Spatial heterogeneity of urban–rural integration and its influencing factors in Shandong province of China

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Based on nighttime light data and statistical data, this study calculated the level of urban–rural integration (URI) of Shandong province, researched spatial heterogeneity of URI levels by local spatial autocorrelation analysis, Geodetector, and geographically weighted regression, and analyzed its influencing factors and spatial heterogeneity. The results concluded that: (1) The spatial pattern of urban–rural integrated level is consistent with the level of regional economic development in Shandong province. The level of URI is higher along the Qingdao–Jinan railway and along the coast, whereas the level is lower in southwest Shandong and northwest Shandong. (2) The cities of Yantai and Weifang are High–High cluster areas of urban integration, and Jining is a Low–Low cluster area. The spatial agglomeration characteristics are not significant in other cities. (3) Among the main factors affecting URI, the explanatory power of the rural population with high school or technical secondary school education or above, the area of urban construction land, and the secondary and tertiary industry GDP to the spatial pattern of URI in Shandong province are 73.58%, 62.08%, and 58.66%, respectively. As the key factors, spatial heterogeneity, such as north–south differences, southwest-to-northeast differences, and east–west differences, is evident.

Urban–rural integration (URI), as spatial patterns realizing urban and rural integration and coordinated development, aims to achieve the coordinated development of urban–rural areas in society, economy, culture, and others. It is a vital path to eliminate urban and rural dual structures, shape new urban–rural relationships, achieve rural revitalization, and advance new urbanization, with building a well-off society being an equally important measure. Urban–rural coordination can enable the relationship of economy and social development between cities and countryside to be fundamentally reconstructed, which is crucial for regional sustainable development and for a coordinated human society. In the era of globalization, agricultural modernization and rural sustainable development are key. Therefore, URI has become a significant area of study warranting considerable attention of scholars both at home and abroad. Both developed and developing countries actively explore responses suitable for national conditions of URI and expected results have been achieved.

There are three important aspects in the study of URI: spatial patterns, influencing factors, and promoting measures. Although the regional systems between cities and countryside intersect, fuse, and integrate, the countryside regional function and urban–rural development coordination have clear spatial differences. Many factors influence URI, for example, long-standing urban and rural binary structure in China11,12, the mass exodus of the rural population because of urbanization process13, capital market transfer and institutional arrangement, and price distortion of land market14, land finance growth and urban bias, etc. China proposed rural revitalization strategies responding to the problems in town and country development. Population, land, and industry are the key elements influencing rural social economy development18, in which the rural industry is an essential foundation for promoting the integration between cities and countryside, and the advantages and drawbacks of industrial structure will affect the sustainability of socio-economic development of rural areas. In addition, economic agglomeration11, market integration25, optimal allocation and highly efficient utilization of population20, and coordinating countryside regional function and order transformation23 all have a positive impact on accelerating URI.

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Constructing an index system is the basis for study of the URI level, based mainly on population integration, economic integration, social integration, spatial fusion, life integration, ecological integration, and other aspects. Per capita income and consumption of residents between cities and countryside are used sometimes to calculate. Relevant scholars used 12 indicators to calculate the urban–rural integration index of Beijing, with the maximum, minimum, and average values of 0.7325, 0.5324 and 0.6158 respectively. There are many research methods, which are relatively mature on the spatial pattern and influential factors of the level of URI. The research methods of spatial patterns are hotspot analysis and global and local Moran’s I index, and the research methods of influential factors are Geodetector, correlation analysis, regression analysis, and spatial econometric. The nighttime light data is so strongly associated with urban built-up areas and economic indices of a region that researchers applied it to the URI area. The index system, constructed by statistical indicators, is comprehensive in the urban–rural integrated level. However, it has a certain level of subjectivity choosing index. Relatively, the nighttime light data is more objective and not conditioned by administrative boundaries, but it is less comprehensive than the index system. This paper integrates statistical indicators and nighttime light data to study the URI level. Firstly, the urban–rural integration level is calculated by using the total brightness of nighttime light data in urban areas, URI areas and rural areas. At the same time, the URI level is calculated by using statistical data, and then the comprehensive level of URI is calculated by using the weights determined by entropy value method, and the spatial pattern of URI level is studied by using GIS. And the main factors influencing URI based on three aspects central city influence, rural development level, and rural–urban connection are analyzed and spatial heterogeneity of its influence is explored.

Data sources and methodologies

Study area and data sources. Shandong is a coastal province and a national comprehensive experimental area for the conversion of old and new kinetic energy. It is in a critical period of eliminating backward production capacity, promoting emerging industries, changing development mode, and optimizing economic structure. At the end of 2020, Shandong province had a resident population of 10,047.24 million, a regional GDP of 73,129 billion, and a tertiary industrial structure of 7.3:39.1:53.6. Shandong Province has three core cities, Jinan, Qingdao, and Yantai, and 13 districted cities. Among them, the value-added cities of Jinan, Qingdao and Yantai are secondary industry accounted for 6.7%, 7.9% and 10.7% of the province respectively, and the value-added of tertiary industry of these three cities accounted for 16.0%, 19.4% and 10.3% of the province respectively. The disposable income per capita reached 43,726 yuan, and the per capita consumption reached 27,291 yuan for city residents. For countryside residents, the disposable income per capita reached 18,753 yuan, and the per capita consumption reached 12,660 yuan.

This study derived statistical data from the third agricultural census data of Shandong province and the 2018 Shandong Statistical Yearbook. The vector data map was taken from Tianditu·Shandong, and NPP/VIIRS remote sensing image data in December 2017 was derived from http://www.ngdc.noaa.gov/. The unit of research was the administrative district in late 2018, including 17 district cities, of which Laiwu city was absorbed into Jinan in 2019.

Methodologies. Range standardization. Due to the different brightness values of nighttime light, statistical indicators, and dimensions of the calculation results, this study range standardized related data and results according to Formula 1 for comparative analysis:

\[
x_{ij} = \frac{x_{ij} - \min_i \{x_{ij}\}}{\max_x \{x_{ij}\} - \min_i \{x_{ij}\}} \quad (i = 1, 2, 3..., m; \quad j = 1, 2, 3..., n) \tag{1}
\]

Entropy weight method. We chose the entropy weight method to determine the weights of indicators. First, Formula 2, defined as \(p_{ij}\), can help calculate the specific gravity of the ith indicator. Then, Formula 3, defined as \(e_{ij}\), helps calculate the entropy values for the ith indicator. Finally, we employ Formula 2 to calculate the weight of the ith indicator defined as \(w_{ij}\).

\[
p_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}} \tag{2}
\]

\[
e_{ij} = \frac{-\sum_{j=1}^{n} p_{ij} \cdot \ln p_{ij}}{\ln n} \tag{3}
\]

\[
w_{ij} = \frac{1 - e_{ij}}{\sum_{i=1}^{m} (1 - e_{ij})} \tag{4}
\]

Local spatial autocorrelation analysis. Local Moran’s I is a common analytical method for spatial autocorrelation, which expresses the spatial agglomeration characteristics of the local range. This paper applies this method to study the spatial pattern and spatial heterogeneity of the urban–rural integration level of each city in Shandong Province, calculated as shown in Formula 5.

\[
L = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} w_{ij} (X_i - \bar{X}) (X_j - \bar{X})}{\sum_{i=1}^{m} (X_i - \bar{X})^2} \tag{5}
\]

where \(X_i\) is the value of the ith indicator in the i-th city, \(\bar{X}\) is the mean value of the indicator in all cities, and \(w_{ij}\) is the spatial weight between city i and city j.
I_i = \frac{(x_i - \bar{x})}{s^2} \sum_j w_{ij}(x_j - \bar{x}) \tag{5}

The significance of the Local Moran's I is tested using standardized statistic Z, which is calculated according to Formula 6\textsuperscript{15}:

\[ z(I_i) = \frac{I_i - E(I_i)}{\sqrt{\text{VAR}(I_i)}} \tag{6} \]

In Formula 5, \( x_i \) and \( x_i \) are the index values of the study area, representing the composite score of URI development levels of \( i \) and \( j \) cities in this paper. \( \bar{x} \) is the mean of \( x \). Spatial weight matrix, defined as \( W_{ij} \), indicates proximity relation of regions \( i \) and \( j \), and it is constructed using Queen in this paper. When regions \( i \) and \( j \) have common sides of the polygons or common points, that is adjacent. In Formula 6, \( E(I) \) is the expected value of math and, theoretically, \( \text{Var}(I) \) is the variance.

**Geodetector.** Geodetector, as a tool, detects spatial heterogeneity, which comprises four parts: the differentiation and factor detector, interaction detector, risk detector, and ecological detector\textsuperscript{37,38}. Of these, the differentiation and factor detector, measured by \( q \) values, is to explore spatial heterogeneity of the dependent variable \( Y \) and the extent to which the independent variables \( X \) explain the dependent variable \( Y \). The larger the values of \( q \), the more obvious the spatial heterogeneity of \( Y \). If the independent variables \( X \) generate the stratification, larger values of \( q \) would indicate that the explanation of the dependent variables \( X \) on the dependent variable \( Y \) is stronger. Conversely, the smaller the \( q \) values, the weaker the explanation. According to Formula 7, \( q \) values were calculated\textsuperscript{38}. Interaction detectors predominantly identify interactions between the independent variables. It can evaluate whether the interaction of two independent variables, such as \( X1 \) and \( X2 \), will significantly enhance or weaken the explanation of the dependent variable \( Y \) or whether these two independent variables affect \( Y \) independently of each other. This paper uses Geodetector to study the key factors and their interactions that affect the level of urban–rural integration in Shandong Province.

\[ q = 1 - \frac{\sum_{h=1}^{H} N_h \sigma_h^2}{N \sigma^2} \tag{7} \]

In Formula 7, \( h \) is the stratification of independent variables \( X \) or dependent variable \( Y \). Both \( N_h \) and \( N \) are the number of units, the former is for layer \( h \) and the latter is for the whole area; \( \sigma_h^2 \) and \( \sigma^2 \) are the variances of layer \( h \) and the \( Y \) value of the whole region, respectively.

**Geographically weighted regression.** The geographically weighted regression (GWR) method is an extension to the global regression model with geospatial space of data to regression parameters. Formula 8 shows the model\textsuperscript{36}.

This paper uses GWR to study the spatial heterogeneity of factors affecting the level of urban–rural integration in Shandong Province.

\[ y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{k} \beta_j(u_i, v_i)x_{ij} + \epsilon_i \tag{8} \]

In Formula 8, \( \beta_0 \) and \( \beta \), refers to the coefficients to be determined. \( \epsilon_i \) is a random error of the ith area, meeting the assumptions of zero mean, homoscedasticity, and independence.

**Calculation of urban–rural integration level.** The mean value of the study area NPP/VIIRS nighttime light brightness is 1.8009, and maximum and minimum values are 466.99 and 0.02, and the standard deviation of the value is 4.9815. As provided in previous studies\textsuperscript{32,33}, with the NPP/VIIRS nighttime light data, the urban–rural level measurement is based on the assumption as follows: There is the largest lighting brightness for the urban built-up area, followed by URI areas and rural areas. Area and total brightness of the urban built-up area reflect urban scaling and development level. The URI area, with large luminance fluctuation, is the critical region reflecting the level of the URI area. The average brightness of the rural area reflects the level of development as well as the URI level. Research ideas and methods are as follows: (1) Thresholds of nighttime light brightness are determined according to the principle that error sum of squares is smallest between the extracted area of nighttime light data and the actual area is minimized, so the grid with the value of nighttime light brightness is greater than 8.9, considered as the urban built-up area, and we extracted URI. When the brightness value of nighttime light of the grid is less than or equal to 8.9, we calculate the range of nighttime light brightness using focus statistics of 3 × 3 neighborhood with ArcGIS10.5. Finally, we define the grid with a range of brightness regions greater than or equal to 3.55 as URI area. Others are rural areas. Figure 1 shows the result. (2) First, we calculate the URI areas of each city of Shandong province and nighttime light total luminance with ArcGIS10.5 "show zoning statistics" tool. From this, we calculate the proportion of URI areas of each city to total areas of this city and nighttime light total luminance per unit area of URI area of each city and normalize them separately using Formula 1. The proportion of URI areas of each city to total areas of this city represents coverage of the URI area of each city. While nighttime light total luminance per unit area reflects the development level of URI areas, they collectively reflect URI level of this city. Finally, the expert evaluation method determines the weighting of the two, both equaling 0.5. Accordingly, we calculate the
development level of the URI area of each city in Shandong province. (3) Using the same method, we calculate the nighttime light total luminance per unit area in rural of each city, normalized with Formula 1 to reflect the development level in rural areas. (4) Weighting of the level of development of URI areas and rural areas, determined by the expert evaluation method, are 0.7 and 0.3, respectively. Accordingly, we calculate the level of URI of each city in Shandong.

We see URI at a smaller gap between per capita consumption and income in cities and countryside\(^2,39\). A significant manifestation of URI is that labor productivity and labor income in cities and countryside converge, and there are two significant aspects for URI development, including income gap and consumption level in cities and countryside\(^1\). Following the previous study\(^2\), we calculate the urban–rural integrated level using statistics of per capita income and consumption of residents between cities and countryside. The ratio of the difference between income and expenditure to income of urban and rural residents is used to calculate the level of URI development in this literature. However, to reflect the difference of urban–rural integrated levels led to by different incomes, this paper uses the standardized income of residents between cities and countryside after weighting to improve. With the same ratio of the differences between income and expenditure to income of residents between cities and countryside, if the income of residents between cities and countryside is high, the level of URI is considered relatively high, while in smaller ratio, lower incomes have lower urban–rural integrated levels, and the opposite happens when income is higher. The calculation of urban–rural integrated level refers to Formula 9.

\[
UR_j = \frac{(RE_j - RC_j)}{(UE_j - UC_j)} \cdot \frac{RE_j}{\max(RE_j)} \cdot \frac{UE_j}{\max(UE_j)}
\]

where \(UR_j\) is the index of urban–rural integrated level in \(j\) city, and the larger the \(UR_j\), the higher will be the level of URI. \(RE_j\) and \(RC_j\) represent disposable income per capita and consumption per capita of rural residents in \(j\) city, respectively, while \(UE_j\) and \(UC_j\) represent per capita disposable income and per capita consumption of urban residents of \(j\) city, respectively. \(\max(UE_j)\) and \(\max(UC_j)\) are the maximum of \(UE_j\) and \(UC_j\). Formula 9 calculates the index of the urban–rural integrated level of each city in Shandong province, and Formula 1 standardizes results.

Study results

Spatial pattern of urban–rural integration levels in Shandong province. Urban–rural integration levels and spatial distribution in Shandong province. The calculation results based on nighttime light data and statistics are shown in Table 1. We perform the spatial distribution analysis of the results, considered in five categories by the natural breaks method. Figures 2 and 3 shows the final results. The weight of the two determined by the entropy weight method (Formula 2–4) are 0.5682 and 0.4318, respectively. From this, the results of the urban–rural integrated level in Shandong province are calculated, as shown in Table 1. Figure 4 shows the results divided into five categories using the natural breaks method.

There are significant differences in the level of URI of each city in Shandong as shown in Table 1 and Figs. 2 and 3, calculated based on nighttime light data and statistical data. Comparison between the calculated results based on statistical data and those based on nighttime light data, Qingdao, Jinan and Weifang are in the same order; Zaozhuang, Linyi, Dezhou and Heze City are 1 bit lower; Binzhou, Laiwu, Zibo, Dongying and Liaocheng are 2–8 bits lower; Weihai, Taian, Yantai, Rizhao and Jining are 3–9 bits higher. However, the ranking of the two calculation results has the biggest gap in Weihai, Taian, Yantai, and Liaocheng with the difference in ranking between 7 and 9.

As shown in Table 1 and Fig. 4, with the highest level of URI in Qingdao, Jinan, and Zibo in Shandong, Qingdao and Jinan are the binucleated cities, which are more influential, and their driving effect on the peripheral rural areas is strong; Zibo is a group city with urban–rural interlaced distribution, and it is favorable for driving the surrounding rural areas to achieve development. The higher level of URI is in Weihai and Weifang, of which,
Table 1. Results of urban–rural integrated level of cities in Shandong province.

| City    | The level of urban–rural integration based on nighttime light data | The level of urban–rural integration based on statistical data | The level of urban–rural integration |
|---------|---------------------------------------------------------------------|-----------------------------------------------------------------|-------------------------------------|
| Qingdao | 0.638                                                               | 0.944                                                           | 0.770                               |
| Jinan   | 0.571                                                               | 0.938                                                           | 0.729                               |
| Zibo    | 0.727                                                               | 0.588                                                           | 0.667                               |
| Weihai  | 0.292                                                               | 0.976                                                           | 0.588                               |
| Weifang | 0.436                                                               | 0.664                                                           | 0.534                               |
| Dongying| 0.481                                                               | 0.479                                                           | 0.480                               |
| Yantai  | 0.264                                                               | 0.693                                                           | 0.449                               |
| Rizhao  | 0.295                                                               | 0.599                                                           | 0.426                               |
| Binzhou | 0.363                                                               | 0.496                                                           | 0.421                               |
| Laiwu   | 0.323                                                               | 0.430                                                           | 0.369                               |
| Jining  | 0.210                                                               | 0.456                                                           | 0.316                               |
| Zaozhuang| 0.237                                                               | 0.373                                                           | 0.296                               |
| Liaocheng| 0.337                                                              | 0.225                                                           | 0.288                               |
| Linyi   | 0.216                                                               | 0.317                                                           | 0.260                               |
| Taian   | 0.065                                                               | 0.489                                                           | 0.248                               |
| Dezhou  | 0.154                                                               | 0.182                                                           | 0.166                               |
| Heze    | 0.094                                                               | 0.171                                                           | 0.127                               |

Figure 2. Urban–rural integrated level of Shandong province based on nighttime light data. This figure was created with ArcGIS 10.5 (URL: http://www.esri.com/).

Figure 3. Urban–rural integrated level of Shandong province based on statistical data. This figure was created with ArcGIS 10.5 (URL: http://www.esri.com/).
Weihai has the higher level of economic development, a relatively small area of city, and a higher economic development level than the cities and countries in Shandong and is beneficial to promote the integration of URI. The cities with the higher and highest levels of URI are along the Qingdao–Jinan railway and the coast. They are regions with higher economic development levels in Shandong. The urban–rural integrated level in Dongying, Yantai, Weifang, Jining, and Weihai are medium levels; Jinan, Zaozhuang, Taian, and Linyi are at lower levels; and the lowest levels are in Dezhou and Heze. The cities with the lower and lowest levels of URI are in Southwest Shandong and Northwestern Shandong, which are regions with a relative lag of economic development levels in Shandong.

Spatial heterogeneity of urban–rural integrated level in Shandong. The local Moran’s I index, Z score, and p value of the comprehensive index of URI level of Shandong cities are calculated with ArcGIS10.5 using Formulas 5 and 6. Table 2 displays the result, and Fig. 5 illustrates the spatial pattern.

As shown in Table 2 and Fig. 5, the spatial distribution pattern of the index of the level of URI in Shandong was obvious. Yantai and Weifang were the High–High cluster areas, with the surrounding area, whose level of URI was higher than the provincial average. Jining, as the Low–Low cluster area, indicated that the level of URI in Jining and its surrounding four cities was lower than the provincial average. However, regions with High–Low outliers and Low–High outliers were not detected. The local spatial autocorrelation of urban–rural integrated levels in other cities was not significant, nor was the spatial agglomeration of urban–rural integrated levels.

Influencing factors and spatial heterogeneity of urban–rural integrated levels in Shandong. Urban and rural areas are complex territorial systems

Table 2. Results of hot-spot analysis of urban–rural integrated level of the cities in Shandong province.

| City   | Moran’s I | Z score | P value | Type |
|--------|-----------|---------|---------|------|
| Jinan  | 3.12 × 10⁻⁵ | 0.5692  | 0.312   |      |
| Qingdao| 1.43 × 10⁻⁵ | 0.8153  | 0.226   |      |
| Zibo   | 2.62 × 10⁻⁵ | 1.0054  | 0.182   |      |
| Zaozhuang| 1.06 × 10⁻⁵ | 1.1063  | 0.150   |      |
| Dongying| 1.90 × 10⁻⁶ | 0.0746  | 0.466   |      |
| Yantai | 4.05 × 10⁻⁶ | 2.1786  | 0.022   | HH   |
| Weifang| 2.04 × 10⁻⁵ | 2.0433  | 0.026   | HH   |
| Jining | 1.97 × 10⁻⁵ | 1.9461  | 0.022   | LL   |
| Taian  | 7.75 × 10⁻⁶ | 0.2532  | 0.400   |      |
| Weihai | 1.31 × 10⁻⁵ | 0.2032  | 0.372   |      |
| Rizhao | 1.55 × 10⁻⁴ | 0.2747  | 0.434   |      |
| Laiwu  | 8.99 × 10⁻⁶ | 1.3344  | 0.102   |      |
| Linyi  | 5.65 × 10⁻⁶ | 0.4885  | 0.322   |      |
| Dezhou | 2.33 × 10⁻⁵ | 0.9265  | 0.216   |      |
| Liaocheng| 8.33 × 10⁻⁶ | 1.4263  | 0.122   |      |
| Binzhou| 8.11 × 10⁻⁶ | 0.9826  | 0.172   |      |
| Heze   | 8.35 × 10⁻⁶ | 0.5976  | 0.422   |      |
with spatial intersection, complementation constructs, and interactions. The urban–rural relations reflect a basic relationship of the dual socio-economic structure of the city and the countryside. Therefore, it is critical for the sustainable development of the region when urban and rural areas integrate and coordinate development. Not only does the level of development of the country itself determine the level of URI, but the influence of the central city also should be considered. Meanwhile, it is associated with the convenience of the connection between cities and countryside. Figure 6 shows their relationship.

The level of development of the country itself includes the status of practitioners, current situation of infrastructure in the rural areas, agricultural production, developing diversified economy in rural areas, the per capita income and consumption of farmers, the life quality of farmers, and so on. The effect of the central city on rural areas depends on size of the cities, economic development level, the situation of infrastructure, as well as investment, consumption, and export. The convenience of the urban–rural relation influences URI, depending upon transport and urban–rural distance. So, Table 3 represents the chosen indicators influencing the level of URI in Shandong.

**Geographical detection of influencing factors of urban–rural integration in Shandong.** Geodetector prepared by Excel can help calculate the detection of influencing factors of URI in Shandong province, freely downloaded from http://www.GeoDetector.org. The dependent variable is the URI level index which is the numerical quan-
tities, and the URI impact index is used as the independent variable. Because raw data are all numerical quantities, K-means clustering or the quantile method is used to change the type quantity37. In this paper, study areas were classified into five categories by the quantile method with the characteristics of each numeric independent variable: top 20%, (20% 40%], (40% 60%], (60% 80%], (80% 100%]. Due to a large number of independent variables, the relative matrix calculated by the software was larger, such as the interaction detector is 24 × 24 Matrix. We summarize the calculation results, Table 4 shows the factor detection results, and Table 5 shows the interaction detection results.

As shown in Table 4, among all the influencing factors, the proportion of the rural population with high school or secondary specialized school and above (X8), urban construction land area (X5), and secondary and tertiary industrial GDP (X1) had the largest q value, with 0.7358, 0.6208, and 0.5866, respectively. It shows that these were the three most important influencing factors in all the independent variables determining the spatial pattern of URI in Shandong Province. Its interpretation power of URI space pattern was 73.58%, 62.08%, and 58.66%, respectively.

| Independent variable | q value | p value | Independent variable | q value | p value |
|----------------------|---------|---------|----------------------|---------|---------|
| X1                   | 0.5866  | 0.5740  | X3                  | 0.0253  | 0.9937  |
| X2                   | 0.3496  | 0.9066  | X13                 | 0.0514  | 0.9870  |
| X3                   | 0.3578  | 0.9092  | X14                 | 0.4573  | 0.3335  |
| X4                   | 0.2400  | 0.6268  | X15                 | 0.0397  | 0.9870  |
| X5                   | 0.6208  | 0.2241  | X16                 | 0.0632  | 0.9966  |
| X6                   | 0.1683  | 0.8122  | X17                 | 0.2535  | 0.8707  |
| X7                   | 0.1882  | 0.6816  | X18                 | 0.1344  | 0.9279  |
| X8                   | 0.7358  | 0.1038  | X19                 | 0.2980  | 0.7416  |
| X9                   | 0.1234  | 0.8777  | X20                 | 0.3909  | 0.8995  |
| X10                  | 0.1311  | 0.9468  | X21                 | 0.3016  | 0.9643  |
| X11                  | 0.3443  | 0.7354  | X22                 | 0.3877  | 0.5661  |
| X12                  | 0.3041  | 0.5848  | X23                 | 0.4750  | 0.3018  |

Table 4. Results of factor detector.
Table 5 was collated by Interaction detector matrix, which was calculated by Geodetector software. We could conclude from Table 5 that interaction between the two independent variables and the spatial pattern of URI was greater than each independent variable act alone among all the influencing factors (independent variables) of URI in Shandong province. Of these, the interactions of 103 pairs of independent variables, for example, $X_1 \cap X_2$, $X_1 \cap X_3$, etc., were two-factor enhancement, while interactions of 173 pairs of independent variables, such as $X_1 \cap X_4$, $X_1 \cap X_6$, etc., were nonlinear enhancement with significant interaction effects, showing $1 + 1 > 2$ interaction effect. It indicated that the level of URI of each city in Shandong province resulted from the positively comprehensive function of the influencing factors.

![Figure 7](image-url). The results of standard error. This figure was created with ArcGIS 10.5 (URL: http://www.esri.com/).

![Figure 8](image-url). Coefficient of $X_8$. This figure was created with ArcGIS 10.5 (URL: http://www.esri.com/).

Spatial heterogeneity of factors influencing URI in Shandong province. Based on the results of the geographical survey of the factors affecting the URI, taking the composite index of URI level of Shandong province as dependent variables, and taking the proportion of the countryside population with high school or secondary specialized school and above, urban construction land area, and secondary and tertiary industrial GDP as independent vari-
ables, the geographical weighted regression analysis was carried out by the spatial statistical toolbox of ArcGIS 10.5, with the geographically weighted regression analysis method (Formula 8). Figure 7 shows the standard error result of the geographically weighted regression analysis and the coefficients $X_8$, $X_5$, and $X_1$ in Figs. 8, 9, 10, respectively.

Figure 7 shows some spatial difference in the standard error of geographically weighted regression prediction results of urban and rural integration levels in Shandong province. The projected result was lower than the actual standard deviation 1.5 times, while Rizhao was 1.5 times higher. The standard errors of prediction results in other cities were less than 1.5 times the standard difference. Among them, the standard deviation of Qingdao, Dongying, Zibo, Linyi, Zaozhuang, and Jining was less than half a standard deviation. As shown in Figs. 8, 9, 10, the proportion of the rural population with high school or secondary specialized school or above ($X_8$), urban construction land area ($X_5$), and secondary and tertiary industrial GDP ($X_1$) had obvious spatial differences on the level of URI in Shandong province. Among them, the effect of $X_8$ on urban–rural integrated levels decreased from south to north, while the effect of $X_5$ on the urban–rural integrated level decreased from northeast to southwest. Effects of $X_1$ on the urban–rural integrated level decreased from west to east.

Conclusion and recommendation

Based on the previous result, we can draw the following conclusions: (1) The cities of the highest and higher level of URI all were located along the Qingdao–Jinan railway and the coast, while the cities of the lowest and lower level were in Southwest Shandong and Northwestern Shandong. The spatial pattern of the urban–rural integrated level was consistent with the development level of regional economy. Central cities of the province field, group cities, and economically developed cities were more conducive to drive URI. (2) Spatial agglomeration characteristics of urban–rural integrated level in Shandong were not significant, and the local spatial autocorrelation of 14 of 17 cities was not significant. Yantai and Weifang were High–High cluster areas, while Jining was a Low–Low cluster area. Regions with High-Low outliers and Low–High outliers were not detected. (3) The main factors affecting the level of URI included rural self-development level, the influence of central cities, and connection between cities and countryside. The proportion of rural population with high school or secondary specialized school or above, urban construction land area, and secondary and tertiary industrial GDP were critical factors, influencing the urban–rural integrated level in Shandong. The explanatory power of these three factors to the
spatial differentiation of urban–rural integration is 73.58%, 62.08% and 58.66% respectively. In addition, the freight volume has a great explanatory power on the spatial differentiation of urban–rural integration, which is 47.5%. The interaction of any two factors on the spatial pattern of URI was greater than the result of each factor acting alone among all influencing factors. (4) The effect of the proportion of the countryside population with high school or secondary specialized school and above (X8), urban construction land area (X5), and secondary and tertiary industrial GDP (X9) on the urban–rural integrated level in Shandong presented obvious spatial heterogeneity. Spatial heterogeneity is mainly caused by the differences of economic development foundation, education level, population migration, city size, industrial structure, technical level, human resources and other factors in different regions of Shandong Province.

According to the results, we made the following suggestions: (1) Overall, the cultural quality of the rural population should be promoted positively. The above-mentioned studies show that culture quality of the rural population and the proportion of the labor population of the right age are essential for URI. Therefore, the importance measure for promoting urban–rural integrated level is to enhance countryside education, strengthen the policy of attracting talent, and improve the level of cultural knowledge of the rural population. (2) Central cities in driving rural areas should fully play their roles. The influence of the central city is crucial to urban and rural integration. So, administrative regional restrictions should be breakthroughs, promoting effect of important central cities on URI of the province by giving full play, and the effect of the provincial center city, regional central city, and specifically important central cities, such as Qingdao, Jinan, and Yantai on the URI of the province, should be further tapped. In addition, we can use long time series nighttime light data to analyze the dynamic direction of central city expansion and spatial impact, and to identify the advantages and disadvantages of URI development. (3) The urban–rural connection needs further strengthening, with convenience directly influencing the spatial pattern of URI. Therefore, concerning traffic conditions and traffic facilities, there is a great need to strengthen the construction. Meanwhile, urban and rural communication needs to drive a smooth channel of contact for urban and rural integration and strength exchanges and cooperation between regions. The economic development level of the areas along the Qingdao–Jinan railway and coastal cities is relatively high. It is necessary to further strengthen its links with other regions to drive the economic development of the whole province. Due to strong complementarity, apparent spatial differences, and the great space to promote each other and improve together from influencing factors of URI in each city, the level of URI needs to improve in response to actual conditions of a region and at advantages and compensation for the deficiency according to regional differences. (4) It is necessary to further advance the process of urbanization, actively develop the secondary and tertiary industries. The proportion of secondary and tertiary industries in GDP of Shandong Province is 3.3% and 3.2% lower than that of Guangdong Province and Jiangsu Province respectively. We should further improve the proportion of the two industries to power for the promotion of URI.

Data availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Author contributions
B.S. and Q.Z. conceived, designed, and refined the study protocol. Q.R., X.Y., and Y.C. collected the data. B.S. and Q.Z. analyzed the data. B.S. drafted the manuscript. Q.Z., Q.R., X.Y., and Y.C. supervised and complemented the writing. All authors have read and agreed to the published version of the manuscript.

Competing interests
The authors declare no competing interests.

Additional information
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