frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 13 February 2023
DOI 10.3389/fenvs.2023.1066371



OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Environmental Economics and Management, a section of the journal Frontiers in Environmental Science

RECEIVED 10 October 2022
ACCEPTED 26 January 2023
PUBLISHED 13 February 2023

CITATION
Zhou C, Yu Z and Wang Q (2023), Analysis of temporal and spatial changes and influencing factors of sewage treatment rates of small towns in Chongqing. *Front. Environ. Sci.* 11:1066371. doi: 10.3389/fenvs.2023.1066371



# Analysis of temporal and spatial changes and influencing factors of sewage treatment rates of small towns in Chongqing

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Small towns are the bridge between urban and rural areas, and their sewage treatment is the focus and problem of urban construction. With Chongqing as the research object, this study explores the influencing factors and the characteristics of temporal and spatial changes in sewage treatment rates of 756 small towns in Chongqing from 2014 to 2020 from four aspects: the overall situation, space, population, and industry. The results show that 1) the sewage treatment rates of small towns showed a certain trend of improvement since 2014 and that the polarization between small towns continued to decrease. 2) The sewage treatment rates of small towns presented a significant spatial correlation in their entirety, but the correlation weakened year by year. In 2014, the sewage treatment rates of small towns were mainly high-high clusters, while those in 2017 were mainly low-low clusters and those in 2020 were low-low clusters in a scattered manner. 3) The sewage treatment rates of small towns with a population of 40,000–60,000 and over 60,000 in 2014 were relatively high, but the gap narrowed year by year. Small towns with more than 60,000 people had the highest sewage treatment rate in 2020, but the gap between the lowest values was reduced to 11.94%. 4) In 2014, small towns with tourism as the leading industry had a significant advantage, but three types of small towns, including industrial and mining towns, were improving fast. 5) Land urbanization, the radiation effect of county towns, the investment in urban construction, population size, and leading industries all had notable driving effects on the increase in sewage treatment rates of small towns, but the impact of urban construction investment was relatively weak because it contained a large scale of real estate investment.

KEYWORDS

**small towns, sewage treatment, temporal and spatial changes, economic geographical factors, Chongqing**

## 1 Introduction

In 2020, China's urban sewage treatment rate exceeded 97% and small towns reached 95%. However, the sewage treatment rates of small towns still had a big shortcoming. In the same period, about 35% of organic towns and 65% of villages failed to treat the domestic sewage[1]. Sewage treatment is an indispensable foundation for urban development and an important

1 Data source: China Urban–Rural Construction Statistical Yearbook released by the Ministry of Housing and Urban–Rural Development of the People's Republic of China.

guarantee for green development and residents' healthy lives, but it is also a difficult point for urban construction. Compared with cities, small towns have evident weaknesses in many aspects in terms of sewage treatment facilities, such as construction cost, operation and maintenance, business model, and capital investment (Gu et al., 2016; Lou et al., 2020). As the tail of cities and the head of villages, small towns own extensive rural areas, bearing a heavy responsibility for environmental protection. The *National Rural Revitalization Strategic Plan (2018–2022)* clearly proposes "to repair and improve the rural ecological environment and to enhance the ecological function and service value." In order to further improve the rural living environment, the central government issued the *Three-Year Action Plan for Rural Living Environment Improvement* in 2018, clearly stating that "the rural domestic sewage treatment should be promoted step by step, and the rural water environment treatment should be managed under the river chief and lake chief systems." The small towns in the western part of China have a large area with rolling mountains, and their sewage treatment is faced with multiple constraints including economic development and geographical conditions. As a typical mountainous area in such a region, Chongqing is located in the upper reaches of the Yangtze River and the hinterland of the Three Gorges reservoir area. It is the last pass of the ecological barrier in the upper reaches of the Yangtze River. The sewage treatment rates of small towns not only relate to Chongqing's own long-term development but also have a close connection with the green development of the Yangtze River Basin. At the same time, a fundamental aspect of China's urbanization is the stark contrast between urban and rural development. Due to the coexistence of big metropolitan regions and rural areas, Chongqing's urban sewage treatment rate and the small-town sewage treatment rate vary significantly from one another. The overall rate of Chongqing's urban sewage treatment from 2014 to 2020 was above 90%, compared with only 57.32% of small towns during the same period. The difference between the two exceeded 22% even in 2020 (see Figure 1).

## 2 Literature review

On the whole, China's water pollution experienced an "inverted U-shaped" development trend of increasing first and then decreasing (Zhang, 2014; Cai et al., 2020). Water pollution was substantially more prevalent than other categories in various environmental emergencies between 1995 and 2010, including water pollution, air pollution, marine pollution, solid waste pollution, noise, and vibration hazards (Zhang, 2014; Wang and Yang, 2016). China's water pollution spread from coastal regions with high economic development levels to interior areas as a result of the expansion of heavy pollution businesses from the eastern region to the central and western regions (Cai et al., 2020; Pan and Fan, 2021). At the same time, China experienced numerous water pollution emergencies due to a lack of pollution management capabilities (Xu et al., 2018; Priyadarshini et al., 2022). Before 2016, the Yangtze River Economic Belt was severely polluted because of the presence of a large percentage of water pollution-intensive companies, creating a serious issue of "enclosing the river by a chemical industry." Water pollution in the Yangtze River Economic Belt has greatly decreased in recent years as a result of the differentiation of internal industrial development of water pollution-intensive businesses and structural adjustments made to the chemical industry (Lu and Song, 2020).

For the sake of economic development, China's secondary industry was developing rapidly, and at the same time, water pollution spread from cities to rural areas due to urbanization (Zhang and Jiang, 2014; Wang and Yang, 2016; Wang et al., 2020). During the period of 2006–2016, all the sudden water pollution events had a significantly positive correlation with economic growth, and the accident places were mainly concentrated in industrially developed provinces and cities including Chongqing, Guangdong, Zhejiang, and Fujian (Xu et al., 2018). Many polluting industries relocated to the central and western regions as a result of the ongoing tightening of environmental regulations in the eastern coastal areas and the growing scarcity of production factors. Eventually, industrial capacity such as population, land, and resources became a significant factor for water pollution (Ebenstein, 2012; Hu and Cheng, 2013; Liang et al., 2019). To cope with the deteriorating ecological environment, the central government put forward the *Five-Sphere Integrated Plan*, placing the construction of an ecological civilization in a prominent position and adopting more stringent environmental regulation measures (Zhang and Liu, 2019). Under the synergistic effect of policies such as ecological compensation and technical improvement, environmental control policies have effectively reversed the deteriorating trend of water pollution in China, and the synergetic degree between economic development and water resource protection has greatly improved. The effect of water pollution control was more evident in cities with good economic development, a high urbanization level, and low water resource endowment (Chen et al., 2018; Luo and Qi, 2021).

Small towns have radiation effects on a large number of surrounding rural areas, and their sewage treatment has always been a prominent problem in the urban construction of China. After 2000, China's urbanization policy changed, resulting in substantial resources flowing into cities, especially large ones, and the shortcomings of infrastructure construction in small towns became more prominent (He, 2019). During the industrial transfer, a large number of heavy industries moving out of cities further increased the ecological and environmental pressure faced by small towns (Qin et al., 2020). The changes in the agricultural production mode and the rural lifestyle are the important causes of rural water pollution. The profit-seeking behavior of individuals caused the "tragedy of the commons" of village water pollution to a certain extent (Ye and Zhu, 2019). Driven by the rural revitalization policy, the central government and local governments invested more resources in the rural living environment and gave support for financing policies, but they still face shortcomings such as a weak foundation, high environmental pressure, and a lack of social capital (Xu et al., 2014; Du, 2019; Shi et al., 2021).

The existing research on water pollution and its treatment in China has made great achievements in terms of development trend and environmental regulation, but there are also three shortcomings. First, the current research on water pollution and treatment focuses on cities and pays insufficient attention to the small towns facing more prominent sewage treatment pressure due to backward infrastructure. Second, the existing research mainly analyzed the sewage treatment in small towns from the aspects of the operation mode and individual behavior, lacking the quantitative analysis of the *status quo* and influencing factors. Third, most of the existing research studies concentrated on sewage treatment in plain areas, but a few concentrated on that in mountainous small towns, especially on the upper reaches of the Yangtze River that have great ecological and environmental pressure. The marginal contribution of this paper lies in two aspects. On the one hand, the research on the sewage

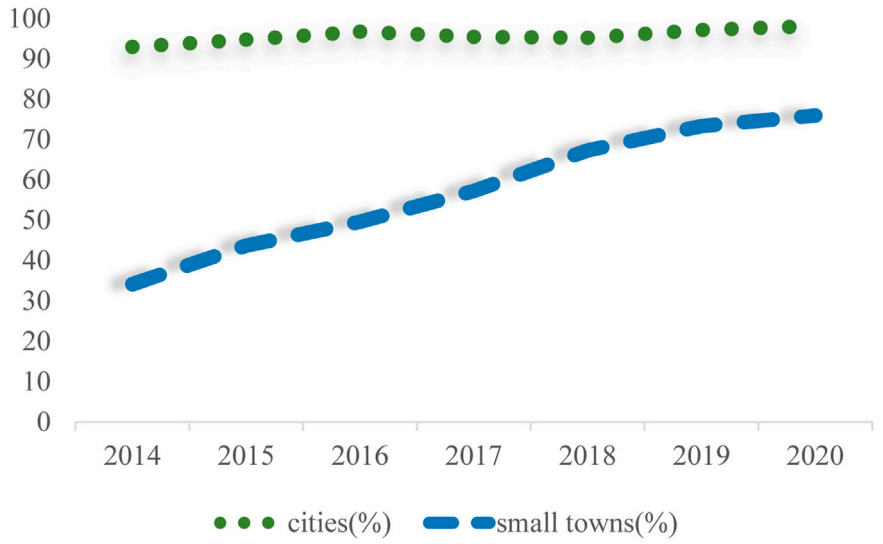


FIGURE 1
Sewage treatment rates of small towns and streets in Chongqing (2014–2020).

treatment of small towns in mountainous locations is supplemented by the study of 778 small towns in Chongqing from 2014 to 2020. On the other hand, the foundation for the initial theoretical research on the mechanism construction of sewage treatment of these towns is laid by the quantitative analysis of the influencing factors of sewage treatment of such towns from the aspects of leading industries and government investment. This work proposes research objects by combining data and vector maps at the level of small towns, expanding the research scope of urban economics from the typical urban region to the small towns that constitute the end of the city. In addition, from a multidisciplinary standpoint, this study adopts research methods based on ArcGIS for the analysis of sewage treatment rates in small towns, including the space analysis method, mathematical analysis method, and econometrics. This diversifies the research methods and also enriches the specific research content.

## 3 Research area, data sources, and research methods

### 3.1 Research area

Mountains and hills characterize Chongqing, which is located in the upper reaches of the Yangtze River, covering an area of 82,400 square kilometers. It has jurisdiction over 26 districts, eight counties, and four autonomous counties. It is a complex of big cities, large rural areas, large mountainous areas, and large reservoir areas. By 2020, there were 758 small towns in Chongqing, including 584 towns and 157 townships[2] (see Figure 2).

There are two reasons for choosing Chongqing as the research object in this study. The first reason is that Chongqing's ecological environment protection is under great pressure but of prominent importance. Different from other regions, Chongqing undertakes the important task of building an important ecological barrier in the upper reaches of the Yangtze River and plays an irreplaceable role in ecological security in the middle and lower reaches of the Yangtze River. Fifteen districts and counties of the 19 in the Three Gorges reservoir area (covering 80% of this area) are located in Chongqing[3] However, it also faces environmental pressure from many factors, such as the large industrial proportion, scattered population caused by mountainous areas, and the insufficient construction of rural environmental infrastructure. Second, Chongqing is a representative area for sewage treatment in small towns in mountainous areas. The area of mountains and hills accounts for 98% of that of Chongqing, while that of valleys and plains is only 2%[4]. In 2020, the permanent resident population of Chongqing was 32 million, but 14.8505 million people, about 46.41% of the permanent resident population, lived in organic towns and townships[5]. Therefore, it is of great significance to improve the sewage treatment rates of small towns to promote the new urbanization with people at its core.

2 Data source: Chongqing Statistical Yearbook (2021), Chongqing Statistics Bureau.

3 Data source: National Cooperation Plan for Counterpart Support to the Three Gorges Reservoir Area (2021–2025) issued by the Ministry of Water Resources and the National Development and Reform Commission (http://www.gov.cn/xinwen/2021-12/20/content_5662885.htm).

4 Data source: Chongqing Statistical Yearbook (2021), Chongqing Statistics Bureau.

5 Data source: Chongqing Urban and Rural Construction Statistics (2021) released by the Chongqing Housing and Urban–Rural Construction Commission.

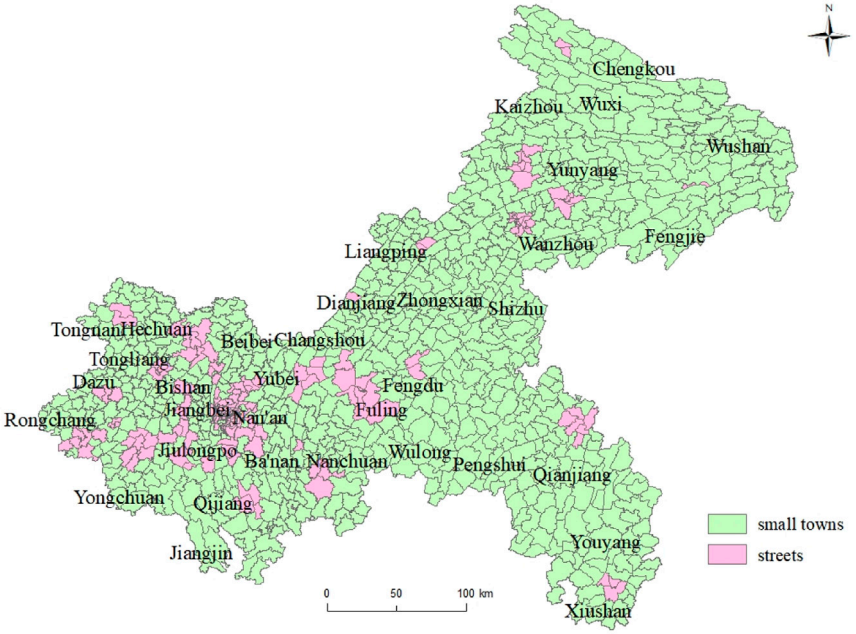


FIGURE 2
Location of the research area.

## 3.2 Data sources

The core data for this study come from *Chongqing Urban and Rural Construction Statistics* from 2015 to 2021 by the Chongqing Housing and Urban-Rural Construction Commission. The statistics contain three parts: cities, county towns, and towns and villages, and the third part includes organic towns, townships, and villages. By 2020, there were 758 small towns in Chongqing including 584 organic towns and 174 townships[6]. After excluding the areas without data, the research sample of this study has 756 small towns, consisting of 584 organic towns and 172 townships, about 97.17% of the total number of small towns in Chongqing.

## 3.3 Research methods

### 3.3.1 Global spatial autocorrelation

The global Moran's I focuses on whether there is a spatial spillover effect among spatial units from the overall level, which can effectively reflect the "Matthew effect" in the sewage treatment rates of small towns in Chongqing, that is, whether there is spatial agglomeration in terms of geographical distribution. The formula of global Moran's I is

$$I = \frac{\sum_{i=1}^{n}\sum_{i\neq j}^{n} w_{ij}\left(X_i - \bar{X}\right)\left(X_j - \bar{X}\right)}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}}. \quad (1)$$

Here, $n$ represents the number of small towns. $X_i$ and $X_j$ are the number of observations in the small town $i$ and the small town $j$, respectively. $w_{ij}$ denotes the element in the spatial weight matrix, and a matrix of 0 to 1 is used in this study. The range of Moran's I is −1 to 1. When the value is between 0 and 1, it means that there is a positive spatial correlation between spatial units. When the value is −1 to 0, it means that there is a negative correlation between spatial units. A value of 0 indicates that there is no spatial correlation between regions (LeSage and Pace, 2009). The hypothesis of normal distribution is usually used to test whether the spatial correlation represented by Moran's I can pass the significance test. The specific calculation formula is as follows:

$$Z(d) = \frac{Moran's\ I - E(I)}{\sqrt{VAR(I)}}. \quad (2)$$

When $|Z| \leq 1.96$, the null hypothesis is accepted, and the autocorrelation between spatial units is not significant. The spatial autocorrelation of observed variables is significant. If not, it means that the null hypothesis is rejected, and the spatial autocorrelation of the spatial units in the target area can pass the significance test.

### 3.3.2 Local Moran's I

Although the global Moran's I can reflect the concentration degree of observed objects in terms of space, it fails to reveal the characteristics of internal distribution. The local Moran's I can make up for this, which can not only analyze the clustering degree and types of each unit but also quantify the contribution of each unit to the global spatial autocorrelation and evaluate the extent to which the spatial autocorrelation masks the local instability. The local Moran's I is calculated as follows:

$$LI = \left(X_i - \bar{X}\right)\sum_{j\neq i}^{n} w_{ij}\left(X_j - \bar{X}\right), \quad (3)$$

6 Data source: China Urban–Rural Construction Statistical Yearbook released by the Ministry of Housing and Urban–Rural Development of the People's Republic of China.

where LI represents the local Moran's I, the local correlative coefficient among small towns; $n$ is the number of small towns; $X_i$ and $X_j$ are the number of observations in the small town $i$ and small town $j$, respectively; and $w_{ij}$ denotes the spatial matrix. When the local Moran's I is bigger than 0, it indicates that the spatial unit has attribute values ("high-high" or "low-low") similar to the neighboring units. When the local Moran's I is less than 0, it indicates that the spatial unit has different attribute values ("high-low" or "low-high") from neighboring units.

### 3.3.3 Panel data model

Three basic types of panel data models are the hybrid model (PA), the fixed-effects model (FE), and the random effects model (RE). The basic form is

$$y_{it} = \alpha_i + \beta_i x_{it} + \varepsilon_{it}, \quad (4)$$

where $i$ means the individual; $t$ is the time; $\alpha$ is the intercept; $\beta$ is the coefficient; $y$ and $x$ represent the explained variable and the explanatory variable, respectively; and $\varepsilon$ is the random error term. A significant variation in time both among individuals and among distinct sections is necessary for the hybrid model to work. The fixed-effects model is appropriate when there are considerable differences in time and sections across individuals with a fixed intercept term, whereas the random-effects model is suitable when the intercept term varies randomly.

The Hausman test determines whether to use a fixed-effects model or a random-effects model. The primary purpose of the Hausman test is to determine if explanatory variables and random error terms exhibit synchronous correlation. The fixed-effects model should be chosen when the Hausman test rejects the null hypothesis, that is, when the random error term is unrelated to the explanatory variable. Otherwise, the random-effects model ought to be chosen.

## 4 Characteristics of temporal and spatial changes in sewage treatment rates of small towns in Chongqing

In February 2018, the General Office of the CPC Central Committee and the General Office of the State Council issued the *Three-Year Action Plan for Rural Living Environment Improvement*. In August of the same year, the Chongqing government also issued the *Implementation Plan for the Three-Year Action Plan for Rural Living Environment Improvement in Chongqing (2018–2020)*. About 22.8 billion yuan would be invested for the improvement of the rural living environment, with rural domestic sewage treatment and the prevention of industrial pollution "going to the mountainous and rural areas" as key tasks. Based on this, this study adopts 2017, the year before the renovation of the rural living environment, as the interval year and focuses on the temporal and spatial changes in sewage treatment rates of small towns from the year 2014 to 2017 and to 2020.

### 4.1 Overall analysis

It can be seen from Figure 3 that in 2014, the sewage treatment rates of small towns in Chongqing were generally low, at only 34.14%, which was similar to the situation in China where that rate of small towns was difficult to improve[7]. From 2014 to 2020, the sewage treatment rates of small towns in Chongqing showed a continuous improvement, rising from 34.14% in 2014 to 75.95% in 2020, with a cumulative increase of 41.81%. From the perspective of improvement, the improvement in 2015 and 2018 was the most prominent, reaching 9.55% and 10.05%, respectively. This result shows that the sewage treatment rates of small towns in Chongqing were significantly improved in the year after the renovation of the rural living environment. With the continuous improvement of sewage treatment in small towns, the magnitude of improvement was also decreasing, with that in 2020 being only 2.61%. On the other hand, although the sewage treatment rates of small towns in Chongqing were greatly improved in the past 7 years, the overall level was only 75.95%, meaning a distinct gap between that of Chongqing's counties and the city whose rates were 99.08% and 98.17%. It also shows that small towns in Chongqing still have shortcomings and difficulties, both at present and in the future.

In order to investigate the internal differences of small towns, 756 small towns are divided into four grades according to the mean and standard deviation of sewage treatment rates (see Table 1). In 2014, the sewage treatment rates of small towns showed a distribution pattern of being "big at both ends and small in the middle." The number of small towns at low and high levels reached 405 and 274, respectively, which is 53.57% and 36.24% of the total. Only about 10% of these towns were at middle, low, and intermediate levels. Compared with that in 2014, the distribution pattern of sewage treatment rates in small towns in 2017 changed significantly, with the number of small towns at the low level decreasing to 163, while that at the advanced level increased to 329. The number of small towns at the middle and low levels and the intermediate level increased from 77 in 2014 to 264, the proportion increasing to 35.92%. In 2020, the polarization of sewage treatment rates of small towns further alleviated, with the number of small towns at the middle, low, and intermediate levels increasing to 293, while that at the advanced level decreasing to 299.

The national and municipal governments have given environmental protection far more consideration since the release of the Integrated Reform Plan for Promoting Ecological Progress in September 2015. The Chongqing's municipal government and all district and county administrations continue to boost their expenditures on sewage treatment in small towns since they have historically been a weak link in environmental protection. Small towns with low sewage treatment rates significantly decreased from 2014 to 2017, in large part due to Chongqing's acceleration of the construction of sewage treatment facilities in these towns since 2015 and the access of all rural areas to sewage treatment facilities by the end of 2017. Moreover, the operation of sewage treatment facilities requires financial assistance, while some small towns with financial issues confront the challenge of being unable to finance the operation. As a result, only a few small towns at the middle and low levels rose to the intermediate level between 2017 and 2020, and the number of small towns with sewage treatment rates at the low level barely changed at all.

7 According to the data of the Ministry of Housing and Urban–Rural Development of the People's Republic of China, the rural sewage treatment rate in 2016 was 22%. In the past five years, the rural sewage treatment rate has only increased by about 6% (https://www.chinacace.org/news/view?id=7974).

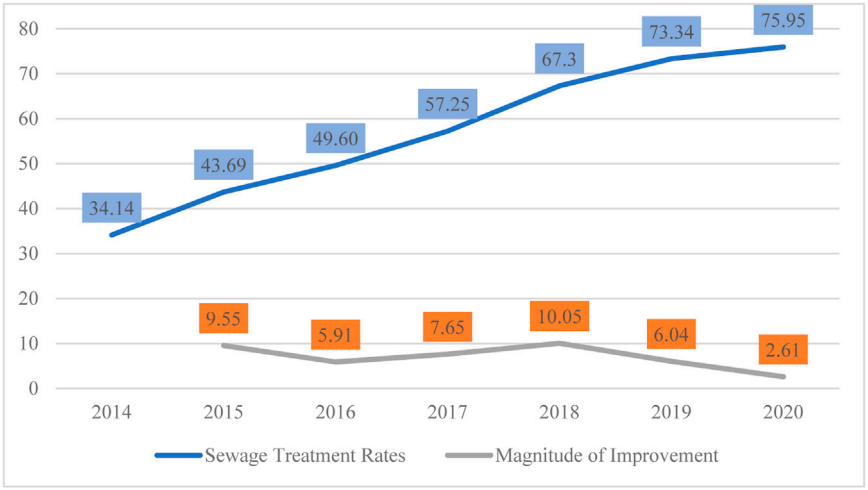


FIGURE 3
Changes in the sewage treatment rates of small towns in Chongqing (2014–2020).

**TABLE 1 Classification standards for sewage treatment in 756 small towns in Chongqing.**

| Grades | Classification standard | 2014 Number of small towns | Proportion (%) | 2017 Number of small towns | Proportion (%) | 2020 Number of small towns | Proportion (%) |
|---|---|---|---|---|---|---|---|
| Low level | $0 \le M \le M_0 - 0.5ST$ | 405 | 53.57 | 163 | 21.56 | 164 | 21.69 |
| Middle and low levels | $M_0 - 0.5ST < M \le M_0$ | 30 | 3.97 | 157 | 20.77 | 94 | 12.43 |
| Intermediate level | $M_0 < M \le M_0 + 0.5ST$ | 47 | 6.22 | 107 | 14.15 | 199 | 26.32 |
| Advanced level | $M > M_0 + 0.5ST$ | 274 | 36.24 | 329 | 43.52 | 299 | 39.55 |

Note: $M_0$ represents the mean of sewage treatment rates of 756 small towns in Chongqing, $M$ means the sewage treatment rates of small towns, and $ST$ represents the standard deviation of sewage treatment rates of small towns. The mean of sewage treatment rates of 756 small towns in Chongqing in 2014 was 34.14, and the standard deviation was 39.50. In 2017, the mean of sewage treatment rates was 57.25, and the standard deviation was 35.17. In 2020, the mean of sewage treatment rates was 75.95, and the standard deviation was 27.15.

## 4.2 Spatial analysis

### 4.2.1 Horizontal distribution

From the perspective of the spatial distribution of regions[8] (see Figure 4), the sewage treatment rates of 756 small towns in Chongqing in 2014 showed significant spatial distribution differences. Due to the relatively high level of economic development and being close to the main urban areas, the sewage treatment rates of small towns in the western part of Chongqing were evidently higher than those in other regions. The sewage treatment rates of small towns in the northeastern part of Chongqing such as Wanzhou, Kaizhou, and Yunyang and those of ecological protection and development areas in the southeastern part of Chongqing such as Wulong, Youyang, and Qianjiang were apparently low. There were big shortcomings in environment protection. Driven by policies such as the rural revitalization strategy and the remediation of the rural living environment, the sewage treatment rates of small towns in Chongqing showed a high rate of improvement. During 2014–2017, the sewage treatment rates of small towns in the northeastern part of Chongqing increased rapidly, while those in the southeastern part, which is an important biodiversity reserve and national key ecological function area, developed slowly. In 2017, there were still a number of small towns in the northeastern and southeastern parts of Chongqing with sewage treatment rates below 20%, but in 2020, the number of small towns at this level decreased significantly. In 2020, the sewage treatment rates of small towns in Chongqing did not show a notable regional difference, which was significantly better than that in 2014. Only a few small towns in Chongqing's northeastern and southeastern parts needed to be further improved.

### 4.2.2 Spatial agglomeration

In this study, ArcGIS 10.2 and GeoDA are used to measure the global Moran's I of sewage treatment rates of 756 small towns in Chongqing to analyze the overall correlation and difference (see Figure 5). In 2014, 2017, and 2020, the global Moran's I of the sewage treatment rates of 756 small towns in Chongqing was 0.28, 0.14, and 0.04, respectively. Most of the scattered points were located in the first and third quadrants, and all of them passed the significance test at the 5% level. It indicated that the sewage treatment rates of

8 The research sample for this study is 584 organic towns and 174 townships in Chongqing, so streets and non-organic towns are blank areas without data.

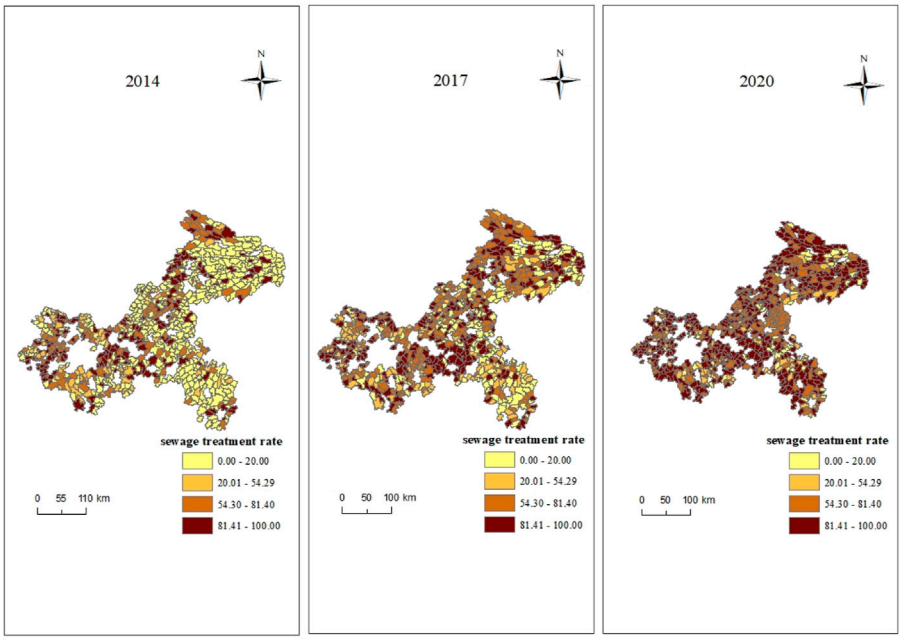


FIGURE 4
Spatial distribution of sewage treatment rates in 756 small towns in Chongqing (unit: %).

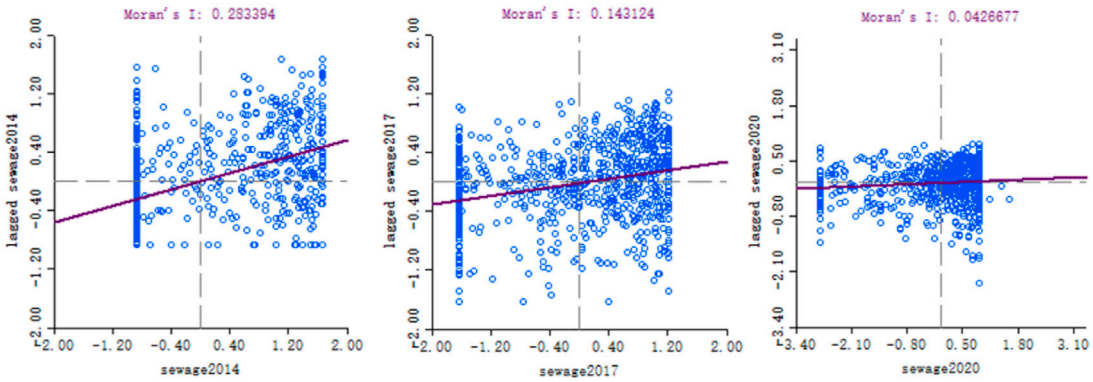


FIGURE 5
Global Moran's I scatterplot of sewage treatment rates of 756 small towns in Chongqing.

756 small towns in Chongqing had a strong spatial correlation, whether they were high or low. On the other hand, the global Moran's I gradually decreased from 0.28 in 2014 to 0.14 and 0.04 in 2017 and 2020, respectively, indicating that the spatial correlation of sewage treatment rates in small towns gradually weakened. The reason for this phenomenon may be that the investment in sewage treatment facilities in small towns in the early stage mainly came from the governments of local districts, counties, or small towns. However, after the implementation of the rural revitalization strategy and the political action of the rural living environment in 2018, the investment of the central and provincial governments began to increase, so the influence of the local government on the sewage treatment rates of small towns gradually decreased.

Through local spatial autocorrelation analysis, the spatial agglomeration effect of sewage treatment rates of small towns in Chongqing can be revealed so as to reflect the interaction and local spatial agglomeration characteristics of these rates (see Figure 6). In 2014, the small towns in Chongqing presented a high-high cluster, most of which were located in the main urban areas and adjacent areas of the western part of Chongqing. Some small towns are also distributed in the northeastern part of Chongqing. However, the high-low outlier, low-high outlier, and low-low cluster were distributed in a scattered way. In 2017, the number of small towns with the high-high cluster decreased significantly and was only distributed in the western part, while a certain number of small towns with the low-low cluster appeared in the northeastern and southeastern parts. In 2020, the number of small towns with the high-

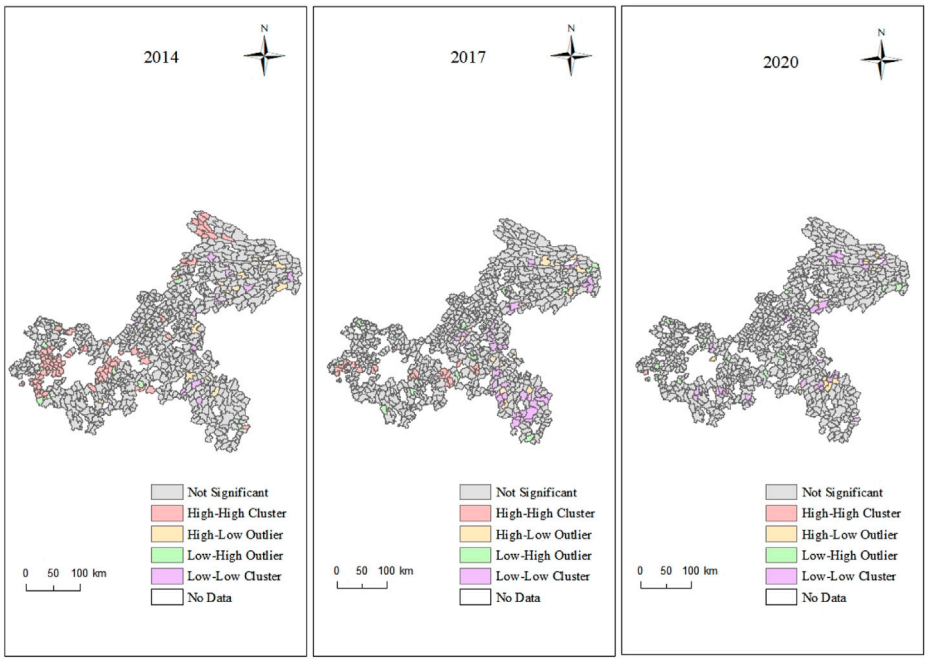


FIGURE 6
LISA agglomeration map of sewage treatment rates of 756 small towns in Chongqing.

high cluster further reduced. Those towns mainly showed the low-low cluster with some scattered in the northeastern, southeastern, and western parts of Chongqing. After the development of 7 years, especially that of the period from 2018 to 2020, the agglomeration characteristics of sewage treatment rates of small towns in Chongqing apparently changed from the high-high cluster in certain areas to the scattered distribution of the low-low cluster.

## 4.3 Analysis of the characteristics of the population size

The population size is closely related to local government revenues and expenditures. First, population size is the cornerstone for local governments to obtain fiscal revenue through economic development (Liu and Gan, 2013; He et al., 2020). Second, one of the main bases for local governments to obtain transfer payments from the central government is the population size (Jia et al., 2014; Lu and Liu, 2019; Shi and Li, 2021). Compared with the national level, Chongqing's economic development level is not high. The larger the permanent resident population size of small towns is, the more transfer payments they can get to invest more financial resources in the construction of environmental infrastructure. Based on this, this study analyzes the variation characteristics of sewage treatment rates of small towns in Chongqing from the perspective of permanent resident population size.

The results in Figure 7 show that the sewage treatment rate will improve with the expansion of the population of small towns. In 2014, the sewage treatment rates of small towns had an evident positive correlation with the population size, and the rates of small towns with a population of less than 20,000 people were the lowest, only 27.97%. With the expansion of population, the sewage treatment rates also increased significantly, among which those of small towns with a population of 40,000 to 60,000 people were the highest, reaching 49.15%. In 2017, the sewage treatment rates among small towns were more balanced, and the gap between the highest level and the lowest level further reduced from 21.18% in 2014 to 10.69%. At the same time, small towns with a population of more than 40,000 have a significantly higher sewage treatment rate than small towns with a population size of less than 40,000. Limited by factors such as large population size and industrial structure, the sewage treatment rate of small towns with a population of more than 60,000 people is maintained at about 60%. In 2020, with the overall increase of sewage treatment rates of small towns, the gap among these towns with different population sizes continued to narrow, and the sewage treatment rates of small towns with population sizes of 0 to 20,000, 20,000 to 40,000, and 40,000 to 60,000 remained at about 75%. Small towns with a population of more than 60,000 people have the most prominent development, with the sewage treatment rate increasing from 60.62% in 2017 to 86.90%.

## 4.4 Analysis of the characteristics of leading industries

The leading industry is not only closely related to economic development but also has a significantly different impact on the region's environmental pressure. *Chongqing Urban and Rural Construction Statistics* classifies the leading industries of small towns into several types including industrial and mining, agriculture, business services, history and culture, and characteristic landscape. As historical and cultural industries and characteristic landscape industries belong to the tourism industry, this study

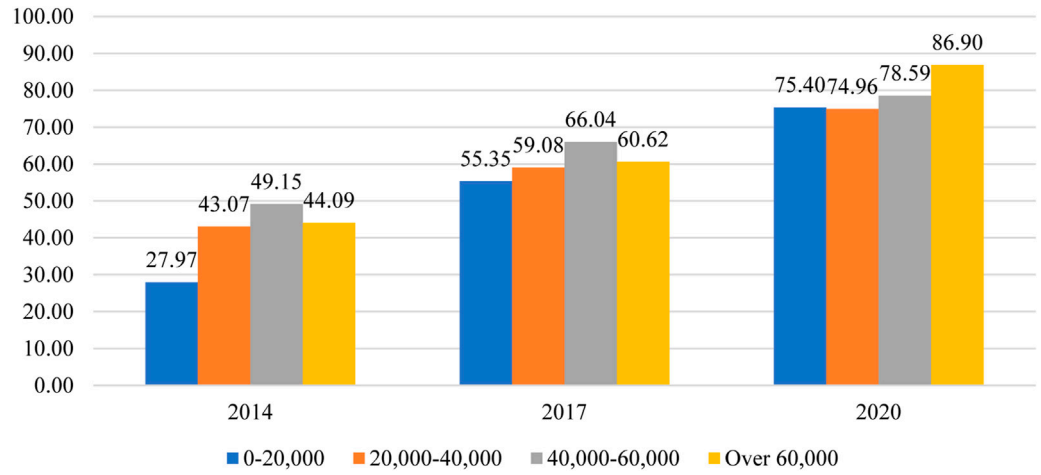


FIGURE 7
Distribution of population size of sewage treatment rates in 756 small towns in Chongqing (unit: %/person).

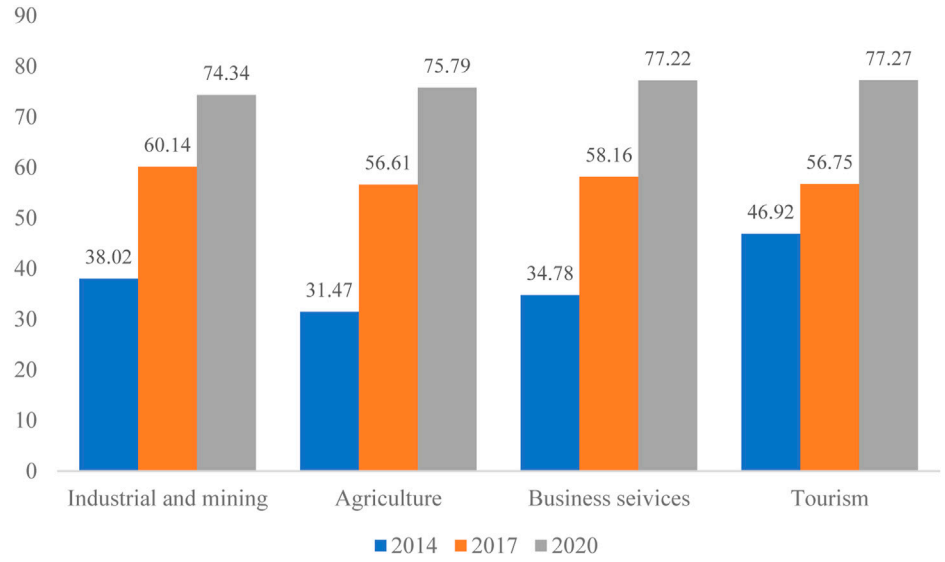


FIGURE 8
Distribution of leading industries of sewage treatment rates of 756 small towns in Chongqing (unit: %/industry).

combines them to analyze the distribution characteristics of sewage treatment rates of small towns in Chongqing from the perspective of leading industries (see Figure 8).

In 2014, the sewage treatment rate of agricultural towns was the lowest among the four types of small towns, only 31.47%, while that of tourist towns with high requirements for an ecological environment reached 46.92%. The sewage treatment rates of small towns with the leading industries of industrial and mining and business services were 38.02% and 34.78%, respectively. In 2017, the gap among four types of small towns was significantly reduced. The sewage treatment rate of agricultural towns rose to 56.61% and that of industrial and mining, business services, and tourist towns also reached 60.14%, 58.16%, and 56.75%, respectively. The gap among the highest and lowest values narrowed to 3.53%. In 2020, the gap between the four types of small towns was further reduced to 2.93%, and the sewage treatment rates of business services and tourist towns exceeded 77%. Although the environmental pressure of industrial and mining towns is prominent, the sewage treatment rate reached 74.34%. In general, the sewage treatment rate of agricultural small towns increased the most to 44.32%. The next are business service towns and industrial and mining towns, reaching 42.44% and 36.32%, respectively. Because of the good foundation in the early stages of tourist small towns, although the sewage treatment rate in 2020 was the highest among the four small towns, the additional rate is only 30.35%.

# 5 Analysis of influencing factors of sewage treatment rates of small towns in Chongqing

## 5.1 Analysis of the influencing mechanism

The sewage treatment rates of small towns that are a complex of continuously gathering population and economic activity would be influenced by both endogenous and exogenous factors in accordance with the new economic geography and the idea of agglomerative economies.

The direct influence of endogenous factors. Since the 21st century, China's urbanization has entered the fast lane, rising from 36.22% in 2000 to 63.89% in 2020. Urbanization refers to the concentration of money, technology, and other production factors in urban areas rather than just the mere movement of people from rural to urban areas. Land urbanization is an inevitable phenomenon in China. While the amount of land available for urban development rises dramatically, the government and social capital would spend a lot of money building urban infrastructure and real estate to improve the environment (Guan et al., 2018; Chen et al., 2019). The financial allocation of the superior government, which is primarily based on the population size of small towns, is the necessary foundation for these towns to improve their own sewage treatment facilities and maintain the operation of sewage treatment plants because of the weak economic strength of such towns. At the same time, a small town's population must meet certain requirements in order to experience endogenous economic growth and generate tax income. Additionally, various leading industries have different impacts on how well small towns treat their sewage. Although there are certain pollution externalities associated with the industrial and mining industries, the local government's environmental regulation intensity for various industries is steadily improving against the backdrop of the central government's intensifying environmental protection (Yu, 2021). The commercial service business would not put environmental pressure on the region while supporting the economic development of small towns. The tourism industry, which is characterized by historical culture and distinctive landscapes, has higher requirements for sewage treatment.

**Hypothesis 1.** Endogenous factors including land urbanization, population size, and leading industries would improve the sewage treatment rates of small towns.

The boosting effect of exogenous factors. County towns receive more funding for development than small towns do. This is particularly true in Chongqing. More than 70% of the city is made up of mountainous terrain. Geographical constraints on the main metropolitan area's radiation effect cause the county towns to take over the role of the growth pole in this area. While it exhibits a "siphon effect" on small town resources such as capital and population, it also has a powerful radiation effect on these towns. The radiation effect of county towns has a certain comprehensive effect on the sewage treatment rates of small towns. The industrial transfer, employment opportunities, and leisure vacation provide economic support for sewage treatment in small towns, while the expansion of environmental infrastructure provides support at the facility level. In addition to building sewage treatment plants, sewage treatment facilities also need supporting pipes and rural sewage treatment equipment that is appropriate for dispersed living. The primary source of funding for small towns to upgrade their own sewage treatment facilities is investment in urban construction. The superior government and small towns themselves would generate a specific amount of money to spend on the construction of urban infrastructure to support the urbanization of small towns, and the environmental infrastructure, including sewage treatment, is one of the essential elements (Yun and Zhao, 2022).

**Hypothesis 2.** Exogenous factors including the radiation effect of county towns and the investment in urban construction improve the sewage treatment rates of small towns.

## 5.2 Variable selection and model construction

Based on the analysis of the temporal and spatial changes in the sewage treatment rates of small towns in Chongqing and with reference to research studies such as those by Van den Berg et al. (2015), Tong et al. (2019), and Xu et al. (2022), this study analyzes the influencing factors from five aspects: land urbanization, the radiation effect of county towns, the investment in urban construction, population size, and leading industries. According to theoretical analysis, it further divides these factors into endogenous and exogenous factors. Endogenous factors include land urbanization, population size, and leading industries, while exogenous factors are the radiation effect of county towns and the investment in urban construction.

### 5.2.1 Land urbanization

Land urbanization is the direct embodiment of urban regional extension. It also means the improvement of basic public service facilities in small towns. The dispersion of rural sewage discharge is a significant issue that has long limited sewage treatment in small towns. By moving people from rural to urban regions, land urbanization also achieves the centralized treatment of sewage discharge while enhancing sewage treatment infrastructure. It is measured by the proportion of the built-up area to the total area of small towns.

### 5.2.2 Population size

Population is the core of urbanization, which is not only the endogenous power of economic development but also an important basis for small towns to obtain higher levels of financial transfer payments and government investment from the superior government. In addition, because a large number of people in small towns flow into higher level cities, their relatively small population size results in higher unit operating costs of sewage treatment facilities, which restricts the improvement of sewage treatment rates of small towns. In this study, the permanent resident population of small towns is used as a representation, with a unit of 10,000 people.

### 5.2.3 Leading industries

Restricted by factors like geographical location and population, leading industries of small towns are often single (Liu and Sun, 2015). According to the classification of the Chongqing Housing and Urban–Rural Construction Commission, the leading industries of 756 small towns in Chongqing are divided into five categories: industrial and mining, agriculture, business services, history and culture, and characteristic landscape. Because the economic development level

**TABLE 2 Descriptive statistics of influencing factors.**

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Variable | N | Mean | SD | Min | Max |
| *urland* | 4,088 | 1.505 | 1.480 | 0.0533 | 17.62 |
| *district* | 4,088 | 39.12 | 22.23 | 3.400 | 146.3 |
| *invest* | 4,088 | 1,599 | 5,063 | 0 | 157,300 |
| *pop* | 4,088 | 2.405 | 1.750 | 0.180 | 18.37 |
| *industry* | 4,088 | 0.130 | 0.336 | 0 | 1 |

of small towns with agriculture as the leading industry is often low, this study considers these towns as the reference group and other towns as the benchmark group so as to investigate the influence of non-agricultural leading industries on the land output rate of small towns in Chongqing.

### 5.2.4 Radiation effect of county towns

Small towns are the heads of villages and the tails of cities. While undertaking a lot of rural environmental pressure in the area under their jurisdiction, they are also positively affected by the economic and social development of county towns and the construction of basic public service facilities. Because of the direct correlation between the radiation effect and geography, small towns closer to county towns experience a stronger radiation influence than those that are farther away. In this study, it is represented by the nearest distance between a small town and the district government or county government. The unit is kilometer, and the data come from Baidu Maps.

### 5.2.5 The investment in urban construction

The investment in urban construction primarily comes from the construction funds of the superior government and local governments in small towns because the majority of urban infrastructures have significant public qualities and the period of returns on investment is lengthy. It is particularly challenging to make money from sewage treatment facilities and the pipes that support them. Government investment, therefore, replaces private investment as the primary source of funding for such environmental infrastructure (Li and Zheng, 2016). It is represented by the urban construction investment in small towns in that year, with a unit of 10,000 yuan.

Based on the aforementioned five aspects, this study constructs a regression model of the influencing factors of sewage treatment rates of small towns in Chongqing:

$$\ln sewage = \alpha + \beta_1 \ln urland + \beta_2 \ln pop + \beta_3 industry + \beta_4 \ln district + \beta_5 \ln invest + \varepsilon, \quad (5)$$

where *sewage* means the sewage treatment rates of small towns, *urland* represents the land urbanization, *pop* represents the population size, *industry* represents the leading industries of small towns, *district* represents the radiation effect of county towns, *invest* means the investment in urban construction, and $\varepsilon$ is the random error term. For the effective elimination of the effect of heteroscedasticity and the marginal significance of modal's economy, all variables except the dummy variables are used in their logarithm form. Descriptive statistics of influencing factors is reported in Table 2.

## 5.3 Analysis of estimation results

According to Formula 1, on the basis of ordinary least squares (OLS), this study uses the panel data model to analyze the influencing factors of sewage treatment rates of small towns in Chongqing. According to Hausman test results, this study uses fixed-effects estimation to carry out relevant regression analysis. It should be noted that although this study may face endogenous problems caused by missing variables, the fixed-effects model of panel data can eliminate errors from unobservable factors. Thus, this problem can be effectively avoided. The specific estimation results are shown in Table 3.

From the perspective of endogenous factors, the coefficient of land urbanization is positive, and it passes the significance test at the 1% level, indicating that with the improvement of the level of land urbanization, the sewage treatment rates of small towns in Chongqing can be further improved. With the expansion of the core areas of small towns, government and social investment would also increase to bring about the improvement of environmental infrastructure. The concentration of sewage treatment rises as people move toward small towns' central areas, and the cost of sewage treatment falls as well. The coefficient of population size is also positive, and it passes the significance test at the 1% level. As mentioned previously, with the increase in population size, the portion of superior financial transfer payments designated for small towns rises accordingly, so both operation and construction funding for infrastructure would be supplemented. The coefficient of leading industries is significantly positive, which indicates that different from agriculture, leading industries such as industrial and mining industries, business services, and tourism play a more prominent role in improving the sewage treatment rates of small towns. Although the industrial and mining industries may have a somewhat detrimental effect on the sewage treatment rates of small towns, they can also boost local economic growth and help pay for sewage treatment. The mining and manufacturing industries' adverse spillover effects are further restrained by the present tough environmental regulating policies. In terms of exogenous factors, the coefficient of the radiation effect of county towns is significantly negative, which indicates that the sewage treatment rates in small towns are closely related to the radiation effect of county towns. The closer the town is to the core area of the county town, the higher the sewage treatment rate is. The majority of Chongqing is mountainous, and its geography is quite compact. The sewage treatment of small towns is significantly impacted by county towns that are the center of local politics, economy, and culture. Compared with other influencing factors, the coefficient of the investment in urban construction passes the significance test at the level of 5%, but its value is evidently smaller. This result shows that it has a limited promotion effect on the sewage treatment rates of small towns. The reason for this phenomenon is that a considerable proportion of urban construction investment is real estate investment, especially in some small towns with a high economic development level or tourism as the leading industry. The previous results also demonstrate that Hypothesis 1 and Hypothesis 2 are valid.

**TABLE 3 Regression results of factors influencing sewage treatment rates of small towns in Chongqing.**

| | OLS | FE | RE |
|---|---|---|---|
| Explanatory variable | (1) | (2) | (3) |
| *urland* | 0.394*** | 0.652*** | 0.529*** |
| | (6.46) | (3.79) | (5.50) |
| *district* | −0.158*** | −0.334*** | −0.307*** |
| | (−3.79) | (−3.16) | (−2.98) |
| *invest* | 0.067** | 0.098*** | 0.101*** |
| | (2.52) | (2.64) | (2.60) |
| *pop* | 0.336*** | 0.420*** | 0.406*** |
| | (4.22) | (3.79) | (3.33) |
| *industry* | 0.359*** | 0.378** | 0.365*** |
| | (2.93) | (3.09) | (3.01) |
| Constant term | 3.648*** | 5.42*** | 5.96*** |
| | (19.28) | (22.11) | (23.14) |
| $R^2$ | 0.316 | 0.340 | 0.343 |
| Number of observations | 5,292 | 5,292 | 5,292 |

Note: ***, **, and *, respectively, indicate that they pass the significance test at the level of 1%, 5%, and 10%. Values in brackets are *t*-test values.

# 6 Conclusion and suggestions

*Opinions on Implementing the Strategy of Rural Revitalization* released by the CPC Central Committee and the State Council clearly puts forward "accelerating the implementation of rural green development mode and strengthening the improvement of rural living environment." Small towns are the bridge between cities and rural areas. Sewage treatment in small towns has always been the focus and problem of urban construction in China. On the one hand, small towns have large rural areas and low population density. On the other hand, they are restricted by the low level of economic development caused by insufficient industrial support. In order to explore the characteristics of temporal and spatial changes and influencing factors of sewage treatment rates of small towns, this study selects 756 small towns in Chongqing that undertake the responsibility of building an important ecological barrier in the upper reaches of the Yangtze River as the research object. Based on the data from 2014 to 2020, this study analyzes the characteristics of temporal and spatial changes in sewage treatment rates of small towns from four aspects: the overall situation, space, population size, and leading industries, and analyzes the influencing factors from five aspects, such as land urbanization and the radiation effect of county towns.

## 6.1 Main conclusion

(1) In 2014, the sewage treatment rates of 756 small towns in Chongqing were generally low. After 7 years of rapid development, it increased from 34.14% to 75.95%, especially after the government carried out rural revitalization and rural living environment improvement in 2018. However, compared with big cities and counties, there is still a big gap. For internal differences, the sewage treatment rates of small towns were seriously polarized in 2014, while they showed notable improvement in 2017 and 2020.

(2) In 2014, the sewage treatment rates of small towns in the western part of Chongqing were significantly higher than those in the northeastern and southeastern parts of Chongqing, but this condition was remarkably better in 2017. In 2020, while the regional differences continued to decrease, the overall level also evidently improved. Only a few small towns in the northeastern and southeastern parts of Chongqing have low sewage treatment rates. The global Moran's I shows that the sewage treatment rates of small towns in Chongqing in 2014, 2017, and 2020 had significant spatial correlation, but the expansion of areas of the living environment to be improved continued to weaken. In terms of local spatial characteristics, the high-high cluster dominated in 2014, while this type of small town decreased significantly in 2017. The number of small towns with the low-low cluster increased significantly. In 2020, small towns with the low-low cluster were distributed in a scattered way.

(3) In 2014, there were significant differences in sewage treatment rates among small towns with different population sizes. In general, the larger the population size, the higher the sewage treatment rates. From 2015 to 2020, the differences among small towns were shrinking, and the gap between the highest value and the lowest value reduced from 21.18% in 2014 to 11.94% in 2020. In 2014, the sewage treatment rates of small towns with tourism as the leading industry were significantly higher than those of small towns with industrial mining, agriculture, and business services as the leading industries. From 2014 to 2017, the sewage treatment rates of all small towns evidently increased. In 2020, although the sewage treatment rates of small towns with tourism as the leading industry were still the highest, the increase was limited, and the gap with the small towns whose leading industry is industrial mining and whose treatment rates were the lowest narrowed to 2.93%.

(4) Land urbanization improves the sewage treatment rates of small towns. County towns have a significant radiation effect on the environmental infrastructure of small towns. The closer they are to the county towns, the higher the sewage treatment rates of small towns are. As the urban construction investment includes a large amount of real estate investment, its promotion effect is limited, although it has a certain positive impact on the sewage treatment rates of small towns. In addition, the increase in population size has a significant positive effect on the improvement in sewage treatment rates of small towns. Compared with agriculture, non-agricultural leading industries such as industrial mining and business services have notable advantages over the improvement in the sewage treatment rates of small towns.

## 6.2 Policy recommendations

(1) The financing mechanism for sewage treatment in small towns must be improved. First, the existing financial security system for sewage treatment in small towns must be optimized. A diversified financial security mechanism should be established that contains the financial budget arrangement, overall planning of the fund, social capital investment, and donations from the public. The government should take stronger steps in their sewage treatment according to the principle of counties, bearing the main responsibility with small towns and townships as the subsidiaries and superiors giving out rewards. The second is to promote the marketization of the operation and maintenance system. The services of package purchase should be given the priority to entrust the successful bidder of the project to be responsible for operation and maintenance. The third-party management mode is suggested to be implemented for small towns with better economic conditions. At the same time, a third-party regulatory agency is engaged for supervision and evaluation of the performance of the operating unit.

(2) Sewage treatment in small towns must be accurately promoted from different aspects. First of all, the methods of sewage collection and treatment must be scientifically decided in accordance with the degree of population agglomeration. The sewage pipe networks and treatment facilities of areas with a relatively concentrated population and centralized sewage treatment shall be subject to uniform planning, uniform establishment, and uniform administration. For areas with a scattered population such as mountainous areas, villagers are encouraged to treat the sewage according to the water quality and consider it a resource. In addition, the differences among the development levels of small towns must be taken into consideration to improve the synergy and economy of rural domestic pollution control. Combined with the economic development of small towns, phased targets should be set for different types of these towns. The source reduction and recycling of domestic sewage can be realized through the classified treatment of pollutants and a precise policy so as to reduce the economic cost and environmental risk of sewage treatment. The third is to formulate precise, classified sewage treatment policies for small towns from the perspective of regional heterogeneity. According to the economic development status of each region, big data should be used to accurately establish the provincial allocation mechanism for small-town sewage treatment resources such as funds, talent, and equipment, so as to improve the accuracy of the policy.

(3) The scientific and technological innovation of sewage treatment must be promoted in small towns. On the one hand, digital technology must be made full use of to solve governance difficulties. With technologies such as data sharing and internet of things technology, the information base and the data management system for sewage treatment in small towns should be established. Also, the application scenario shall be built with the synergy effort of counties, small towns, and enterprises. On the other hand, it is wise for these towns to introduce new technologies to improve the efficiency of sewage treatment. Technical exchanges shall be promoted between different provinces, cities, districts, and counties within the province to strengthen sewage treatment in small towns. Finally, disciplines including edaphology and microbiology shall be introduced to jointly promote the technical level of sewage treatment.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

## Author contributions

CZ designed the study and performed the field work and analysis. ZY completed the conceptualization and handled the software and validation. CZ completed the formal writing, and supervision was carried out by QW.

## Funding

This work was supported by the Doctor Program of Chongqing Federation of Social Sciences under grant no. 2021BS058, Technological Innovation Project of the Chongqing Education Commission under grant no. KJQN202100902 and Research Project of Sichuan International Studies University under grant no. sisu202129.

## Conflict of interest

Author CZ was employed by the company Chongqing Real Estate Group Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

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