \pm \max\left\{ \left| C_1(Y_i, X_j) \right|, \left| C_2(Y_i, X_j) \right| \right\} \quad (6)$$

$$C_2(Y_i, X_j) = \pm \max\left\{ \left| C_1(\ln Y_i, X_j) \right|, \left| C_1(Y_i, \ln X_j) \right|, \left| C_1(\ln Y_i, \ln X_j) \right| \right\} \quad (7)$$

where Y_i is the i th dependent variable; X_j is the j th independent variable; $C_1(Y_i, X_j)$ is the Pearson correlation coefficient between the Y_i and X_j ; $C_1(\ln Y_i, X_j)$ is the Pearson correlation coefficient between $\ln Y_i$ and X_j ; $C_1(Y_i, \ln X_j)$ is the Pearson correlation coefficient between Y_i and $\ln X_j$; $C_1(\ln Y_i, \ln X_j)$ is the Pearson correlation coefficient between $\ln Y_i$ and $\ln X_j$; $C_2(Y_i, X_j)$ is the coefficient with the greatest absolute value among $C_1(\ln Y_i, X_j)$, $C_1(Y_i, \ln X_j)$ and $C_1(\ln Y_i, \ln X_j)$ and its sign is consistent with that of the original coefficient; $C(Y_i, X_j)$ is the coefficient with greater absolute value between $C_1(Y_i, X_j)$ and $C_2(Y_i, X_j)$ and its sign is consistent with that of the original coefficient.

3.1.5. Identifying Urbanization Pattern

Population urbanization level, land urbanization level, and industrial urbanization level were selected as three basic indices of urbanization. After PU_i , LU_i , and IU_i were calculated, their values were graded at 10% intervals. Then, the values were ranked and their ranks RPU_i , RLU_i , and RIU_i were obtained. This means that rank data, in addition to absolute value data, were used to examine the relationship among population, land, and industrial urbanization in the same region. The aim is to examine which dimension changes faster and which one tends to lag in the process of regional urban-rural structural change. On this basis, the urbanization pattern can be classified into 13 categories, corresponding to different relationships among the three dimensions of urbanization (Table 1).

Table 1. Urbanization patterns.

Urbanization Pattern	Relationship	Connotation
I	$PU_i > LU_i > IU_i$	Population structure changes fastest, followed by land structure and then by industrial structure.
II	$PU_i > IU_i > LU_i$	Population structure changes fastest, followed by industrial structure and then by land structure.
III	$PU_i > LU_i = IU_i$	The changes in land structure and industrial structures are comparable and slower than the changes in population structure.
IV	$PU_i < LU_i = IU_i$	The changes in land structure and industrial structures are comparable and faster than the changes in population structure.

Table 1. Cont.

Urbanization Pattern	Relationship	Connotation
V	$LU_i > PU_i > IU_i$	Land structure changes fastest, followed by population structure and then by industrial structure.
VI	$LU_i > IU_i > PU_i$	Land structure changes fastest, followed by industrial structure and then by population structure.
VII	$LU_i > PU_i = IU_i$	The changes in population structure and industrial structures are comparable and slower than the changes in land structure.
VIII	$LU_i < PU_i = IU_i$	The changes in population structure and industrial structures are comparable and faster than the changes in land structure.
IX	$IU_i > PU_i > LU_i$	Industrial structure changes fastest, followed by population structure and then by land structure.
X	$IU_i > LU_i > PU_i$	Industrial structure changes fastest, followed by land structure and then by population structure.
XI	$IU_i > PU_i = LU_i$	The changes in population structure and land structures are comparable and slower than then changes in industrial structure.
XII	$IU_i < PU_i = LU_i$	The changes in population structure and land structures are comparable and faster than the changes in industrial structure.
XIII	$PU_i = LU_i = IU_i$	The changes of population, land and industrial structures are consistent, indicating good coordination among population, land and industrial urbanization.

3.2. Data Sources

This paper selected the 87 counties of Gansu Province as the research object and took 1998–2016 as the research period. Basic data including total population, rural population, urban population, urban construction land area, rural construction land area, industrial and mining land area, regional GDP, primary-sector GDP, etc. Those data were from the Gansu Province Development Yearbook (1998–2016).

4. Results

4.1. Temporal-Spatial Patterns of PU_i , LU_i , and IU_i

4.1.1. Temporal Pattern of PU_i , LU_i , and IU_i

From 1998 to 2016, population and land urbanization proceeded slowly in the Gansu Province and showed similar trends (Figure 3). In comparison, industrial urbanization was at a high level and proceeded faster than population and land urbanization (Figure 3). The PU_i and LU_i results were relatively consistent with the actual urbanization status (black curve, Figure 3) of the Gansu Province from 1998 to 2016, while IU_i results tended to deviate from the actual urbanization status of the Gansu Province. The fitting degrees between PU_i and the actual urbanization rate and between LU_i and the actual urbanization rate were high, with fitting coefficients reaching 0.47 and 0.81, respectively. This shows that the urbanization process in the Gansu Province is more affected by changes of population and land structures.

From 1998 to 2016, PU_i and LU_i were generally lower than IU_i of 87 evaluation units in the Gansu Province. The outliers of PU_i and LU_i were concentrated on the larger value side, the median differed greatly from the average, and the median was located in the lower end of the interquartile range (Figure 3). Therefore, both indices presented skewed distribution. The distribution of PU_i changed from dispersion to concentration with time, and the difference between the average and the median was gradually decreased. In 1998, 28.74% of the counties had a PU_i greater than the average. In 2016, this proportion increased to 35.63%. The change process of LU_i can be divided into two stages: 1998–2006 and 2007–2016. There was no obvious change in LU_i distribution in the previous stage, while in 2007–2016 the interquartile range and the full range of LU_i distribution shrank gradually. In 2016, the maximum value of LU_i reached 0.938 and decreased by 0.047 and 0.055 than those in 1998 and 2007, respectively. In 2016, the average of LU_i increased by 36.28% and 25.2% compared with those in 1998 and 2007, respectively. IU_i values were concentrated within the range about 1.5 times

of interquartile range and basically presented symmetrical distribution. In 1998–2016, the difference between the average and median of IU_i remained smaller than 0.043 and was only 0.0145 in 2008. IU_i showed a rising trend with time and since 2003 it remained greater than 0.4. In 2016, 43.53% of counties had an IU_i value greater than the average (0.793).

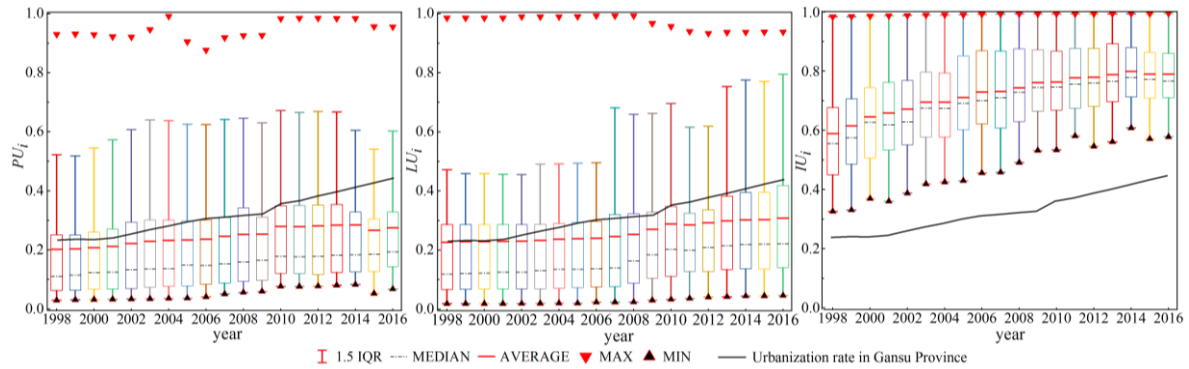


Figure 3. Trends of PU_i , LU_i , and IU_i of evaluation units of the Gansu Province in 1998–2016.

4.1.2. Spatial Pattern of PU_i , LU_i , and IU_i

Natural breaks method was used to classify PU_i , LU_i , and IU_i into five grades and then their spatial patterns in 1998, 2008, and 2016 were obtained (2008 is a key year for transformation of China’s urban-rural relationship from urban-rural integration to urban-rural economic and social integration). All three indices showed significant spatial variation and generally decreased from southwest to northeast (Figure 4).

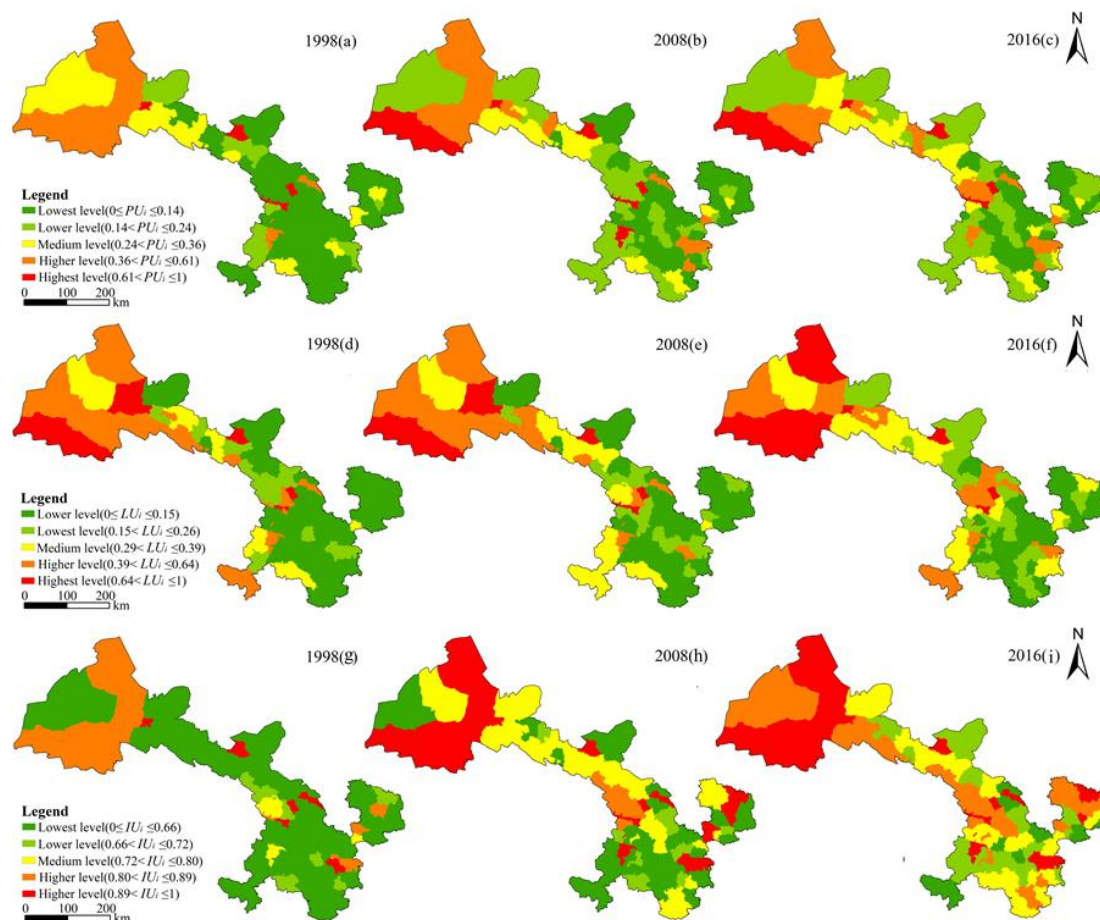


Figure 4. Spatial patterns of PU_i , LU_i , and IU_i in Gansu Province in 1998–2016.

The spatial pattern of PU_i changed significantly from 1998 to 2008 and remained almost stable after 2008. In 1998, the number of evaluation units with V-level PU_i was small and such evaluation units only included Jiayuguan city, Lanzhou city, and several municipal districts. The PU_i of the regions to the west of central Hexi Corridor were relatively high, mainly of III- or IV-level. The PU_i of the regions to the east of Zhangye City (except Lanzhou city and Baiyin city) were generally low, mainly of I-level, and the evaluation units with I-level PU_i accounted for 60.92% of all evaluation units. From 1998 to 2008, the PU_i of most evaluation units in the Gansu Province increased significantly. The PU_i of central Hexi Corridor increased steadily, whereas the PU_i of the regions to the east of Lanzhou city were still mainly of I- and II-levels. Evaluation units with IV- or V-level PU_i were sparsely distributed in municipal district regions. From 2008 to 2016, the PU_i of the eastern part of Hexi Corridor increased, while the changes in PU_i of other regions were insignificant.

The spatial pattern of LU_i was similar to that of PU_i . In 1998, LU_i decreased from west to east. The evaluation units with III-level or higher LU_i were mainly distributed in the central and western parts of Hexi Corridor, Lanzhou city, and Gannan region, accounting for 29.88% of all evaluation units. From 1998 to 2008, the LU_i of the central and western parts of Hexi Corridor changed little, still mainly of level-III or higher level. The LU_i of the regions to the east of central Hexi Corridor changed significantly: The number of evaluation units with level-III or higher LU_i increased, while that of evaluation units with I-level LU_i decreased. These evaluation units were mainly distributed in Longzhong, Longdong, and Longdongnan regions to the east of Lanzhou city. From 2008 to 2016, LU_i changed little, and the LU_i of evaluation units around the evaluation units already with III-level or higher LU_i increased to reach level III or higher levels. The number of evaluation units with I-level LU_i decreased a little, and such evaluation units were mainly distributed in Longzhong, Longdong, and Longdongnan regions, accounting for 89.29% of all evaluation units in these three regions.

The spatial pattern of IU_i changed dramatically. In 1998, the IU_i was low in general. The number of evaluation units with I-level IU_i reached 62, accounting for 71.26% of all evaluation units. The number of evaluation units with level-III or higher IU_i reached 19, and these evaluation units were sparsely distributed in municipal district regions. From 1998 to 2008, IU_i increased significantly. It presented a spatial pattern of high value in the west and low value in the east. The number of evaluation units with I-level IU_i decreased to 32, and the number of evaluation units with III-level or higher IU_i increased to 45, accounting for 51.72% of all evaluation units. In Hexi Corridor region, more than 75% of evaluation units had a III-level IU_i . In the regions to the east of Lanzhou city, 42.53% of evaluation units had a I- or II-level IU_i . From 2008 to 2016, IU_i increased again. There were only nine evaluation units with I-level IU_i , sparsely distributed in Longzhong and Gannan regions. The number of evaluation units with III-level or higher IU_i reached 61, accounting for 70.11% of all evaluation units.

A hotspot analysis tool was used for local spatial autocorrelation analysis to obtain the hotspots and coldspots of PU_i , LU_i , and IU_i (Figure 5). The spatial patterns of hotspots and coldspots of each index were consistent in all three years, all presenting certain spatial agglomeration. The hotspots of PU_i were distributed in the municipal districts of Jiuquan city and Jiayuguan city and the regions surrounding Lanzhou city urban area. The coldspots of PU_i were distributed in Longzhong and Longdongnan regions. With the extension of time, the spatial range of hotspots and coldspots of PU_i increased first and then increased. The hotspot and coldspot regions of LU_i expanded compared with those of PU_i . The hotspots of LU_i included the municipal districts of Jiuquan city and Jiayuguan city as well as the regions surrounding Lanzhou city urban area. The coldspots of LU_i included Longzhong, Longdongnan, and Longdong regions. These results suggest that population and land urbanization were spatially consistent in the Gansu Province, and the urbanization of lands in some evaluation units was even faster than that of population. With the extension of time, the hotspot and coldspot regions of IU_i expanded. Notably, the coldspots of IU_i expanded toward the northwest of the Gansu Province.

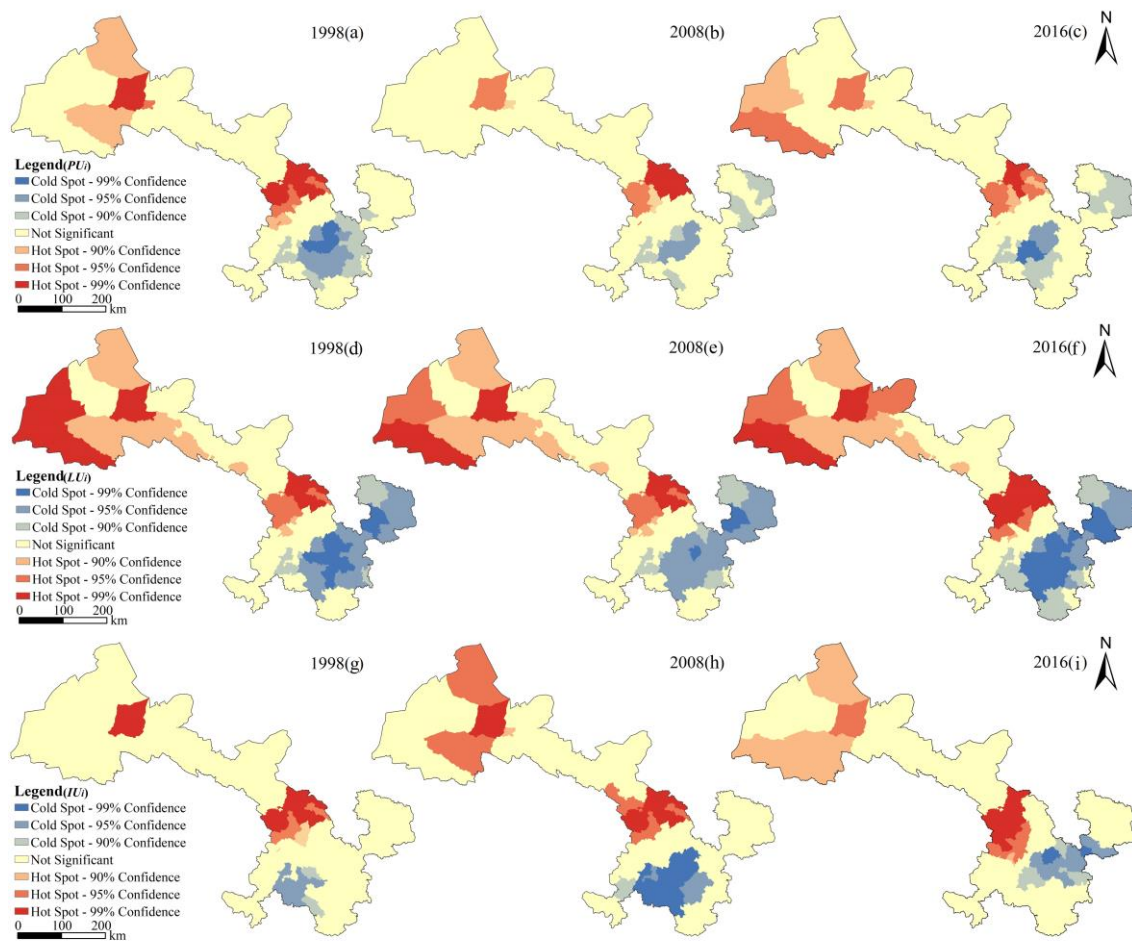


Figure 5. Hotspots and coldspots of PU_i , LU_i , and IU_i in the Gansu Province in 1998–2016.

4.2. The coupling Relationship among PU_i , LU_i , and IU_i

4.2.1. Temporal Pattern of Coupling Relationship among PU_i , LU_i , and IU_i

From 1998 to 2016, the coupling degree (C) of population, land, and industrial urbanization in Gansu Province remained higher than 0.3 (Figure 6). The minimum and average values of C increased from 0.389 and 0.741 to 0.515 and 0.809, respectively. The difference between the average and the median remained smaller than 0.012 and in 2013 the two were equal. The median gradually reached the middle of the box with the extension of time. C values were mainly in the range about 0.15 time of the interquartile range, and the distribution tended to be concentrated. In 2016, the C of 95.4% of evaluation units exceeded 0.6. Therefore, the population, land, and industry systems in Gansu Province were in run-in stage or high coupling stage.

4.2.2. Spatial Pattern of Coupling Relationship among PU_i , LU_i , and IU_i

The coupling relationship among the population, land, and industrial urbanization in Gansu Province showed significant spatial variation. The coupling degree (C) of them decreased from northwest to southeast (Figure 7a–c).

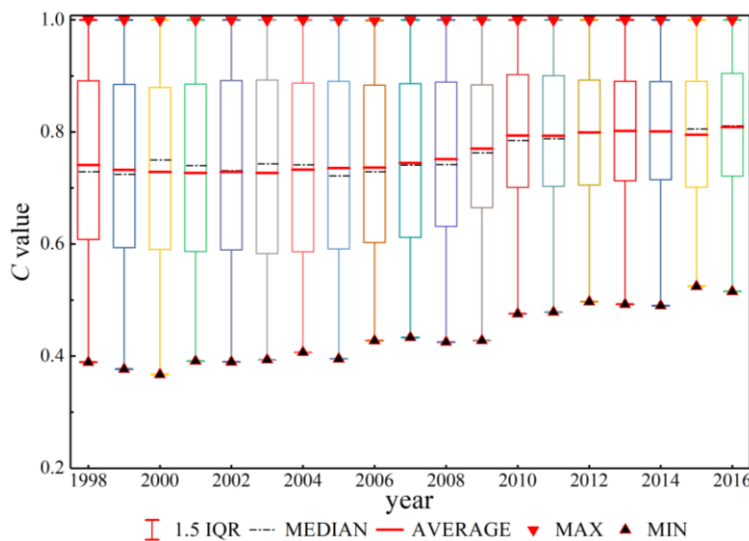


Figure 6. Trend of coupling degree C of PU_i , LU_i , and IU_i of Gansu province from 1998 to 2016.

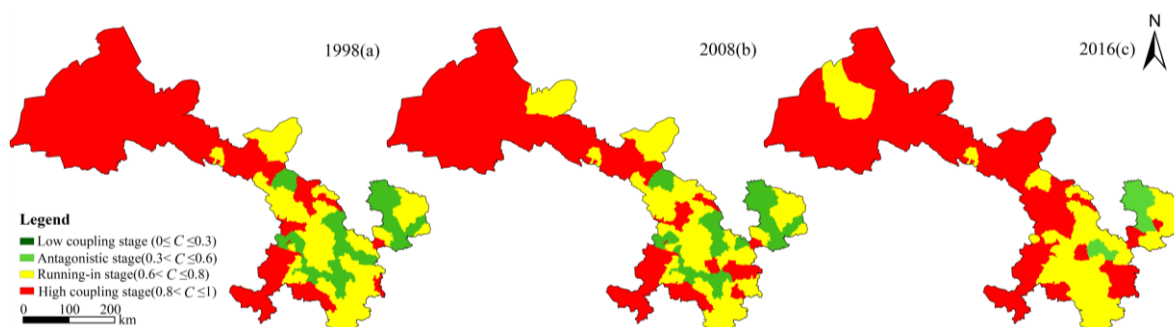


Figure 7. Spatial pattern of coupling degree (C) of population, land, and industry systems during urbanization in the Gansu Province in 1998–2016.

In 1998, the population, land, and industrial urbanization in 68 (78.16%) evaluation units were in high coupling stage or run-in stage. Specifically, the three processes were mainly in high coupling stage in the Hexi Corridor and Gannan region, and in run-in stage in the Longdongnan region. The coupling of the three processes in Longzhong and Longdong regions showed significant center-periphery pattern: Three processes in run-in stage in central regions and in antagonistic stage in peripheral regions. From 1998 to 2008, the spatial pattern of the coupling degree of the three processes changed little. From 2008 to 2016, the coupling degree of the three processes increased. The number of evaluation units with three processes in antagonistic stage decreased from 16 in 2008 to four in 2016 and these evaluation units were mainly in Longzhong and Longdong regions. The number of evaluation units with three processes in high coupling stage reached 47. More than 90% of evaluation units in the regions to the west of Lanzhou city had three processes in high coupling stage, while the regions to the east of Lanzhou city had three processes in run-in stage. Hexi Corridor is characterized by good economic development. Its industrial agglomeration, transformation and upgrading have effectively accelerated regional urbanization. The demand for lands for industrial development, infrastructure construction, and human settlement expansion continue to increase, resulting in large-scale conversion of cultivated lands to construction uses. The urbanization of lands is extremely rapid, leading to the transfer of farmers who lose their lands to nonagricultural sectors for employment. In comparison, the Longzhong, Longdong, Longdongnan, and Gannan regions are all characterized by a relatively simple industrial structure and a relatively high proportion of primary industry. Their industrialization is in an initial stage. Compared with industrial and employment transformation, the conversion of cultivated lands

to construction uses is of small scale and slow. Therefore, the coupling degree of population, land, and industrial urbanization is relatively low.

4.3. Mutual Feedback among PU_i , LU_i , IU_i , and C

Population, land and industry all play a role in urbanization. The mutual feedback between the indices of urbanization can reflect the degree of synergy among different processes in urbanization. The correlation between PU_i , LU_i , IU_i , and C was analyzed by the Pearson correlation analysis (in SPSS, the variance inflation factor (VIF) of PU_i , LU_i , and IU_i was far less than 10, which means that there is no collinearity among them).

Figure 8 presents Pearson correlation analysis results of PU_i , LU_i , IU_i and C . It reveals that the Adjust R^2 value for fitting PU_i and LU_i was greater than 0.75, thus, there was a significant positive correlation between them and the correlation coefficient reached 0.86. No stable mutual feedback was found between IU_i and PU_i as well as between IU_i and LU_i . Generally, the increase of IU_i means the optimization and upgrading of industrial structure, that is, the transformation from agricultural industry to nonagricultural industry. This can then lead to the rapid development of rural secondary industry and commercial service industry and promote the diversification of employment choices of farmers. Ultimately, the proportion of urban population in the total population is increasing. However, for the Gansu Province, the increase of IU_i did not lead to the increase of PU_i [37], which is possibly due to the low education level and low professional skills of farmers. The weak mutual feedback between LU_i and IU_i is mainly caused by the overexploitation and illegal occupation of lands [38].

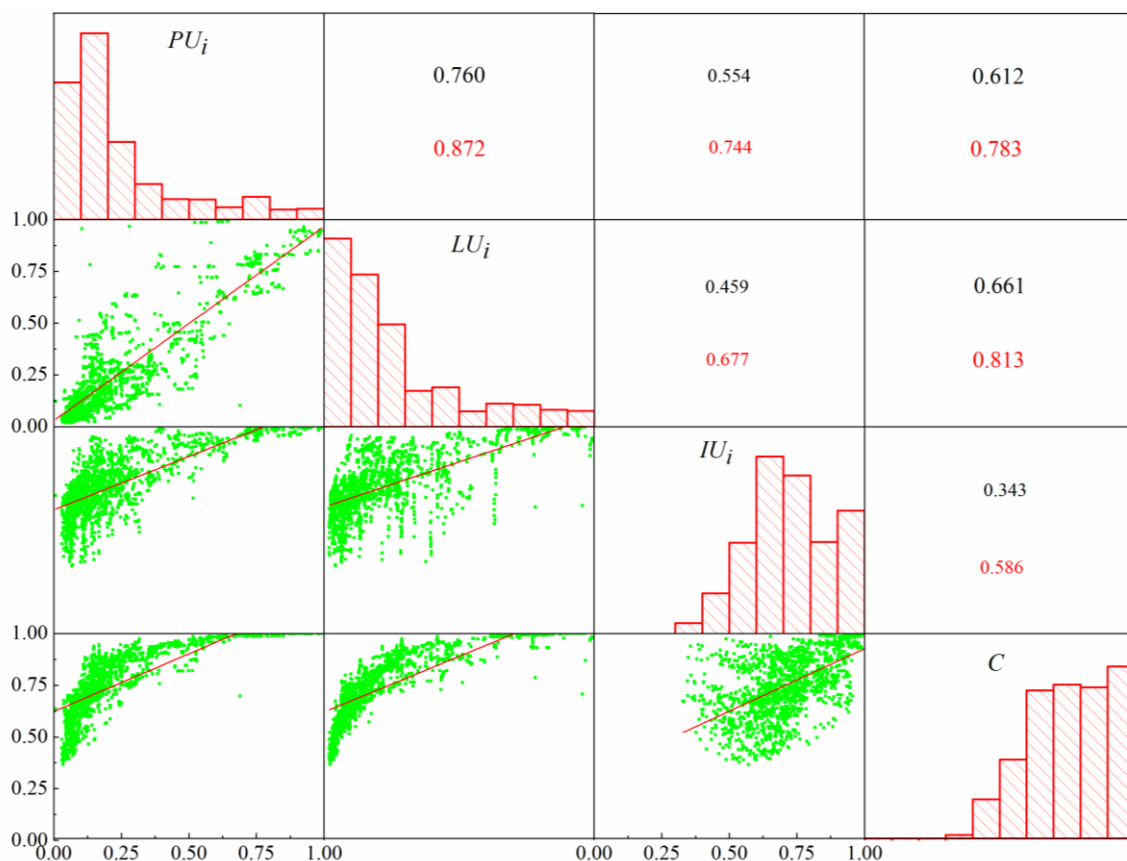


Figure 8. Pearson correlation analysis of indices of urbanization. Note: At the lower left corner in the figure are scatter plots and the red line in each scatter plot represents the fitted line between each two variables investigated. At the upper right corner in the figure are Adjust R^2 values (in black) and Pearson's r values (in red). At the diagonal of the figure are histograms of PU_i , LU_i , IU_i , and C .

C was significantly and positively correlated with PU_i , LU_i , and IU_i and the correlation coefficients were 0.949, 0.947, and 0.786, respectively. C indicates the state of coupling among population, land, and industrial urbanization. The results suggest that the increases in PU_i , LU_i , and IU_i lead to the improvement of coupling degree. The rapid urbanization of each dimension (population, land or industry) may lead to a higher comprehensive urbanization level, which often means a higher level of economic development.

4.4. Spatiotemporal Variation of Urbanization Pattern

4.4.1. Temporal Variation of Urbanization Pattern

The PU_i , LU_i , and IU_i results were graded and compared, and seven urbanization patterns based on different relationships among PU_i , LU_i , and IU_i were obtained (Table 2). From 1998 to 2016, the urbanization patterns in the Gansu Province remained stable, with IX, X, and XI as primary patterns and the other four patterns as secondary patterns (evaluation units with these four urbanization patterns accounted for less than 10% of all evaluation units). In 1998, 2008, and 2016, XI remained the dominant pattern, and evaluation units with XI urbanization pattern accounted for 55.17%, 36.78%, and 44.82% of all evaluation units in these three years, respectively. Note that the three primary urbanization patterns suggest high IU_i and close PU_i and LU_i . This reflects that the industrial urbanization of industry proceeded fast in the Gansu Province. The population and land urbanization proceeded coordinately and slowly, which were the major driving forces of urbanization in the Gansu Province. The relationship between population urbanization and land urbanization changed with time. In 2008, the urbanization of population was faster than that of lands. In 2016, the latter was faster than the former.

Table 2. Urbanization patterns in the Gansu Province.

Relationship	Urbanization Pattern	1998	2008	2016
$PU_i < LU_i = IU_i$	IV	2	2	1
$LU_i > IU_i > PU_i$	VI	2	0	0
$LU_i < PU_i = IU_i$	VIII	0	0	2
$IU_i > PU_i > LU_i$	IX	16	31	18
$IU_i > LU_i > PU_i$	X	18	21	26
$IU_i > PU_i = LU_i$	XI	48	32	39
$PU_i = LU_i = IU_i$	XIII	1	1	1

Transition matrices for the transformation of urbanization patterns in 1998–2008 and 2008–2016 were constructed (Table 3). As can be seen, the urbanization pattern of the same evaluation unit changed with time. This variation is mainly reflected in the relationship between population and land urbanization. From 1998 to 2008, the number of evaluation units with changes in urbanization pattern reached 35, accounting for 40.23% of all evaluation units. Among them, the number of evaluation units with urbanization pattern changing from XI to IX was the largest, reaching 16, accounting for 33.33% of all evaluation units with XI urbanization mode. However, the number of evaluation units with urbanization pattern changing from IX to XI was the least. This means that the urbanization of population was faster than that of lands in the evaluation units with changing urbanization patterns. In addition, X was found to change to XI, and XI was also found to change to X. The number of such evaluation units was considerable. Six evaluation units had urbanization pattern changing from XI to X and five evaluation units had urbanization pattern changing from X to XI. From 2008 to 2016, urbanization patterns changed dramatically. There were 55 evaluation units with changes in urbanization patterns, accounting for 63.22% of all evaluation units. The number of evaluation units with urbanization pattern changing from IX to XI and from X to XI reached 18 and nine. These account for 58.06% and 42.86% of all evaluation units with IX and X urbanization patterns, respectively. The number of evaluation units with urbanization pattern changing from XI to IX and

to X reached eight and 12, together accounting for 62.5% of evaluation units with XI urbanization pattern. This implies that population and land urbanization proceed at different speeds, resulting in urbanization pattern transformation. The Ganzhou District of Zhangye City and Jinta County of Jiuquan City in 1998 were the typical area for the XI pattern. In 2008, the area changed to IX pattern, and returned to the XI pattern in 2016. In 1998, Qingshui County and Wushan County of Tianshui City were the typical area for the XI pattern. In 2008, the area changed to the X pattern, and returned to the XI pattern in 2016.

Table 3. Transition matrix for urbanization pattern from 1998 to 2008 and from 2008 to 2016.

Year	Mode	2008							In total
		IV	VI	VIII	IX	X	XI	XIII	
1998	IV	0	0	-	0	2	0	0	2
	VI	1	0	-	0	1	0	0	2
	VIII	-	-	-	-	-	-	-	-
	IX	0	0	-	14	1	1	0	16
	X	1	0	-	1	11	5	0	18
	XI	0	0	-	16	6	26	0	48
	XIII	0	0	-	0	0	0	1	1
	In total	2	0	-	31	21	32	1	87
Year	Mode	2016							In total
		IV	VI	VIII	IX	X	XI	XIII	
2008	IV	0	-	2	0	0	0	0	2
	VI	-	-	-	-	-	-	-	-
	VIII	0	-	0	0	0	0	0	0
	IX	0	-	0	9	4	18	0	31
	X	1	-	0	1	10	9	0	21
	XI	0	-	0	8	12	12	0	32
	XIII	0	-	0	0	0	0	1	1
	In total	1	-	2	18	26	39	1	87

4.4.2. Spatial Variation of Urbanization Pattern

There was crisscross distribution of different urbanization patterns in the Gansu Province, making it difficult to observe the agglomeration center of certain pattern. Also, evaluation units with the same urbanization pattern were spatially close to each other (Figure 9). In 1998, the XI urbanization pattern was dominant in the province, presenting certain agglomeration in the west part of the Hexi Corridor, Longzhong, Longdongnan, and Longdong regions. Under this pattern, population and land urbanization levels were close to each other, but both lower than industrial urbanization level. IX and X patterns were also important urbanization patterns in the province. The patterns mainly distributed in the central part of the province and Gannan region. Under these two patterns, regional development is mainly limited by population and land urbanization. In 2008, the spatial pattern of urbanization pattern changed significantly. The Hexi Corridor was dominated by IX and XI patterns. The Longzhong and Gannan regions were dominated by IX pattern and population urbanization proceeded relatively fast. The Longdong and Longdongnan regions were characterized by crisscross distribution of X, IX, and XI patterns. In 2016, with Lanzhou city as a boundary, both the east and the west parts presented significant center-periphery pattern of urbanization pattern. The Hexi Corridor (Jiuquan city and Zhangye city) and Longzhong region (Dingxi city and Linxia prefecture) were the two centers. The urbanization pattern of these regions, mainly based on XI pattern, indicated close population and land urbanization levels. Peripheral regions were characterized by crisscross distribution of X, IX, and XI patterns.

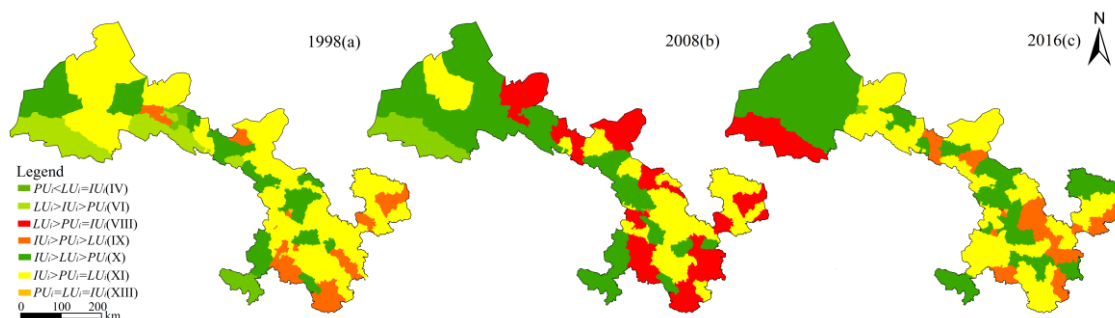


Figure 9. Spatial pattern of urbanization patterns in the Gansu Province.

5. Discussion

This paper studied the degree of coupling and mutual feedback among population urbanization, land urbanization, and industrial urbanization. Three processes are related with each other. Nonagricultural population is the key link of urbanization. Nonagricultural industries employ a large number of agricultural labor force, fundamentally promoting the process of population urbanization. Some studies take urbanization as the connotation and direct extension of industrialization. These studies hold that the differences among regional urbanization models are often significant. The reason is the differences in regional path models of industrialization [39]. In addition, labor force is a necessary input factor for industrial development. The flow of labor force among different departments or regions is an important way to promote knowledge spillover, information diffusion, and industrial growth [40,41]. Population urbanization is also an inevitable path of industrial structure adjustment. Other influencing factors brought by population agglomeration can significantly promote the development of nonagricultural industry. As land is an induced demand, land urbanization is often regarded as a direct result of population urbanization and industrial nonagricultural transformation [42]. Due to the differences in the spatial form of industrial lands and labor productivity, the changes in population, land, and industry from a perspective of urban-rural structure during urbanization are different. Thus, the relationship among the three systems will change with the progression of urbanization [43].

The interaction among population, land, and industry is supported by empirical research on multiple scales, involving case regions at different levels [44]. In China, the mismatch among population urbanization, land urbanization, and industrial urbanization has currently become a prominent problem [24]. During urbanization, the three dimensions are independent and at the same time related to each other, on which basis a relationship model can be established among them [45]. This paper used qualitative and quantitative methods in combination to reveal the coupling degree of population, land, and industrial urbanization in Gansu Province, further recognized the mutual feedback-relationship between different elements and between elements and C, and laid a foundation for guiding the coordinated development of urban and rural areas in the future. In addition, the analysis of the transformation process of urbanization pattern in different stages provides a basis for the in-depth study of urbanization process-pattern-mechanism in Gansu Province [31,46]. Above all, the urbanization pattern proposed in this paper provides a simple way to understand the characteristics of urbanization process. Urbanization pattern was used as a relative standard and development background, under which a certain spatial unit can be evaluated. Then, the dominant and secondary urbanization patterns were identified. Theoretically, urbanization should be based on good industrial development, and the output value structure and the employment structure should adapt to each other. This will form a reasonable urban-rural spatial structure [47]. It means the coordination among population, industry, and land should be ensured in the various stages of urbanization, including the orderly flow of all elements, rational allocation of resources, constant optimization of industrial structure. Thus, there should be a stable population-land-industry relationship during urbanization [48]. However, in rapid regional development, the flow of factors and the change of regional structure are

rapid, which can easily lead to some problems, such as conflict among population, economy and land use, mismatch between dimensions, and a sudden change in population-land-industry relationship. Therefore, special attention should be paid to the causes of these problems [49]. The research on the 87 evaluation units of the Gansu Province from 1998 to 2016 also verified the effectiveness of our method. For regions with a relatively high level of urbanization, particular attention should be paid to the coordination among population, land, and industry in future development. For regions with a medium level urbanization, attention should be paid to the relationship among the development of regional factors. For regions with low level of urbanization, it is necessary to first improve regional urbanization level and then pay attention to the coordination among population, land, and industry. In this way, the urbanization in the Gansu Province can work toward a healthier direction.

There has been increasing demand for research on coordination in urbanization. Urbanization itself is a very complex and systematic concept involving social, economic, ecological, spatial, population, and land aspects [50,51]. This paper only studied urbanization from population, land, and industry aspects, and it is necessary to include more aspects into our research. The following problems still need further research: In particular, it is necessary to carry out research in regions with relatively stable urbanization development process to verify the applicability of this method, and then analyze the relationship between urbanization speed and factor coupling stage. Moreover, this paper tends to regard urbanization as a unique path of rapid development from a neutral point of view. This may not be necessarily applied to all urbanization processes, but it is a unique feature of China, which is determined by China's specific development stage, institutional system, and land finance mode. However, it is necessary to spend more in health urbanization due to the development of healthy people, healthy urban-rural interaction, and healthy resource environment. At the same time, we should pay attention to pay attention to the process of industrial non-agriculturalization [52]. Third, according to the regional environment, this paper analyzes the impact of natural factors such as altitude and slope on the urbanization speed, pattern, and coordination. Finally, the index system and method for evaluating urbanization level should be further improved. Future research will focus on spatial optimization and policy regulation based on population-land-industry coordination.

6. Conclusions

In this paper, we analyzed the degree of coupling and mutual feedback among population urbanization, land urbanization, and industrial urbanization, and identified urbanization patterns and their spatiotemporal variation. The results have certain guiding significance for solving the problems which affect the sustainable and healthy urban development caused by rapid urbanization and economic development. The problems include the disordered flow of population, the imbalance of economic structure, the widening income gap between urban and rural residents, and the overdevelopment of urban and rural land. The following conclusions were drawn.

(1) Population and land urbanization proceed slowly in the Gansu Province and their trends were similar, whereas industrial urbanization proceeded faster than population and land urbanization. The urbanization process in the Gansu Province was mainly affected by population and land use changes. From a spatial perspective, population, land, and industrial urbanization levels decreased from southwest to northeast. From 1998 to 2016, the coupling degree of population, land, and industrial urbanization remained higher than 0.3 and showed a rising trend. It also showed significant spatial variation and decreased from northwest to southeast.

(2) Population, land, and industry all play a role in urbanization. PU_i was significantly and positively correlated with LU_i . However, there was no significant correlation between IU_i and PU_i as well as between IU_i and LU_i . C was significantly and positively correlated with PU_i , LU_i , and IU_i , with correlation coefficients of 0.949, 0.947, and 0.786, respectively. This suggests that the improvement of PU_i , LU_i , and IU_i effectively led to a higher urbanization level.

(3) Thirteen urbanization patterns were classified according to the relationship among population urbanization, land urbanization, and industrial urbanization. Seven urbanization patterns were

identified in the Gansu Province. Evaluation units with the same urbanization pattern tended to be spatially close to each other. IX, X, and XI patterns remained the dominant urbanization patterns, whereas the remaining four patterns were secondary. There was crisscross distribution of various urbanization patterns and it was thus not easy to observe the agglomeration center of certain urbanization patterns.

(4) The urbanization pattern of the same evaluation unit changed with time. This change was mainly reflected in the change of relationship between population and land urbanization. Urbanization pattern changed more significantly in 2008–2016 than in 1998–2008. There were 63.22% and 40.23% of evaluation units with changes in urbanization patterns in 2008–2016 and 1998–2008, respectively. The changes were dominant by IX→XI, X→XI, XI→IX and XI→X. More attention should be paid to the transformation of the urbanization pattern. Urbanization in different stages has different leading driving forces. Identifying influencing factors of it will be beneficial to the healthy development of urbanization.

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