Postprint: Analysis of Population Shrinkage Patterns and Driving Forces in the Loess Plateau Region

Authors: Chen Qi

Date: 2021-03-03T00:00:00+00:00

Abstract

Based on population data from 2005 and 2015, this study employs methods such as shrinkage index, geostatistical analysis, and Geodetector to investigate the population shrinkage phenomenon and spatial differentiation patterns in the Loess Plateau region at different geographical scales, revealing the differential driving forces and mechanisms of population shrinkage in this region. The results indicate that: (1) The proportion of population shrinkage is relatively high under both county-level and prefecture-level administrative units in the Loess Plateau region, and identifying population shrinkage at a single geographical scale exhibits biases. (2) The population shrinkage phenomenon in the Loess Plateau region conforms to the "core-periphery" pattern at regional, provincial, and prefecture-level city scales, with population agglomeration in core areas (cities) and population loss in peripheral areas (counties). (3) Disparities in economic development levels and urban-rural development imbalances have become the primary driving factors for population agglomeration and loss in the Loess Plateau region. The prefecture-level city shrinkage type is mainly driven by urbanization and industrialization levels, representing population shrinkage resulting from insufficient comprehensive urban development capacity; the prefecture-level city local shrinkage type occurs during periods of rapid socio-economic development, where uneven distribution of internal factors leads to localized internal shrinkage.

Full Text

Abstract

Based on population data from 2005 and 2015, this study employs the shrinkage index, geostatistical analysis, and geographic detector methods to investigate population shrinkage phenomena and regional differentiation patterns in the

Loess Plateau region across different geographic scales. The analysis reveals differences in driving forces and mechanisms of population shrinkage in the Loess Plateau. The results indicate that: (1) Both prefecture-level and county-level administrative units in the Loess Plateau exhibit high proportions of population shrinkage, with single-scale identification showing bias. (2) Population shrinkage in the Loess Plateau follows a "core-periphery" pattern at both regional and prefecture scales, with population concentrating in core areas (cities) and declining in peripheral areas (counties). (3) Differences in economic development levels and imbalances in urban-rural development have become the primary drivers of population agglomeration and loss in the Loess Plateau. Prefecture-level city shrinkage is mainly driven by urbanization and industrialization levels, representing population shrinkage caused by insufficient comprehensive development capacity; prefecture-level cities with localized shrinkage are in a period of social development, where uneven distribution of internal factors leads to localized internal shrinkage.

Keywords: population shrinkage; population density; spatial pattern; geographic detectors; Loess Plateau

Introduction

Since the 1950s, influenced by socioeconomic factors, many cities in Western countries have experienced severe population loss [1], accompanied by numerous social problems. For example, Manchester in the UK saw a large number of factory closures and worker out-migration around 2000, with housing vacancy rates exceeding 25.6% [2]; Leipzig in Germany experienced similar issues [3]. This phenomenon of urban population shrinkage began attracting attention from planning and academic circles. The "International Network for Shrinking Cities" (SCIRN) defines urban shrinkage from a population size perspective as cities with populations greater than 10,000 experiencing continuous population decline [4]. Liu Helin analyzed progress in quantitative methods for urban shrinkage [5], providing a theoretical foundation for subsequent empirical research.

At the practical level, domestic urban shrinkage research primarily uses census data to analyze national shrinking city phenomena and patterns [6-8], supplemented by remote sensing imagery [9], nighttime light data [10], and statistical yearbooks [11]. Long Ying et al. [12] identified 180 Chinese cities with declining permanent resident populations and densities using 2000 and 2010 census data, finding that domestic urban shrinkage is characterized by large numbers, wide distribution, and relatively mild shrinkage intensity. Foreign studies indicate that Western urban shrinkage mainly results from globalization [13], deindustrialization [14], suburbanization [15], and post-socialist transformation [16], with shrinking cities often facing human resource shortages [17] and economic or fiscal crises [18]. In response, Western planning circles have proposed strategies such as green infrastructure construction [19], land banking, and public participation centered on "smart decline" to address urban shrinkage [20].

Chinese cities have also experienced population shrinkage phenomena [21]. Among 650 shrinking cities, over 500 exhibit land sprawl problems [22]. Numerous researchers have studied eastern China (Yangtze River Delta [23], Pearl River Delta [24]) and Northeast China [25], with some research on central China' s Hubei [26] and Henan [27] provinces and southwestern Sichuan-Chongqing region [28], while relatively less attention has been paid to other central and western regions.

In recent years, China' s socioeconomic development has entered a high-speed period. Unbalanced regional development [29] has induced inter-regional population migration, with "peacocks flying southeast" [30] and "moving to cities" becoming typical social phenomena. Large numbers of migrant workers have flocked to coastal developed areas or nearby better-developed cities seeking opportunities, triggering new population shrinkage phenomena in central and western regions. Based on this context, this article selects the Loess Plateau, which spans central and western China, as the study area to analyze its population agglomeration and loss characteristics, measure shrinking cities in the Loess Plateau, and analyze spatial patterns. The study explores driving factors of shrinkage at the prefecture-level city scale from a socioeconomic perspective, analyzes the universality and specificity of population shrinkage patterns, enriches mesoscale urban shrinkage research in China' s less developed regions, and provides theoretical support for urban positioning and related planning for shrinking cities in the Loess Plateau.

1.1 Data Sources

According to the *Comprehensive Management Planning Outline for the Loess Plateau Region (2010-2030)*, this study selects 45 prefecture-level administrative units and 399 county-level administrative units as research objects (municipal districts of prefecture-level cities are merged and treated as one county-level administrative unit) (Fig. 1). Administrative divisions are corrected according to the 2015 administrative geographic scope. Prefecture-level administrative units include 8 prefecture-level cities and 2 autonomous prefectures in Shanxi Province, 7 prefecture-level cities in Shaanxi Province, 6 prefecture-level cities in Inner Mongolia Autonomous Region, 5 prefecture-level cities in Gansu Province, 5 prefecture-level cities in Ningxia Hui Autonomous Region, 9 prefecture-level cities in Henan Province, 3 prefecture-level cities in Qinghai Province, and 1 provincial-level city; county-level administrative units comprise 45 municipal districts, 12 county-level cities, 51 banners, 17 autonomous counties, 1 forest region, and 273 general counties.

Permanent resident population data are obtained from statistical yearbooks of provinces (autonomous regions, municipalities) in the Loess Plateau region for 2005 and 2015 [Gansu population data from *Gansu Development Yearbook 2006/2016*, Inner Mongolia Autonomous Region county-level permanent population data from *Inner Mongolia Statistical Yearbook 2006/2016* as year-end population data]. The proportion of population aged 65 and above comes from

2005 and 2015 population sampling statistics, and related economic data are from provincial (prefecture-level) statistical yearbooks.

1.2 Research Methods

The study uses the population shrinkage index to identify shrinking research units, employs Geoda for spatial correlation verification, conducts correlation analysis and multiple regression analysis for factor screening and preliminary analysis, and finally uses geographic detectors to identify factor importance.

1.2.1 Shrinkage Measurement and Identification

Methods for measuring population shrinkage are relatively mature [5, 7, 24-27], with indicators such as employment and infrastructure levels [28] commonly used. This study uses the absolute value of resident population change, which is more representative, for population shrinkage measurement. The formula is as follows:

Rij = Pij2015 Pij2005

where Rij is the population shrinkage index; P is population; i is the prefecture-level administrative scale (i = 1, 2; 1 represents prefecture-level administrative units, 2 represents county-level administrative units); j is the corresponding research unit; Rij $<$ 0 indicates a shrinking city, while Rij $\geq$ 0 indicates a non-shrinking city.

1.2.2 Exploratory Spatial Analysis

Spatial autocorrelation [29] is an important indicator for testing whether attribute values of certain elements are significantly associated with those of adjacent spatial elements. It includes two measurement methods: global spatial autocorrelation, which describes the overall distribution of observation values in regional units, and local spatial autocorrelation, which measures the similarity or dissimilarity between spatial unit attributes and surrounding units.

1.2.3 Factor Detection

The geographic detector [30] is a novel tool for exploring spatial heterogeneity, widely applied in land use, regional differences, and population pattern studies. This method can effectively analyze differentiation mechanisms in small sample data. The geographic detection value of each factor is represented by q, with the formula:

q = 1 - (1/Nσ^2) [h=1 to L] Nhσ^2h

where q represents the explanatory power of the detection factor; larger q values indicate greater driving effects of X on urban development. N and σ^2 are the total number of samples and variance; Nh and σ^2h are the number of units and variance in stratum h.

2.1.1 Loess Plateau Urban Shrinkage Phenomenon

Permanent resident population plays an important role in urban development. This study uses prefecture- and county-level permanent population data from the Loess Plateau region to investigate population shrinkage. Population shrinkage index calculation results are shown in Fig. 2, with numerous county-level administrative units analyzed using tables for assistance (Table 1). At the prefecture-level administrative unit scale, the overall shrinkage proportion is relatively high, with significant differences among provinces. Provincial capital cities and autonomous prefectures did not experience shrinkage, while general prefecture-level cities had high shrinkage rates. Ten prefecture-level administrative units experienced shrinkage, accounting for 22.22% of all prefecture-level administrative units. Among the six provinces, Gansu had the most severe population shrinkage. Shanxi, Qinghai, and Henan provinces experienced no population decline within the Loess Plateau region during the study period. Shaanxi Province had two prefecture-level cities with population shrinkage (Weinan and Xianyang), Inner Mongolia Autonomous Region had two (Bayannur and Ulanqab), and Ningxia Hui Autonomous Region had only Guyuan. Gansu had the largest number of shrinking prefecture-level cities (9 out of 12), accounting for 75.00% of prefecture-level cities in Gansu within the study area and 71.43% of all shrinking prefecture-level cities in the Loess Plateau.

At the county-level administrative unit scale, the overall shrinkage proportion is even higher. Shrinking county-level administrative units show a pattern of high shrinkage rates in general counties and low shrinkage rates in banners, municipal districts, autonomous counties, and county-level cities. A total of 109 county-level administrative units experienced shrinkage, accounting for 27.32% of all county-level administrative units in the Loess Plateau. Among them, 90 general counties experienced shrinkage, accounting for 82.57% of shrinking county-level administrative units; 7 banners shrank (6.42%); 6 county-level cities shrank (5.50%); 5 municipal districts shrank (4.59%); and 1 autonomous county shrank (0.92%). Prefecture-level city scale can provide an overall judgment of shrinkage in the Loess Plateau, while county-level scale can further reveal population agglomeration and loss patterns within prefecture-level cities, verifying and supplementing prefecture-level city shrinkage indices.

The population shrinkage phenomenon in the Loess Plateau is universal at both prefecture and county scales, and single geographic scale identification has certain limitations. Forty-three prefecture-level administrative units have shrinking county-level units, but panel data at the prefecture-level city scale only shows 10 shrinking units. If only prefecture-level city scale is used, shrinkage phenomena in 33 prefecture-level administrative units would be ignored. Meanwhile, some prefecture-level administrative units with overall population loss still have accelerating population agglomeration in their municipal districts. For example, Taiyuan experienced overall population growth, but its Qingxu County showed population shrinkage. Therefore, understanding population shrinkage should proceed from multiple geographic scales to increase identification accuracy and classification scientificity.

2.1.2 Loess Plateau Urban Shrinkage Pattern

While statistical analysis can reveal urban shrinkage phenomena in the Loess Plateau, geospatial analysis tools are needed for spatial patterns. Global autocorrelation verifies the spatial agglomeration of shrinkage in the Loess Plateau, while Local Indicators of Spatial Association (LISA) analyzes consistency and heterogeneity of spatial unit attributes. The Z-value and P-test for Rij passed global autocorrelation, indicating that shrinking cities in the Loess Plateau have significant regional agglomeration characteristics.

Moran' s I index expresses the degree of similarity or dissimilarity between spatial attributes. Positive local spatial autocorrelation (high-high, low-low) can explore the overall distribution pattern of shrinkage indices in the Loess Plateau; negative local spatial autocorrelation (high-low, low-high) can identify abnormal shrinkage index points. Local autocorrelation analysis results for the Loess Plateau show that at the prefecture-level administrative unit scale, positive local spatial autocorrelation concentrates in Gansu, Ningxia, and Inner Mongolia, while negative local spatial autocorrelation sporadically distributes in peripheral areas. Low-low value areas mainly concentrate in Gansu, forming population loss zones; high-high value areas concentrate in southern and central Ningxia and Inner Mongolia, where population growth is significantly higher than surrounding areas. Abnormal points exist between high and low value areas. Low-high abnormal points are Shizuishan, Xinzhou, and Bayannur—Shizuishan and Xinzhou still have population growth but less obvious than surrounding areas, while Bayannur has absolute population decline. The high-low abnormal point is Zhongwei, whose southern area is a concentrated population loss zone in Gansu.

At the county-level administrative unit scale, spatial distribution is similar to prefecture-level units but with more precise identification of population shrinkage indices. Low-low agglomeration mainly occurs in the Liupan Mountain area and surrounding regions of Gansu, with a new low-value agglomeration area appearing in southern Yulin. High-high agglomeration mainly occurs in Ningxia and Inner Mongolia, with new high-value agglomeration areas in Qinghai centered on autonomous prefectures and in Henan centered on county-level cities. The number of spatial outliers increases, with low-high abnormal points appearing at the border of Ningxia and Inner Mongolia, northern Inner Mongolia, and southern Luoyang, becoming population-deprived zones mostly adjacent to municipal districts. High-low abnormal points are mostly municipal districts in peripheral areas of shrinking prefecture-level cities, distributed relatively dispersedly. Due to adjacency constraints, the LISA map shows some phenomena contradictory to reality, such as numerous low-value outliers in northern Inner Mongolia. From the perspective of shrinkage indices, these low-value outliers should be low-value agglomeration areas.

2.1.3 Loess Plateau Regional Population Shrinkage Types

The "city-leading-counties" development model has long existed in China. Multi-scale phenomenon analysis aims to clarify similarities and differences in population shrinkage across different prefecture-level administrative units and accurately identify characteristics of prefecture-level city shrinkage. Considering the high similarity of socioeconomic attributes among counties within prefecture-level cities, this study classifies Loess Plateau population shrinkage types by prefecture-level administrative unit and compares driving forces across different types. Based on comprehensive population shrinkage indices at prefecture and county scales, the 45 prefecture-level cities in the Loess Plateau are divided into three types (with abbreviations in parentheses), with classification results shown in Table 3.

Type A: Prefecture-level city shrinkage type (A-type), where prefecture-level administrative units show overall population loss trends, with a high proportion of internally shrinking county-level administrative units. Most prefecture-level cities have more than 50% of internal counties experiencing population shrinkage.

Type B: Prefecture-level city localized shrinkage type (B-type), where prefecture-level administrative units show overall population growth but contain a small number of shrinking county-level administrative units.

Type C: Prefecture-level city growth type (C-type), where both prefecture-level and county-level administrative units experience population growth. Type C serves as a non-shrinking city for comparison with the other two shrinkage types.

Based on the spatial distribution pattern and agglomeration characteristics of population shrinkage indices in the Loess Plateau, population shrinkage demonstrates a unified "core-periphery" feature across multiple geographic scales. From the perspective of the entire Loess Plateau region, the Guanzhong Plain and Ningxia Plain, as core regional development areas, attract more capital, information, and technology, with higher population agglomeration; the Liupan Mountain area focuses on ecological protection, with local populations choosing to migrate out for livelihoods. At the provincial level, provincial capital cities maintain strong population attraction with multiple advantages, exerting strong pull on populations from surrounding prefecture-level cities; ordinary prefecture-level cities experience outward migration and population shrinkage. Within prefecture-level cities, most municipal districts remain optimal destinations for population agglomeration with low shrinkage rates; general counties have relatively low population carrying capacity, with surplus labor transferring to more developed areas like municipal districts. Notably, based on existing data, ethnic minority areas show relatively stable population growth characteristics, with potentially lower willingness for outward migration.

2.2.1 Indicator Selection

Numerous factors cause urban or regional population shrinkage, mainly "economic factors"and "social factors"[17, 22, 26]. This study selects 7 economic indicators and 4 social indicators, uses Pearson correlation analysis and collinearity diagnosis to eliminate statistically irrelevant factors and those with large variance inflation factor (VIF) values (large VIF indicates poor factor independence and high information redundancy with other factors). Ultimately, 3 economic factors and 3 social factors are selected for driving force analysis of the three shrinkage-type prefecture-level cities.

Economic factors selected are: per capita GDP (X_1) measuring regional economic comprehensive development level, fiscal self-sufficiency rate (X_2) measuring regional economic health development level, urban-rural income ratio (X_3) measuring regional economic imbalance and urban-rural gap, and annual change rate of secondary industry value-added proportion (X_4) measuring regional industrialization (deindustrialization) level. Social factors selected are: urbanization rate (X_5) measuring regional social comprehensive development level, and proportion of population aged 65 and above (X_6) measuring regional aging degree. Correlations between selected indicators and population shrinkage index are shown in Table 4.

2.2.2 Loess Plateau Population Shrinkage Driving Force Analysis

Geographic detectors are used to conduct factor detection on cities with different spatial shrinkage types to explore differences in dominant factor driving forces across different population shrinkage types. Detection results are shown in Fig. 4. Using type means (Table 5) to assist in analyzing internal socioeconomic attribute differences of different shrinkage types, the internal logic of factor driving force differences is explored.

Type A factor decision power q values show that Type A is mainly driven by urbanization and aging, with industrialization effects secondary and minimal impact from urban-rural gap, representing a low-level equilibrium state. The driving factors are poor urban comprehensive capacity and severe aging. Type A shrinking cities in the Loess Plateau have low economic development levels, with per capita GDP of 26,200 yuan; young people choose to work outside due to regional unbalanced development, while elderly populations remain, making aging problems prominent; industrial foundations are weak, mostly still in the early industrialization stage, with low secondary industry value-added proportions (38.2%) and high shrinkage probability.

Type B factor decision power q values show that Type B is driven by urbanization, urban economic development level, and urban-rural gap, with minimal deindustrialization impact, representing a high urbanization, high economic development level state with large urban-rural gaps causing localized shrinkage.

Type B shrinking cities have relatively good socioeconomic development, with urbanization rate mean of 60.28% and per capita GDP of 46,700 yuan; these are comprehensively well-developed prefecture-level cities in Shaanxi Province. However, large urban-rural gaps within prefecture-level cities create polarization effects, with surplus rural labor continuously agglomerating toward central areas.

Type C factor decision power q values show that Type C is mainly driven by urbanization and aging, with smaller industrialization impact compared to Type A and smaller urban-rural gap impact compared to Type B, but larger aging impact. Under high economic development levels, Type C attracts population inflow while maintaining small urban-rural gaps, preventing further polarization within prefecture-level cities or making polarization effects insignificant.

Different shrinkage types have certain differences in dominant factors. X_2 (fiscal self-sufficiency rate) and X_5 (urbanization rate) have large q values across all three types, requiring attention for all Loess Plateau city types. X_2 can reflect urban development health to some extent, while X_5 reflects urban population, economic, technology, information, and land agglomeration. Combined correlation analysis (Table 4) and factor decision power (Fig. 4) show that higher urban comprehensive development levels lead to smaller population shrinkage probability; areas with large urban-rural gaps, low deindustrialization, and severe aging have greater shrinkage probability.

Loess Plateau population shrinkage is a complex socioeconomic process and local response under multi-factor interaction. Population shrinkage is strengthened by multiple factors, with interaction q values greater than single-factor q values (Table 6), all showing non-linear enhancement. Industrialization has significant effects in Type A areas, with internal logic: poor resource endowment, low per capita GDP, and accelerated urbanization stage, plus large urban-rural income ratios (3.02), creating strong interaction between X_3 and X_5 that increases population shrinkage probability. X_2 and X_5 interaction q values are large (0.82), representing the interaction between urban-rural income ratio and urbanization rate, indicating that when prefecture-level cities have large urban-rural gaps and relatively high comprehensive development levels, internal polarization increases localized shrinkage probability. X_2 and X_5 have large interaction values with other factors, showing obvious strengthening effects after factor interaction.

3.1 Conclusions

Through research on urban shrinkage patterns and mechanisms at different scales in the Loess Plateau, the main conclusions are:

(1) Population shrinkage in the Loess Plateau region is universal, with high shrinkage proportions at both prefecture and county administrative scales. The shrinkage rate of prefecture-level administrative units is 22.22%, while county-level administrative units is 34.49%, with county-level units showing relatively higher shrinkage. Multi-scale comparative research improves

accuracy in population shrinkage identification. The proportion of shrinking prefecture-level administrative units is relatively low at 22.22% of total prefecture-level cities; however, the number of prefecture-level cities with shrinking county-level units is 31, accounting for a high proportion of 68.89% of all prefecture-level cities. Overall, prefecture-level scale population shrinkage shows a "one low, one high" pattern, while county-level scale shows a "four low, one high" pattern. Among shrinking county-level administrative units, county-level cities, banners, municipal districts, and autonomous counties have low shrinkage rates, collectively accounting for 16.51% of shrinking county-level units; general counties have high shrinkage rates, with 90 shrinking counties accounting for 82.57% of shrinking county-level units.

(2) Loess Plateau population follows a "core-periphery" pattern at regional-provincial-prefecture scales, with core area (city) population agglomeration and peripheral area (county) population loss. Regionally, the Guanzhong Plain and Ningxia Plain have become core population concentration areas, while the Liupan Mountain area has become a concentrated population loss zone. Provincially, provincial capital cities have stronger population concentration capabilities, while ordinary prefecture-level cities experience population shrinkage. Within prefecture-level cities, municipal districts remain optimal destinations for population agglomeration with low shrinkage rates, while peripheral counties are at the loss margin with population shrinkage.

(3) The three shrinkage types in the Loess Plateau have different dominant driving factors, differing from shrinkage causes in typical Chinese shrinking regions. Economic level, aging degree, and urban-rural gap significantly impact Loess Plateau urban shrinkage, while deindustrialization has minimal impact. Type A is mainly driven by weak economy, severe aging, and low industrialization level. Type B mainly results from rapid socioeconomic development causing unbalanced regional development, leading to localized internal shrinkage. The Loess Plateau has low industrialization and socioeconomic development levels, currently still in the stage of promoting urban development by undertaking industrial transfer from central and eastern China, differing from deindustrialization-dominated urban shrinkage in Northeast China [25]. Type B has some similarities with localized shrinkage in the Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Hebei region [17, 24] and is similar to shrinkage in some cities in the Sichuan-Chongqing region [28].

3.2 Research Prospects

Based on identification and driving force analysis of population shrinkage in the Loess Plateau, future research may focus on:

(1) Urban development follows a pattern from low-level balanced development

to higher-level polarized development and finally to high-level balanced development. Whether population shrinkage at the prefecture-level administrative unit scale follows the development pattern of Type A → Type B → Type C requires validation with longer time series and larger samples.

(2) The *National New Urbanization Plan (2014-2020)* proposes requirements such as "coordinated regional development" and "equalization of public services."Whether the 倾斜 of economic resources to certain areas indirectly causes urban shrinkage, and whether cities with high resource 倾斜 degrees will not shrink, are urban shrinkage issues worth attention.

Note: Figure translations are in progress. See original paper for figures.