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Research on Evolution of Population and Economy Spatial Distribution Pattern in Ecologically Fragile Areas: A Case Study of Ningxia, China

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Sustainable development is particularly important for ecologically fragile areas. The relationship between population and economy is a key factor affecting the sustainable development of ecologically fragile areas. This study uses the population and regional GDP data of 22 districts (cities, counties, etc.) under the jurisdiction of Ningxia from 2010 to 2019 to analyze regional gravity center, geographic concentration, inconsistency index, and spatial autocorrelation, therefore uncovers the population and economy spatial distribution pattern evolution of Ningxia. The results show that: 1) The population and economy in Ningxia is in an unbalanced spatial distribution pattern of "high in North and low in Middle and South," and their geographical connection is relatively close. 2) The imbalance of economic development in Ningxia exceeds that of population development, but their relationship is becoming increasingly coordinated. 3) Ningxia's economically advanced zones and coordinately developing zones are mainly concentrated in the north, and most of the central and southern areas have always been economically lagging. 4) There is a strong trend of agglomeration in Ningxia's population and economic distribution. The districts with similar inconsistencies between population and economy tend to be spatially agglomerated, and the overall LL-type and HH-type agglomeration trend is significant. This research provides an important basis for the formulation of population and economic policies in ecologically fragile areas.

Keywords: population, economy, spatial distribution pattern evolution, ecologically fragile area, sustainable development, Ningxia, China

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1 INTRODUCTION

Sustainable development is a developing approach based on the coordinated and all-around development of society, economy, population, resources, and the environment. The relationship between population and economy is a key factor affecting regional sustainable development. It is conducive to regional sustainable development when the regional population, its growth rate and spatial distribution match the regional economic development. And in cases where they are unmatched, regional sustainable development will be posed under potential threat.

In terms of empirical research, Coale and Hoover Calculated the impact of rapid population growth on India's economic development (Coale and Hoover,1958). By introducing demographic variables into empirical models of economic growth, Bloom and Williamson proved that the demographic transition in East Asia, the transition from high to low mortality and fertility rates,

contributed significantly to the so-called economic miracle in East Asia (Bloom and Williamson, 1998). Nakibullah studied the development process of Bangladesh and found that population growth does not cause real per capita GDP of Granger, but real per capita GDP will lead to population growth (Nakibullah, 1998). Thornton studied the long-term relationship between population and GDP per capita in seven Latin American countries and found no long-term relationship between population and GDP per capita. Population growth neither causes per capita GDP growth nor is caused by it (Thornton, 2001). Tsen and Furoka studied the relationship between population and economic development in Asian economies. They found that the relationship between population and economic growth is not direct. Population growth may be beneficial or unfavorable to economic growth, which may impact population growth (Tsen and Furuoka, 2005). Huang and Zixiong studied the relationship between population growth and economic growth in 90 countries. They found that population affects economic growth in the short term, but there is no relationship in a long time. However, economic growth does not affect population growth in any period (Huang and Xie, 2013). Yao et al. (2013) used China's time-series data to predict the determinants of GDP per capita. The results show that population has a significant negative impact on GDP per capita (Yao et al., 2013). Peterson and EWF draw on historical data to map the links between population growth, growth in output per capita, and overall economic growth over the past 200 years. It is found that low population growth in high-income countries may cause social and economic problems, while high population growth in low-income countries may slow down their development (Peterson, 2017). Batunova and Perucca (2020) analyzed the relationship between population decline and economic development in various regions of Russia from 1998–2012, showing how the shrinking areas performed different economic growth patterns. In addition, many scholars have carried out empirical studies on the impact of population structure, population aging, demographic dividend and floating population on economic growth (Chen et al., 2017; Ma and Guo, 2017; Fang, 2018; Pan and Chang, 2021).

However, Western scholars seldom focus on the spatial pattern's matching relationship between population and economy. In recent years, the gap between different regions has widened due to the uneven distribution of population and economy. Therefore, the relationship between the spatial distribution of population and economy has attracted more and more attention from Chinese scholars. Chinese scholars mainly conduct national, regional, and provincial research by analyzing regional center of gravity, coupling degree, imbalance index, etc., Fanjie et al. (2010), Juwei and Cai (2013), Zi-long et al. (2014), Zhao and Zhan (2014) conducted in-depth studies on the relationship of China's population and economy in spatial distribution and its evolution. Ye-xi and Yu-qi (2011), Chu (2012), Wang et al. (2013), Zhang et al. (2015), Guoping and Luo (2017), Dongsheng and Jin (2017), Zhou (2019), Luo et al. (2019), Qin-qiang et al. (2020) have conducted qualitative and quantitative researches on the similar topic in specific regions of China such as the Poyang Lake Ecological Economic Zone, the Liaoning Coastal Economic Zone, the Beijing-Tianjin-Hebei Region, the Yangtze River Economy and Influencing Delta, the Central Plain City Cluster, the Beibu Gulf Economic Zone of Guangxi. Other scholars have conducted such studies in cities or provinces such as Chongqing (Zhou et al., 2011), Shanxi (Wang and Qin, 2013), Jiangsu (Qin et al., 2021) domestically. Existing research on the spatial distribution of population and economy is mainly concentrated in eastern developed areas, and less focused on the ecologically fragile areas in the northwest. Besides, the research methods chosen are not diversified enough, which has limitations.

This study selects Ningxia, China, which is in the ecologically fragile northwestern region and of which the socio-economic development is in an industrial transition period, as the research object. Using various research methods and technologies, we systematically analyze the evolution of the spatial distribution pattern of its population and economy in the past 10 years to fully reveal the relationship between population and economy within the region. The research will help fill the gaps in studies of the northwestern ecologically fragile areas, provide references for its policies formulation in the future, and promote the regional socio-economic sustainable development.

2 RESEARCH BACKGROUND ON THE REGION

Ningxia's administration covers an area of 66,400 km^2 and governs five prefecture-level cities and 22 counties (cities, districts). In 2019, the total permanent population of the district was 6.946 million, the permanent urban population was 4.1581 million, the urbanization rate was 59.86%, the regional GDP was 374.848 billion yuan. The landform of Ningxia is complex. The natural geographic spatial pattern features 3 distinctive major subregions: the north Yellow River irrigation area, the middle arid area, and the south mountainous area. The ecological environment is generally sensitive and fragile. Ecological problems such as soil erosion in the south, land desertification and grassland degradation in the middle, and salinization in the north are prominent, and water resources are scarce. Therefore, using the perspective of sustainable development to study the evolution of the spatial distribution pattern of population and economy in this area is in the interest of local development (**Figure 1**).

3 MATERIALS AND METHODS

3.1 Regional Gravity Center

The regional center of gravity is an indicator to measure the overall distribution of a particular attribute in the region. Its distribution trend can reveal the degree of imbalance in the spatial distribution of the attribute. This study follows the gravity center analysis approach to figure out the spatial locations of the population center of gravity and economic center of gravity in Ningxia, as well as the direction and distance of the centers' spatial movement through years, to determine the degree of

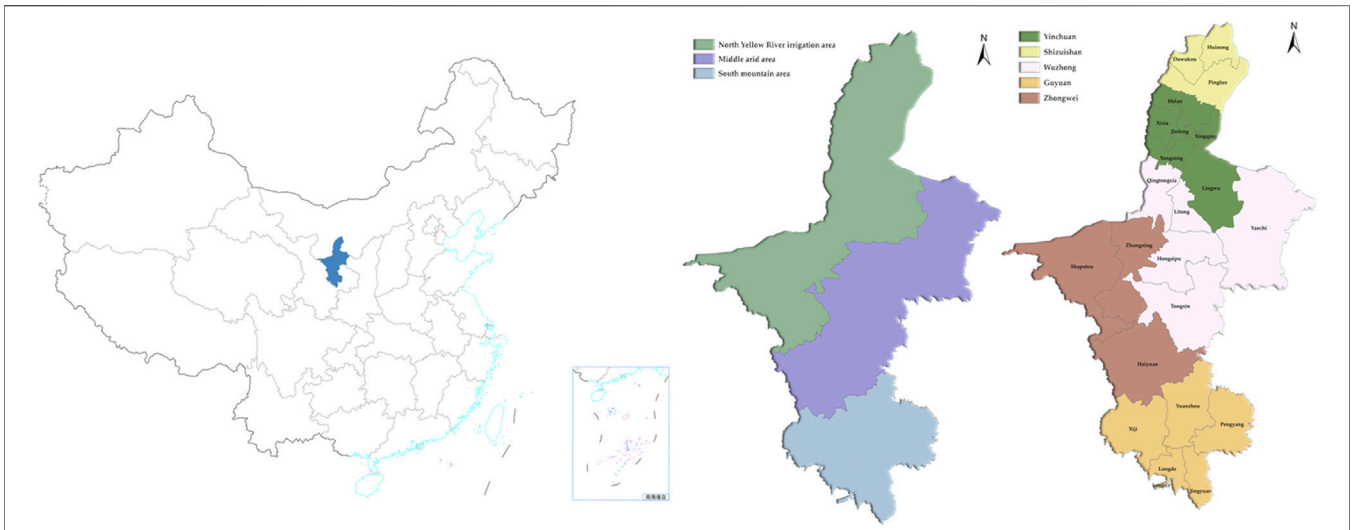

FIGURE 1 | The location of Ningxia.

imbalance in the spatial distribution of population and economy and its dynamic evolution. The calculation formula of the center of gravity (*X, Y*) is:

$$X = \frac{\sum_{i=1}^{n} x_i w_i}{\sum_{i=1}^{n} w_i}, Y = \frac{\sum_{i=1}^{n} y_i w_i}{\sum_{i=1}^{n} w_i}$$

x_i and y_i are the longitude and latitude coordinates of the *i*th sub-region, w_i represents the magnitude of an attribute value of the *i*th sub-region; in this study, w_i is assigned to the area, population or gross regional product, and the center of gravity (*X, Y*), respectively, represent the regional geometric center, population center of gravity and economic center of gravity (Zhang et al., 2015).

3.2 Geographical Concentration

The regional center of gravity analysis studies the relationship between the regional population and economic development in general, but it doesn't show the relationship between the districts within the region. Therefore, this study uses the geographical concentration of population and economy analysis to investigate the spatial distribution of population and economy and its evolution. The geographical concentration of population and economy comprehensively measures population scale, economy volume, and land area to effectively reflect the spatial distribution of population and economy and the status and role of a district in the region. The calculation formula:

$$R_{pop_i} = \frac{pop_i \sum pop_i}{s_i \sum s_i}, R_{GDP_i} = \frac{GDP_i \sum GDP_i}{s_i \sum s_i}$$

pop_i, GDP_i, s_i respectively represent the population, regional GDP and land area of District *i*; R_{pop_i} and R_{GDP_i} ,respectively, represent the population geographic concentration and economic geographic concentration of District in a specific year.

For the convenience of comparison, this study averages the calculated population geographic concentration and economic geographic concentration. 0.4, 0.8, and 1.6 are chosen as the three cut-off values to divide the population geographic concentration index and economic geographic concentration index of each region into four levels, namely the level-4 agglomeration interval (0.0, 0.4) and the level-3 agglomeration interval (0.4, 0.8), level-2 agglomeration interval (0.8, 1.6), and level-1 agglomeration interval (>1.6) (Ye-xi and Yu-qi, 2011).

3.3 Inconsistency Index

By calculating geographic concentration, the relationship between Ningxia's population and economic development can be preliminarily revealed. Furthermore, the inconsistency between Ningxia's population and economy can be analysed in depth through the inconsistency index. The calculation formula is:

$$I = \frac{R_{pop_i}}{R_{GDP_i}}$$

R_{pop_i} and R_{GDP_i} represent the geographic concentration of population and the economic geographic concentration of District *i* in a particular year. *I* is the inconsistency index. For different places, the closer the value of *I* is to 1, the more consistent their population and economy are in spatial evolution trends.

The calculated inconsistency index divides the districts into 3 categories: economically advanced zones (0.0, 0.75), co-ordinately developing zones (0.75, 1.25), and economically lagging zones (>1.25). In the economically advanced zones, economic agglomeration is ahead of population agglomeration; in a co-ordinately developing zone, economic agglomeration and population agglomeration develop in harmony; in an economically lagging zone, economic agglomeration lags behind population agglomeration (Ye-xi and Yu-qi, 2011).

3.4 Spatial Autocorrelation

The above methods can lead to the spatial distribution of population and economy characteristics and the spatial distribution relationship in Ningxia. Still, they cannot explain the overall spatial correlation between population and economy, the internal connection and the evolution process of the relationship between population and economy distribution. Therefore, this paper uses *Global Moran's I* index and *Local Moran's I* to analyse the inconsistency index of population and economy in Ningxia.

Global Moran's I index calculation formula:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \bar{x})\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \bar{x})^2}$$

I is the *Global Moran's I* index; n is the total number of districts in the region; x_i a and x_j represent the attributes of District i and District j, respectively; w_{ij} is the adjacent weight of the spatial unit, reflecting the degree of influence of the spatial unit; $\bar{x}$ is the average of the attributes.

The value of I is between −1 and 1. The correlation between spatial units is positive when the value is over 0 and negative when the value is under 0. Therefore, the closer its absolute value is to 1, the closer the relationship between the spatial units is (Griffith, 2003).

Local Moran's I index calculation formula:

$$I_i = \frac{x_i - \bar{x}}{S^2}\sum_{j} W_{ij}(x_i - \bar{x})$$

I_i is the local autocorrelation index; x_i is the attribute value of spatial unit i, and w_{ij} represents the degree of influence between spatial unit i and j; $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$; $S^2 = \frac{\sum_{i=1,j\neq 1} x_i^2}{n-1} - \overline{x^2}$

Measured by the value, the regional units can be grouped into four types: High-High, Low-Low, High-Low, and Low-High. For HH Type or LL Type, the adjacent units are both high or low in the value of, indicating local spatial agglomeration. In contrast, HL Type or LH Type shows local spatial differentiation (Anselin, 2010).

3.5 Pearson Correlation Coefficient

Pearson correlation coefficient is commonly used to measure the degree of linear correlation between two variables (with normal or nearly normal characteristics). This paper uses the correlation coefficient in SPSS statistical analysis software to analyze the correlation of factors affecting the relationship between population and economy (Hauke and Kossowski, 2011).

3.6 Multiple Linear Regression

In SPSS statistical analysis software, regression analysis is a widely used method to analyze the linear relationship between dependent and independent variables. In addition, this method is used to analyze the quantitative relationship between various variables. This paper selects linear regression method to discuss the factors affecting the relationship between population and economy in Ningxia, and because there are many factors affecting population and economy in Ningxia, that is, the independent variables are multiple, so this paper selects multiple linear regression model to analyze the influencing factors. The basic equation of this model is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon$$

Y represents the dependent variable, X_n represents the nth independent variable, and n represents the number of independent variables that can eventually be incorporated into the model. β_0 is the constant regression term, β_1, β_2,... β_n is the regression coefficient (Sun, 2000).

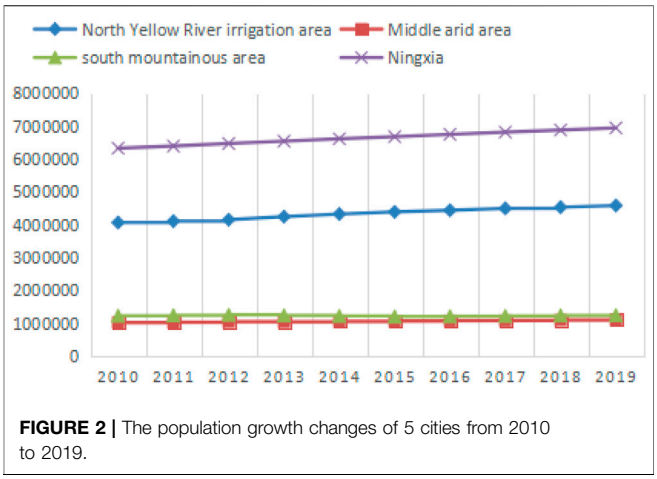

FIGURE 2 | The population growth changes of 5 cities from 2010 to 2019.

4 RESULTS OF TEMPORAL AND SPATIAL POPULATION-ECONOMY EVOLUTION ANALYSIS

4.1 Population-Economy Growth Changes Analysis

The population of different districts in Ningxia varied greatly. The population of the north Yellow River irrigation area exceeded 50% of the total population of Ningxia, and this trend was still increasing. The population of Ningxia showed an overall upward trend. The total permanent population increased from 6,329,600 in 2010 to 6,946,600 in 2019, and the population increased by 617,000 in 10 years, with an average annual growth rate of 1.04%. The population growth rate varies significantly across Ningxia, showing that the north Yellow River irrigation area was higher than the middle arid area, and the middle arid area was higher than the south mountainous area (**Figure 2**; **Table 1**) (Jiaxin and Zhang, 2021).

The economic share varied in different districts in Ningxia. The GDP of the north Yellow River irrigation area accounted for more than 80%, and Yinchuan accounted for about 50%. Ningxia's GDP increased by about 205.887 billion yuan from 2010 to 2019, with an average annual growth rate of 9.26%. There were also significant differences in the growth of GDP in various districts of Ningxia. From 2010 to 2019, the net increase of the

TABLE 1 | The descriptive statistics of population (unit: people).

	Minimum value	Maximum value	Mean value	Standard deviation	median
2010	101,279.000	683,009.000	301,407.143	130,877.701	284,982.000
2011	102,317.000	690,023.000	304,502.333	132,369.151	288,509.000
2012	103,884.000	697,365.000	308,186.095	133,822.571	291,360.000
2013	101,552.000	707,151.000	311,520.857	134,720.383	295,364.000
2014	102,664.000	725,168.000	315,017.905	136,838.387	299,157.000
2015	99,488.000	734,353.000	318,037.048	138,801.168	302,047.000
2016	100,604.000	740,155.000	321,378.905	140,016.712	307,898.000
2017	101,349.000	747,648.000	324,660.619	141,333.007	323,088.000
2018	102,408.000	751,478.000	327,672.524	142,088.926	336,891.000
2019	102,865.000	755,441.000	330,790.524	143,000.510	339,003.000

TABLE 2 | The descriptive statistics of GDP (unit: 10,000 yuan).

	Minimum value	Maximum value	Mean value	Standard deviation	median
2010	69,955.000	2,709,800.000	755,886.571	709,471.551	608,036.000
2011	82,687.000	3,183,700.000	944,015.048	863,620.569	793,339.000
2012	95,557.000	3,567,300.000	1,088,082.048	977,329.875	942,324.000
2013	110,397.000	3,956,300.000	1,218,728.333	1,077,227.935	1,055,693.000
2014	120,664.000	4,184,300.000	1,304,851.810	1,141,315.241	1,156,403.000
2015	133,769.000	4,443,759.000	1,388,698.381	1,204,003.237	1,218,014.000
2016	147,770.000	4,755,034.000	1,501,259.381	1,290,981.330	1,342,276.000
2017	159,689.000	5,464,917.000	1,662,194.048	1,447,139.845	1,359,380.000
2018	184,413.000	6,337,946.000	1,784,820.762	1,587,482.497	1,364,359.000
2019	204,172.000	5,315,783.000	1,785,011.810	1,447,930.496	1,368,038.000

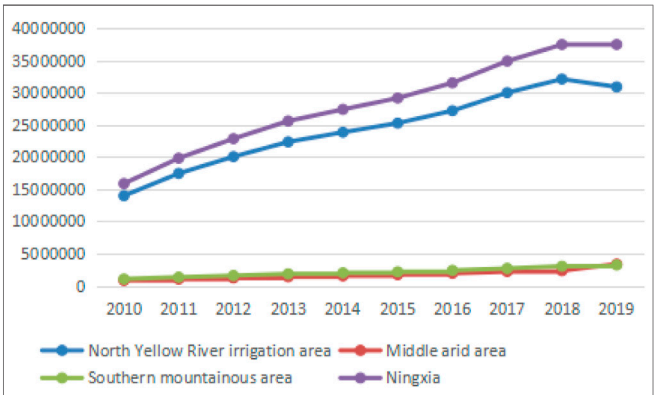

FIGURE 3 | The economic growth changes of 3 major subregions from 2010 to 2019 (yuan).

north Yellow River irrigation area exceeded 70% of that of Ningxia. And the net increase of Yinchuan, 110.417 billion yuan, was 3–5 times that of other cities. However, the growth rate has slowed down in the north Yellow River irrigation area, the fastest in the middle arid area and the second in the south mountainous area (**Figure 3**; **Table 2**).

The population and economy in Ningxia showed an uneven spatial distribution pattern of "high in North and low in Middle and South," and their connection in geography was considerably close. The population and economic proportions of districts in Ningxia varied greatly. The total population of the north Yellow River irrigation area exceeded 50% of that of Ningxia, with its GDP exceeding 80% of the total regional GDP. The overall population growth rate appeared to be highest in the north Yellow River irrigation area and lowest in the south mountainous area. However, the economic growth rate in the north has slowed down and stayed lower than that of the central and southern areas, but the net increase exceeded 70% of the region's net growth.

4.2 Gravity Center Evolution

The population gravity center of Ningxia was between 106.1535°E–106.1585°E, 37.5850°N–37.6350°N, which was located in Hongsipu from 2010 to 2014 and in Litong from 2015 to 2019. The population gravity center of Ningxia has always been north of the geometric center with an average deviation of 38 km from 2010 to 2019. This showed the imbalanced population distribution in Ningxia, and the population density in the north was higher than that in the south. From 2010 to 2019, the population gravity center of Ningxia has not moved much, mainly in the north-south direction, which changed 0.045°N in the north-south direction and 0.0038°E in the east-west direction. From 2010 to 2012, it continued to move southward. After 2012, it began to move northward. After 2018, it moved slightly to the south and then turned to move northward (Jiaxin and Zhang, 2021).

The center of gravity of Ningxia's economy was between 106.2365°E–106.2469°E and 37.9902°N–38.1322°N, which was located in Lingwu. The center of gravity of Ningxia's economy has been east of the geometric center with an average deviation of

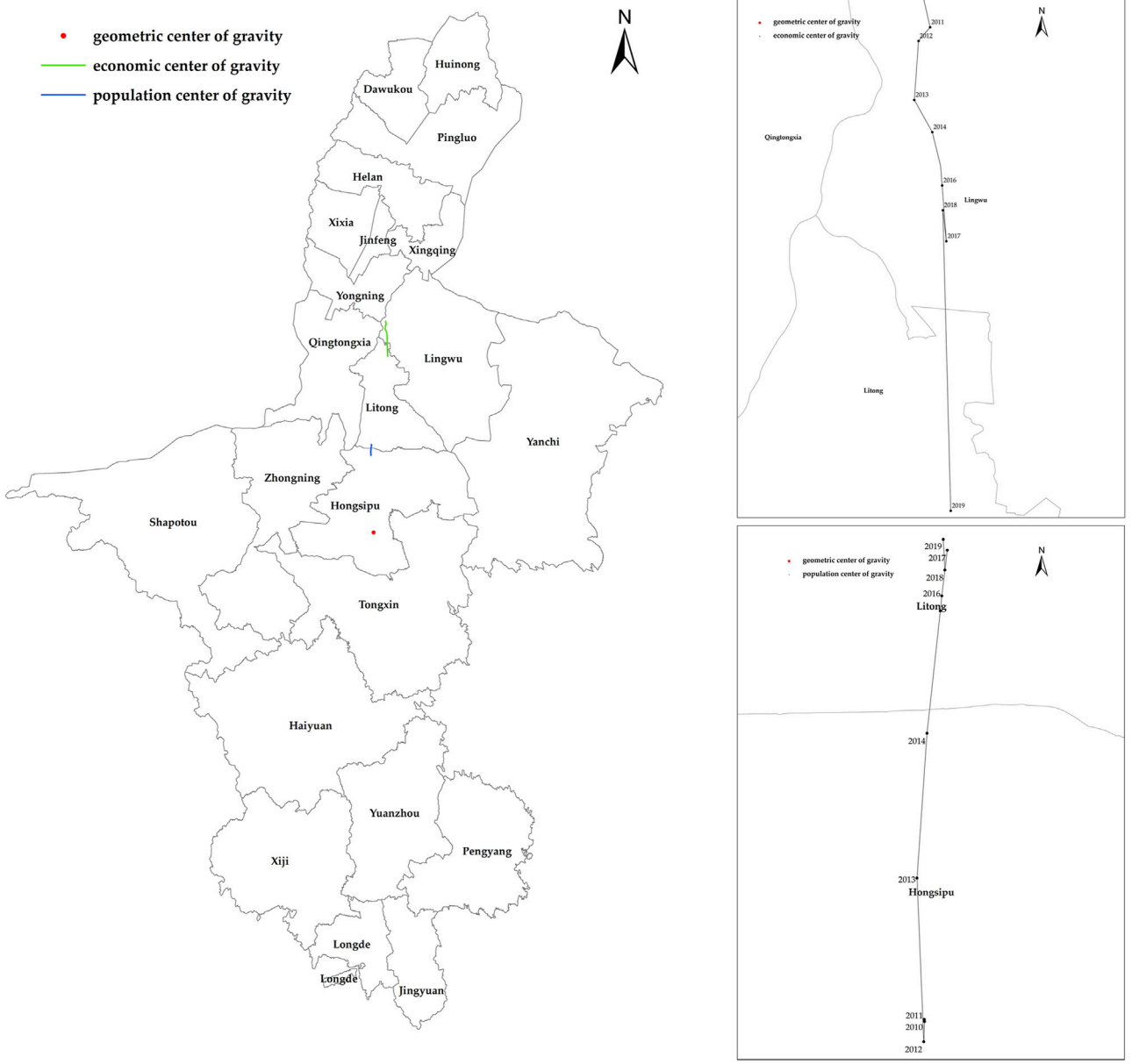

FIGURE 4 | The gravity center evolution of Ningxia's population and economy from 2010 to 2019.

88 km from 2010 to 2019. indicating the uneven economic development in Ningxia with the north and east most developed. From 2010 to 2019, the economic center of gravity in Ningxia has not moved much, mainly in the north-south direction, which changed 0.14°N from north to south and 0.01°E from east to west. From 2010 to 2017, it continued to move to the south. In 2018, it moved slightly to the north and then turned to move south.

The position changes of the economy and population gravity centers showed that the economic development imbalance in Ningxia exceeded the population development imbalance, but their relationship was increasingly coordinated. Ningxia's economic center of gravity was always in the north of the population center, and its distance from the geometric center is greater than the distance between the population gravity center and the geometric center. However, from 2010 to 2019, the population center of gravity continued to move south, and the economic center of gravity continued to move north. 40.69 km separated the population center of gravity from the economic center of gravity in 2019, compared to 60.87 km separating them in 2010, indicating that the relationship between the two is becoming more harmonious (**Figure 4**).

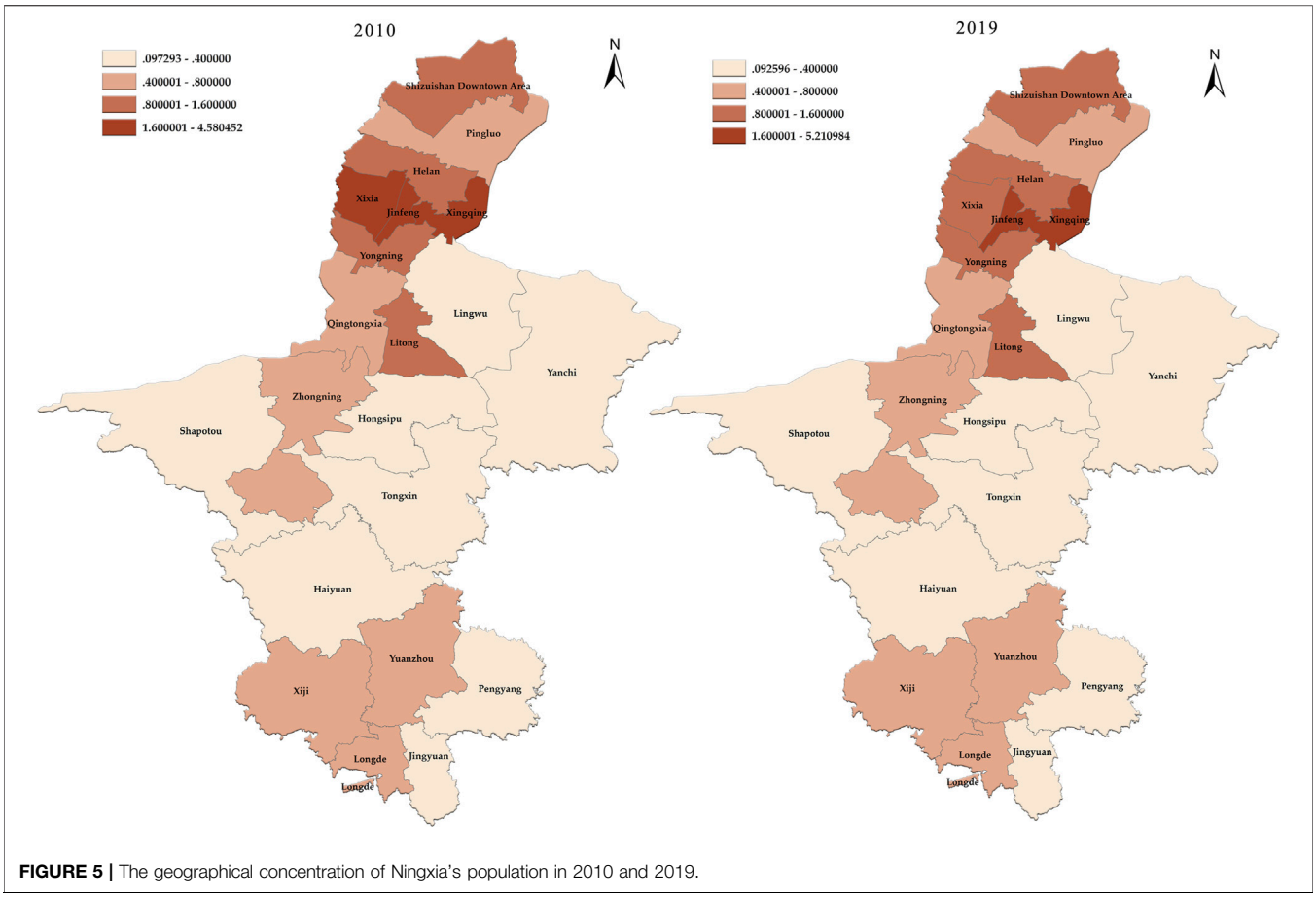

FIGURE 5 | The geographical concentration of Ningxia's population in 2010 and 2019.

4.3 Geographic Concentration

In general, the geographical concentration of Ningxia's population has not changed much from 2010 to 2019, with only Xixia downgraded from level-1 to level-2. Numerically, the geographical concentration of population was decreasing in most districts, and increasing only in Jinfeng, Helan, Pingluo, and Hongsipu, with the most significant increase in Jinfeng. The geographic concentration of population in Jinfeng was always the highest significantly higher than other districts. The geographic concentration of population in Yanchi was always the lowest, substantially lower than other districts. The ratio of extreme values has increased from 47.08 in 2010 to 56.28 in 2019, indicating that Ningxia's population development was polarizing. As the population agglomeration effect in the north Yellow River irrigation area continued to increase, the gap kept expanding, further strengthening the polarization effect. The diffusion effect has not yet appeared (**Figure 5**) (Jiaxin and Zhang, 2021).

In terms of economic geographic concentration, the number differentiated in different levels. The economic geographic concentration has not changed much from 2010 to 2019, and no district has their level changed. Numerically, the economic geographic concentration increased in most districts but decreased in Xingqing, Xixia, Yongning, Shizuishan, Pingluo, Qingtongxia, and Shapotou. The district with the highest economic geographic concentration changed from Xingqing to Jinfeng, which were significantly higher than other districts. The district with the lowest economic geographic concentration changed from Yanchi to Haiyuan, considerably lower than other districts. The ratio of extreme values decreased from 158.15 in 2010 to 70.38 in 2019, indicating that the gap in economic development in Ningxia has gradually reduced, the polarization effect has been weakening, and the diffusion effect has begun to appear (**Figure 6**).

The geographic concentration of population and that of the economy in Ningxia were highly correlated and also characterized by "high in the north, low in the middle and south." However, there were also certain deviations between the two, with a one-to-one correspondence between areas with higher (lower) population concentration and those with higher (lower) economic concentration not being achieved. The Yinchuan downtown area's population and economic concentration index were the highest, and it gradually decreased outward, forming a contiguous area of high and medium values with the Yinchuan downtown area as the core. This showed that Yinchuan has a significant effect on the surrounding districts but minimal on the central and southern districts concerning population and economic development. The ratio of extreme values pointed at a more considerable polarization effect on geographic concentration of economy

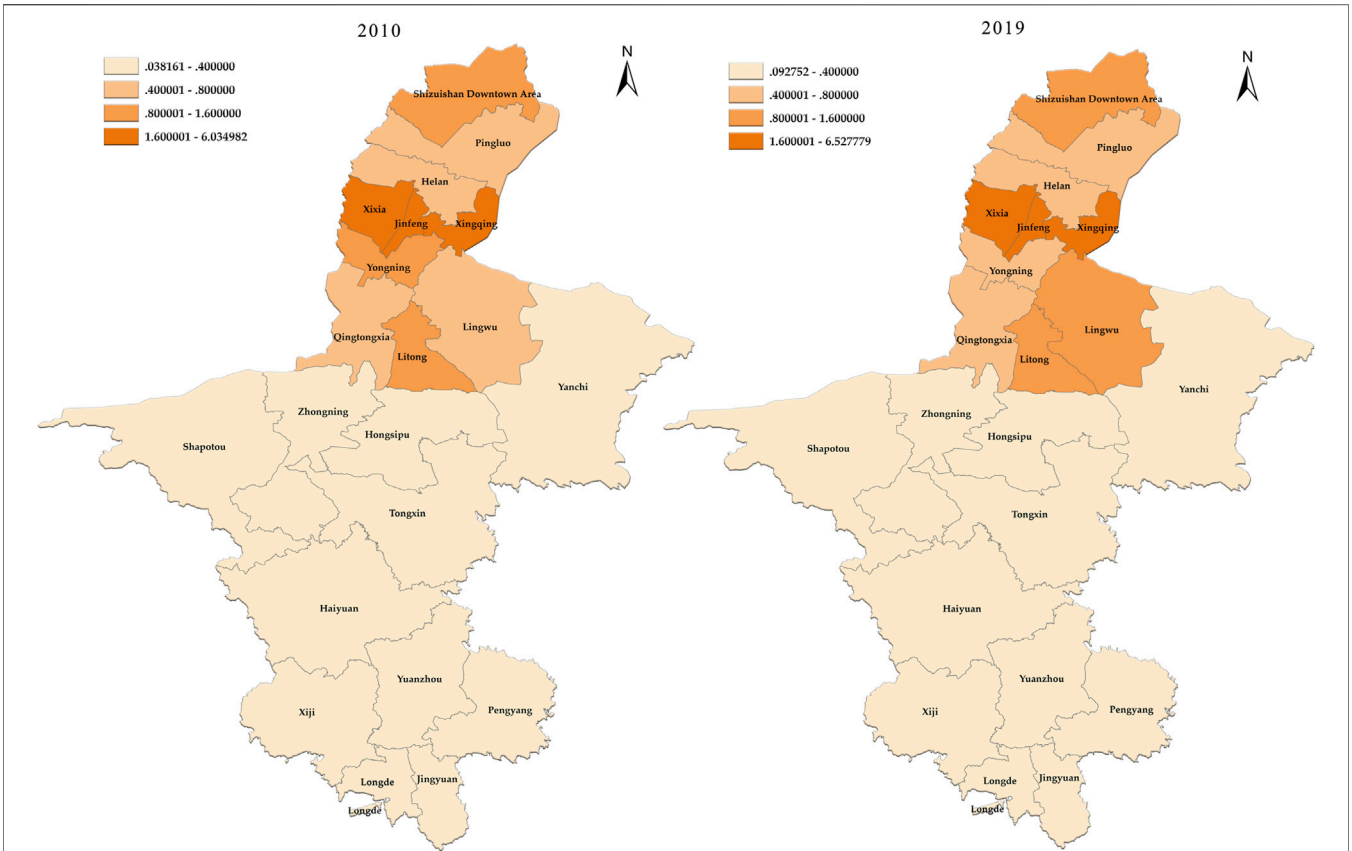

FIGURE 6 | The geographical concentration of Ningxia's economy in 2010 and 2019.

than that of population, indicating that the imbalance of Ningxia's economic distribution was greater than that of population. However, judging from the geographic concentration evolution in various districts, the polarization effect was constantly strengthening in population geographic concentration and weakening in economic geographic concentration, resulting in an increasingly coordinated relationship between the two.

4.4 Inconsistency Index

Ningxia's economically advanced zones and coordinately developing zones were mainly concentrated in the north. In 2010, there were three economically advanced zones, namely Xixia, Lingwu, and Shizuishan. In 2019, the number of economically advanced zones was reduced to two, and Shizuishan changed from an economically advanced zone to a coordinately developing zone. Numerically, the inconsistency index of the economically advanced zone was showing an upward trend, indicating that its population development and economic development were increasingly coordinated. In 2010, there were 6 coordinately developing zones, namely Jinfeng, Xingqing, Helan, Yongning, Pingluo, and Qingtongxia. In 2019, the number of coordinately developing zones remained unchanged, with Yanchi levelling from an economically lagging zone to a coordinately developing zone. Yongning and Qingtongxia were transformed from coordinately developing zones to economically lagging zones. The number of economically lagging zones has increased from 12 in 2010 to 13 in 2019, indicating that most regional economic development lags behind population concentration. The lagging zones were mainly concentrated in central and southern Ningxia. On the whole, the standard deviation of the regional Inconsistency Index has decreased from 1.8 in 2010 to 0.88 in 2019, and the average has dropped from 2.32 in 2010 to 1.67 in 2019, certifying to a certain extent that the relationship between population and economy in Ningxia has become more coordinated (**Figure 7**).

4.5 Spatial Autocorrelation

4.5.1 Global Moran's I

It was calculated that the region-wide autocorrelation coefficient Moran's I of the Ningxia population and economy inconsistency index in 2010 and 2019 were 0.58 and 0.71 (the results passed the Z test, $p \leq 0.01$), which were significantly greater than 0. This situation indicated that the inconsistency index between the population and the economy in Ningxia was characterized by evident positive spatial autocorrelation. Thus, areas with similar inconsistencies between population and economy tended to be spatially agglomerated, and this situation was intensifying.

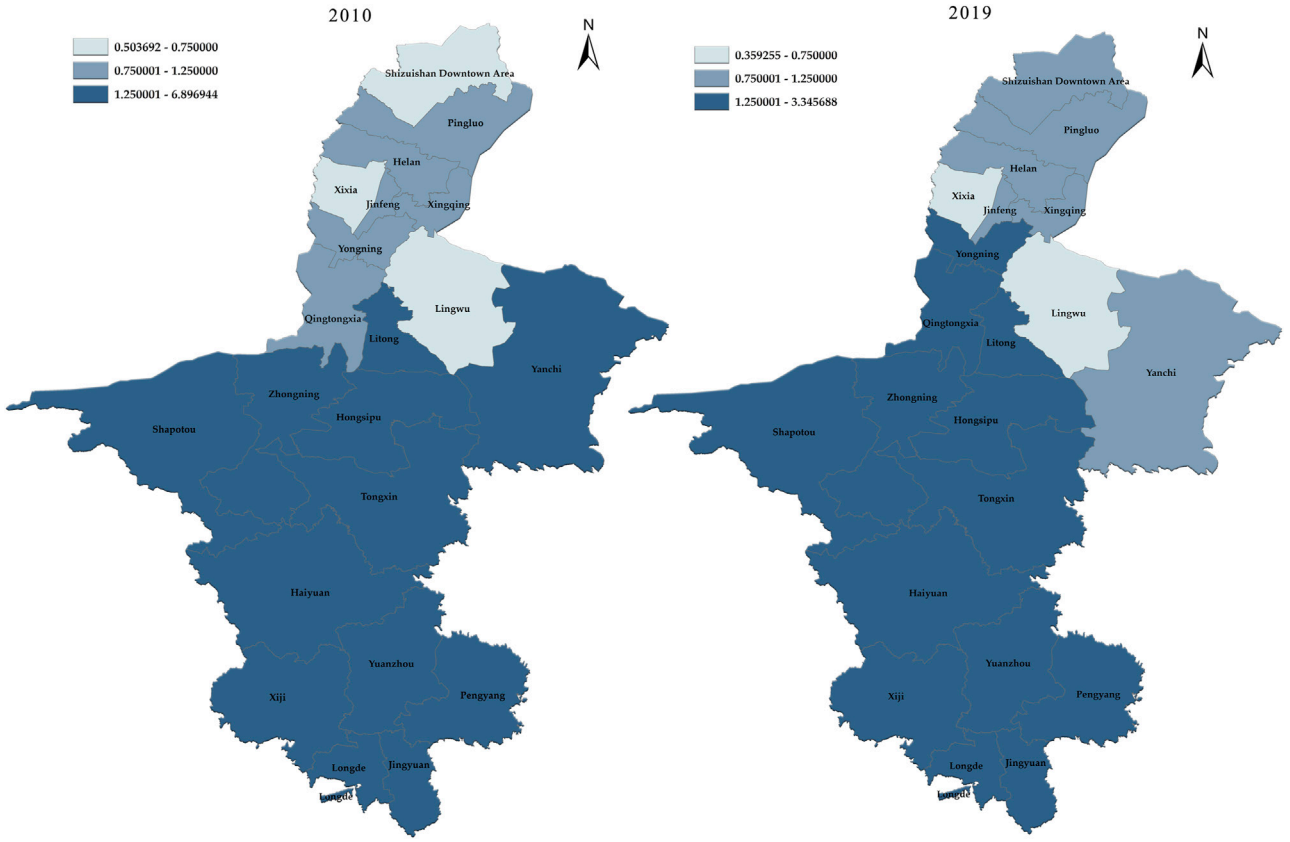

FIGURE 7 | The inconsistency index of Ningxia in 2010 and 2019.

4.5.2 Local Global Moran's I

This study used ArcGIS to analyze the Local Global Moran's I of the inconsistency index between population and economy in Ningxia. In 2000, only Xingqing, Jinfeng, and Xixia were of LL type, Xiji was of HH type, and HL and LH types did not appear, while most districts had no significant characteristics. In 2019, Xixia changed from LL type to insignificant type, Lingwu changed from insignificant type to LL type, Longde, Jingyuan, and Haiyuan changed from insignificant type to HH type, and HL and LH types still did not appear, other districts' characteristics were still insignificant. This showed that the districts where economic agglomeration was ahead of the population agglomeration were clustered in north Ningxia. In contrast, the sparsely populated and economically lagging areas were clustered in the south, and such effects were intensifying. However, the population and economic linkages in most districts were still weak (**Figure 8**).

4.6 Influence Factors

Based on the correlation analysis between the importance of ecological protection, industrial structure, urbanization level, per capita local general public budget expenditure and the spatial inconsistency index of population and economy in 2019, it is found that the importance of ecological protection, industrial structure, urbanization level are the important factors affecting the spatial distribution of population and economy in Ningxia (**Table 3**).

The proportion of the area of general importance for ecological protection, urbanization rate, the proportion of the added value of the primary industry, the proportion of the added value of the secondary industry was used as an independent variable, and the inconsistency index was used as a dependent variable for linear regression analysis.

The R^2 value of the model is 0.881. The proportion of the area of general importance for ecological protection, urbanization rate, the proportion of the added value of The primary industry, and the proportion of the secondary industry's added value can explain the reasons for the inconsistency index of 88.1%. The model passed the F-test ($F = 29.638$, $p = 0.000 < 0.05$). The proportion of the area of general importance for ecological protection, urbanization rate, the Proportion of added value of the secondary industry will have a significant negative impact on the inconsistency index. However, the proportion of the added value of the primary industry will not affect the inconsistency index. In addition, The test of the model's multicollinearity shows that all VIF values in the model are less than 5, which means there is no collinearity problem. In addition, the D-w value is near the number 2, which indicates that the model does not have

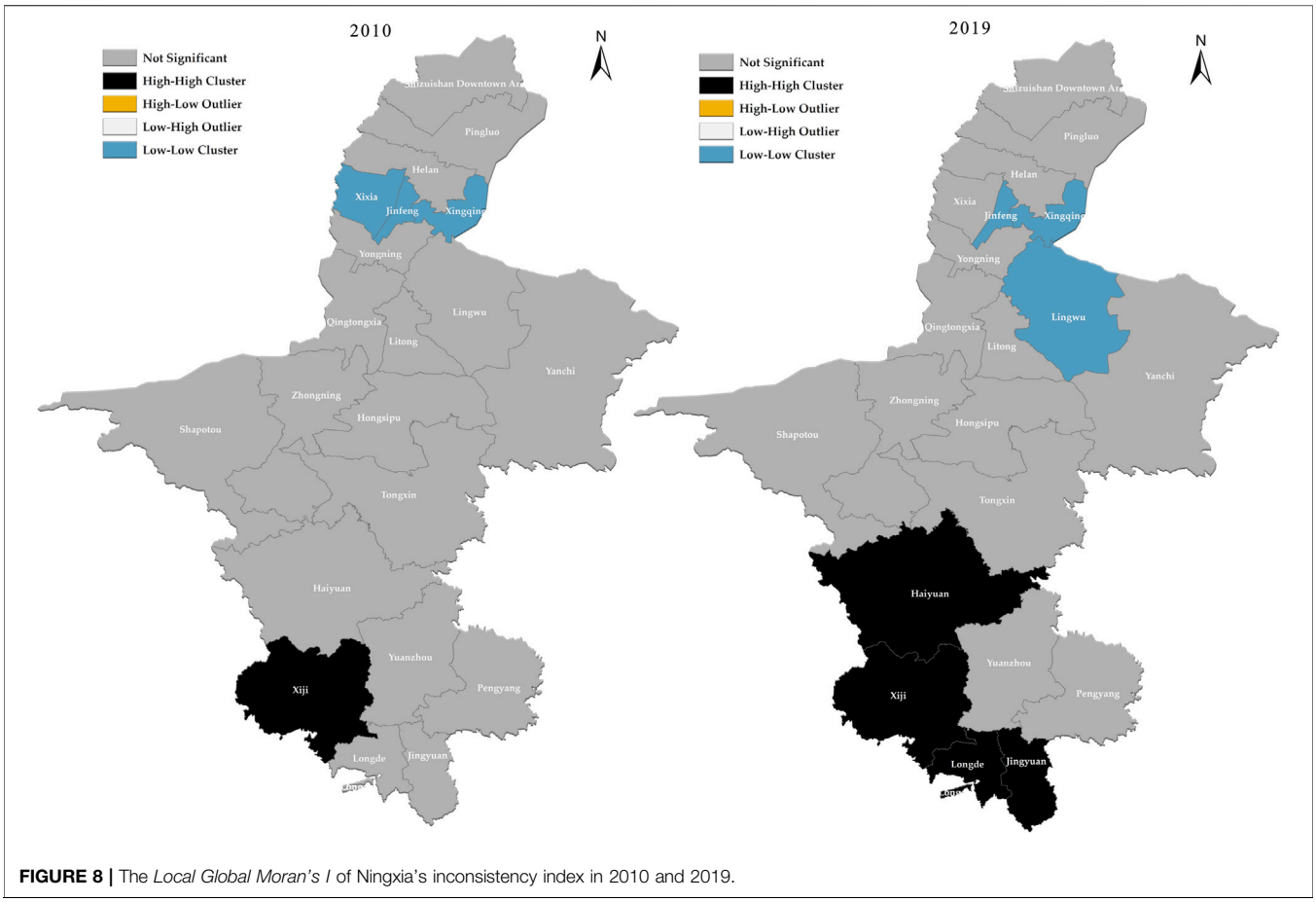

FIGURE 8 | The *Local Global Moran's I* of Ningxia's inconsistency index in 2010 and 2019.

TABLE 3 | Pearson correlation coefficient analysis results.

		Inconsistency index
per capita local general public budget expenditure	correlation coefficient	0.340
	p value	0.132
the proportion of the area of general importance for ecological protection	correlation coefficient	–0.611**
	p value	0.003
urbanization rate	correlation coefficient	–0.776**
	p value	0.000
the proportion of the added value of the primary industry	correlation coefficient	0.781**
	p value	0.000
the proportion of the added value of the secondary industry	correlation coefficient	–0.628**
	p value	0.002
the proportion of the added value of the third industry	correlation coefficient	0.378
	p value	0.091

*p < *0.05*, **p < *0.01*.

autocorrelation and there is no correlation between sample data (**Table 4**).

5 DISCUSSION AND CONCLUSION

First, the population and economy of Ningxia present an uneven spatial distribution pattern of "high in North and low in Middle and South." Natural conditions have laid a foundation for the formation of this pattern, and the uneven development strategies and policies have accelerated the formation of this pattern. Natural conditions determine the spatial variability and vulnerability of the ecological environment, thus affecting the spatial distribution of population and economy. There are significant differences in natural conditions in Ningxia. The north Yellow River irrigation area is blessed by the Helan

TABLE 4 | Multiple Linear Regression analysis results.

	Nonstandardized coefficient		Normalization coefficient	*t*	*p*	VIF	R^2	AdjustR^2	*F*
	B	Standard error	*Beta*						
the constant regression term	3.996	0.750	—	5.331	0.000**	—	0.881	0.851	$F(4,16) = 29.638$, $p = 0.000$
the proportion of the area of general importance for ecological protection	−1.003	0.418	−0.286	−2.398	0.029*	1.912			
urbanization rate	−2.051	0.830	-0.461	−2.472	0.025*	4.686			
the proportion of the added value of the primary industry	0.294	2.337	0.022	0.126	0.901	4.290			
the proportion of the added value of the secondary industry	−2.535	0.496	−0.527	−5.116	0.000**	1.427			

Dependent variable: inconsistency index (2019).
D-W Value: 2.060.
**p < 0.05, **p < 0.01.*

Mountains and the Yellow River to form a plain area rich in resources and suitable for agricultural production and urban construction. Therefore, it is an area with better conditions for population and economic agglomeration. The central area is a low hill and arid sandy area, while the southern area is loess hilly and gully area and mountainous area. The natural environment of the central and south is harsh, the ecological environment is fragile, and the resources are scarce, which are not suitable for agricultural production and urban construction. As a result, the agricultural and economic activities are less, leading to a low degree of population and economic agglomeration. Due to the implementation of the regional development strategy, the government's support for each area shows regional differences. As the strategic center of Ningxia's development, the northern area along the Yellow Belt has received the external driving force of regional policy support. The north area has developed rapidly and become a high-value area for economic development and population agglomeration. As the core of the Urban belt along the Yellow River, Yinchuan has become the core of the high-value area of economic development and population agglomeration.

Second, urbanization level and industrial structure are the essential factors affecting the spatial distribution of population and economy in Ningxia. A high level of urbanization means a larger scale of cities and towns, a higher level of economic development, more employment opportunities and more significant attraction to capital, population and other factors of production. It is calculated that the Person correlation coefficient between the urbanization rate of Ningxia and the spatial inconsistency index of population and economy in 2019 is −0.776, which is significantly negative at the level of 0.01. This indicates that the higher the level of urbanization of areas, the economic development is ahead of the population agglomeration, while the lower the level of urbanization of areas, the economic development is behind the population agglomeration. Reasonable industrial structure helps maximize economic and social benefits. The optimization of industrial structure will promote regional economic development and affect regional population flow, thus affecting the relationship between population and economic spatial distribution. The Person correlation coefficient between the proportion of added value of three industries in GDP of Ningxia and the spatial inconsistency index of population and economy in 2019 is calculated. The change of primary and secondary sectors has the most significant impact on the population and economic distribution, with correlation coefficients of 0.781 and −0.628 (showing a significance level of 0.01), respectively. This indicates that where the higher the added value of the secondary industry is, the more the regional economic development is ahead of the population agglomeration, while where the higher the added value of primary sector of areas is, the more the economic development lags behind the population agglomeration.

Third, the imbalance of economic development in Ningxia exceeds the imbalance of population development, but the relationship between the two is becoming increasingly coordinated. The population changes always accompany the economic changes with a certain lag. The spatial imbalance of economic development is the fundamental driving force of population agglomeration. Areas with higher economic level have better production and living conditions, which constantly attract people to gather here. Recently, the industries in the urban agglomerations along the Yellow River have developed rapidly, and the economic agglomeration capacity of the north has improved fast. The agglomeration capacity improvement of the economy precedes that of population, so the uneven economic development outweighs the uneven population development. The Person correlation coefficient of the geographical concentration of population and the geographical concentration of economy in Ningxia 2019 is calculated to be 0.985, which is significantly at the 0.01 level positive correlation, confirming that the spatial imbalance of economic development is the fundamental driver of population concentration. However, as the regional economic differences between northern and south-central Ningxia continue to expand, coupled with the implementation of various talent introduction policies in the north area and the ecological migration project policies, a large number of people have moved from the south and central area to the north area to obtain ideal living conditions, which accelerates the population concentration in the north and reduces the population pressure in the south and central areas. As a result, the population in each area of Ningxia is more matched with the

level of economic development, and the relationship between population and economy tends to be constantly coordinated.

Fourth, the polarization effect of Ningxia's economic development is constantly weakening, the diffusion effect has begun to appear, and the polarization effect of the population has continued to increase. The emergence of this trend is mainly due to changes in the development stage of the urban agglomeration along the Yellow River. Ningxia's urban agglomeration along the Yellow River has a small population base, a small number of towns and weak connections, and low economic aggregates. As China implements policies such as Western Development, the urban agglomeration along the Yellow River have gradually matured. As a result, its radiating effect has progressively changed from the single radiating spread of the core city of Yinchuan within the urban agglomeration to the radiating spread of the urban agglomeration as a whole to the surrounding non-urban agglomeration areas, and even the central and southern areas are radiated. Driven by the urban agglomeration along the Yellow River in the north, the economic development level of the central and southern areas has continued to improve, so the polarization effect of Ningxia's economic development has weakened over time. However, the economic scale of central and southern areas is still far smaller than that of the north and not attractive enough for population agglomeration. Therefore, the population agglomeration in the northern area is increasingly polarized.

Fifth, ecological environment, industrial structure, urbanization level and other factors are important factors that affect the harmonious relationship between population and economy in Ningxia. We should continue to improve the environmental quality and ecosystem quality in the central and southern regions of Ningxia. According to the types and characteristics of ecologically fragile areas, ecological restoration and management projects should be carried out according to local conditions, and ecological compensation funds and project support should be given to the areas in the middle and south of Ningxia. The industrial structure should be optimized and industrial distribution adjusted in Ningxia. According to each region's resource endowment, industrial foundation and environmental capacity, the leading industries shall be identified, and the industrial division and cooperation within the area shall be strengthened. We should accelerate industrial upgrading and transformation, replace high-emission and high-pollution models with high-efficiency, energy-saving and advanced manufacturing methods, and form a new industrial pattern in which the three industries develop harmoniously. We should speed up the construction of new-type urbanization in Ningxia, build a scientific and reasonable urban pattern, closely connect with regional economic development and industrial layout, and adapt to the carrying capacity of resources and environment. The central cities along the Yellow River should continue to speed up the construction of new urbanization and promote the development of surrounding cities. For the economic lagging areas in the central and southern regions with relatively low urbanization level, we should scientifically plan the urban development ideas and framework, construct a new urban and rural system, pay attention to infrastructure construction, improve public service capacity, promote urban-rural integration development, and improve the total population carrying capacity of the central and southern regions. It is necessary to enable the high-quality integrated development of Ningxia Urban agglomeration along the Yellow River, accelerate industrial aggregation and economic development, strengthen the policy of talent introduction, form its population attraction, intercept the outflow of population, enhance the core competitiveness of the Urban agglomeration along the Yellow River, and improve the radiating and driving ability of the urban agglomeration along the Yellow River to the central and southern regions. Guyuan will be built into the central city of population gathering in south Ningxia and the regional public service supply center. The radiation and driving role of Guyuan in southern Ningxia will be strengthened.

Finally, research limitations and prospects: first, the depth of the study needs to be further strengthened. This study only analyzes the relationship between the permanent population and the spatial distribution of the economy from the perspective of the total quantity, without considering the spatial matching status of other indicators of population, such as population age structure, population quality, labor force employed population, and other indicators of the economy, such as industrial structure. Second, in discussing the factors influencing the relationship between population and economy, we could not collect the data related to location conditions, traffic conditions, history and culture and failed to carry out quantitative analysis on their correlation. Third, the possible social effects caused by the mismatch between population and economic distribution need to be further studied. These problems still need further discussion in future studies and research.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://nxdata.com.cn/publish.htm?cn=G01.

AUTHOR CONTRIBUTIONS

JL and WH contributed conception of the study. JL analysed the data. JL and WH interpreted the results. JL wrote the manuscript. JL and WH contributed to manuscript revision and the final version of the manuscript.

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