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Influence of Urban Expansion on Land Subsidence: A Case Study of Tongzhou District, Beijing

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Abstract: Land subsidence is a common urban geological disaster. With the acceleration of urbanization, land subsidence is increasingly affected by urban expansion. It is of great significance to study the influence of urban expansion on land subsidence for urbanization construction and policy guidance. Under the strategic background of building Beijing into a sub-center of the city, the rapid expansion of Tongzhou city, the accelerated construction of infrastructure and the sharp increase of population will all put new pressure on the evolution of land subsidence in Tongzhou. This paper takes Tongzhou District of Beijing as an example, and takes 2015-2021 as the research period. In order to reflect the increment of urban expansion process, the improved multilinear model and land use monitoring based on RS and GIS are used to study the urban expansion process, and the relationship between urban expansion and land subsidence in Tongzhou District is analyzed by using Sentinel-2 satellite remote sensing image data and GIS spatial analysis method. The results show that: 1) With the increase of years, the annual settlement in Tongzhou District of Beijing shows a slowing trend. 2) The process of urban expansion is accelerating, and the urban expansion shows a trend of first accelerating and then slowing down, which leads to the evolution of land subsidence in Tongzhou city. 3) There is a high correlation between the process of urban expansion and the trend of settlement.

1. Introduction

Urban development depends on land, and while the process of urbanization is accelerating, social and economic activities are affecting the use of urban land. Land subsidence is an environmental geological phenomenon in which the regional ground elevation is reduced due to the compression of the surface soil layer, and it is an irreparable permanent loss of the environment and resources [1][2]. At present, research scholars at home and abroad have found that land subsidence is a common environmental geological problem in the process of urbanization around the world [3]. The causes of land subsidence are complex and diverse. The role of subsidence has become increasingly prominent [4][5]. The research results of Su Xiaojie et al. [6] show that economic development will inevitably

accelerate the process of urban expansion, and the urban land will continue to increase. Under the GIS and RS technology, it is found that the urban land has a continuous expansion trend in the process of urban development [7][8]. Studies by foreign scholars have shown the relative importance of socioeconomic and policy factors to urban expansion and related farmland conversion [9][10][11]. In recent years, under the background of implementing the Beijing-Tianjin-Hebei coordinated development and Beijing's strategy of building an urban sub-center, Tongzhou will become an important area where high-end resources are rapidly gathered in the process of accelerating the restructuring of the capital's functions [12]. In the process of rapid urban construction, the population is excessively concentrated in the built-up area, social and economic activities encroach on the ecological space, and the demand for groundwater exploitation increases, which will also bring a new round of impact on the evolution of land subsidence in Tongzhou's sub-center [13].

To sum up, the research on the status quo of land subsidence in the sub-center of Tongzhou City has become an important demand for the healthy and sustainable development of Tongzhou City's social economy. How to effectively monitor land subsidence, enhance the carrying capacity of urban land resources, and coordinate the contradiction between urban development and land use under the huge pressure of rapid urban development and relatively fragile ecological conditions has become an important issue facing the current urban development of Tongzhou. Challenges [14][15]. Based on Sentinel-2 satellite remote sensing image data, this paper uses an improved multi-linear model and land use monitoring based on RS and GIS to study the process of urban expansion, and combines GIS spatial analysis methods to analyze urban expansion and land subsidence in Tongzhou District from 2015 to 2021 Relationship.

2. Research areas and methods

2.1. Overview of the study area

Tongzhou District is located in the southeastern part of Beijing, at the northern end of the Beijing-Hangzhou Grand Canal, at 39°36′-40°04′ north latitude, 116°32′-116°54′ east longitude, on the east extension of Chang'an Avenue, and has a superior geographical location. It is known as "one capital, two guards and three connected states". Tongzhou District faces Sanhe City, Xianghe County, and Dachang Hui Autonomous County of Hebei Province across Chaobai River in the east; Chaoyang District and Tongzhou District in the west; Wuqing County in Tianjin City and Langfang District in Hebei Province in the south; Shunyi District in the north. Tongzhou District is positioned as the sub-center of Beijing City. In 2015, the Beijing Municipal Party Committee Plenary Session officially announced "Focus on Tongzhou and speed up the planning and construction of the city's administrative sub-center" [12]. Enter the stage of rapid development. The geographical location of Tongzhou District is shown in Figure 1.

Tongzhou District is located in the northeast of the North China Plain. The terrain in the jurisdiction is flat, all of which are plains, with an altitude of 27.6-8.2m. The overall terrain is high in the northwest and low in the southeast, with a slope of one thousandth. Tongzhou District has a warm temperate continental semi-humid monsoon climate, with dry and windy spring, hot and rainy summer, high and crisp autumn and cold and dry winter. The average precipitation in Tongzhou District for many years (1974-2021) is 550 mm, and the inter-annual variation of precipitation is uneven, with the characteristics of alternating high season and dry season. Affected by the continental monsoon climate, the distribution of precipitation within the year is also uneven, mostly concentrated in July-August, accounting for more than 70% of the annual precipitation.

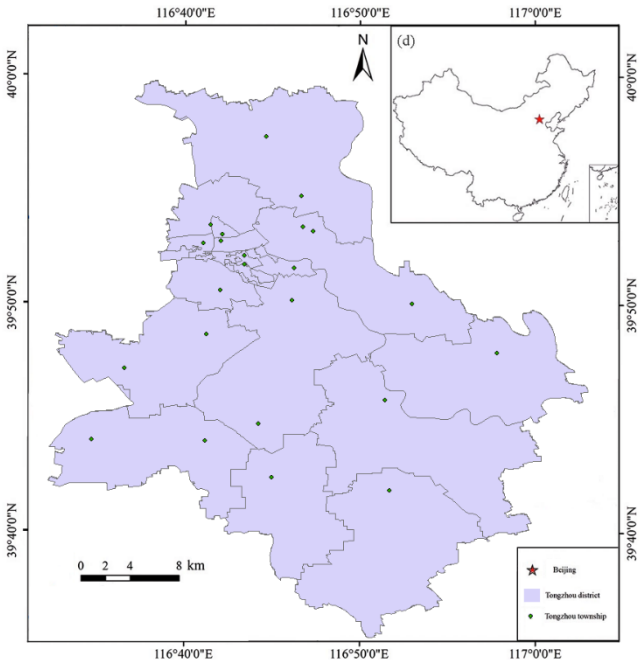

Figure 1 Schematic diagram of geographical location of Tongzhou District

2.2. Research data sources and methods

The Beijing Land Subsidence Monitoring System Operation-Leveling and Calculation (2015-2021) year Tongzhou leveling data used in this paper has a total of 95 benchmarking points and 8 consecutive years of elevation data. The remote sensing images use Sentinel 2 data, which are all downloaded from the official website of ESA (European Space Agency) with a resolution of 10M. Two or three images of the T50 domain from mid-September 2015 to mid-September 2021 were selected for splicing. Completely includes Tongzhou District. The socioeconomic data are selected from the 2015-2021 statistical yearbook data of Tongzhou District, Beijing, as shown in Table 1.

Table 1 Data Sources and Contents

Data type	Data source	Data content	Data description
Land subsidence data	Land subsidence monitoring system	2015-2021 leveling data	Elevation data
Remote sensing data	European Space Agency	2015-2021 image	Raster data
Socio-economic data	Tongzhou District Statistical Yearbook	Economic data	Tabular data

2.2.1. Urban expansion data processing

Seto & Kaufimann (2003) developed a multilinear model to describe urban sprawl as a function of several socioeconomic variables [9]. In this study, possible relevant variables are selected and their correlation with urban growth rate is tested using a random coefficient model, as shown in formula (1).

$$Y=p0+p1\times X_1+p2\times X_2+p3\times X_3+p4\times X_4+p5\times X_5 \quad (1)$$

Among them, Y represents the annual changes in urban land use in Tongzhou District, Beijing; pn represents the model parameters for each socio-economic factor; Xn represents the socio-economic

or geographic data for each year. X_1: $\frac{Completed\ investments\ in\ capital\ construction}{population}$;X_2: $\frac{Gross\ agricultural\ output}{agricultural\ population}$;$X_3$: $log($ wages in private units$)$;X_4: $log(average\ total\ wages)$;

X_5: $\frac{\frac{gross\ agricultural\ output}{agriculture\ area}}{\frac{gross\ industrial\ output}{urban\ land\ area}}$

The socio-economic data come from the 2015-2021 Statistical Yearbook of Tongzhou District, Beijing, and selected seven data items: capital construction investment, population, value of total agricultural output, agricultural population, value of total agricultural output, agricultural land, and urban land value, the basic situation of the data can be seen in Table 2.

Table 2 Statistical Yearbook Data of Seven Socioeconomics in Tongzhou District from 2015 to 2021

Kind	2015	2016	2017	2018	2019	2020	2021
Capital construction investment (ten thousand)	8007603	5480494	6789280	5867529	7103621	8548860.2	7724896.9
Population (ten thousand)	137.8	142.8	150.8	157.8	167.5	184	184.3
Total agricultural output (ten thousand)	227963	219284	184546	140813	99721	131306	168008
Agricultural population (ten thousand)	27.8	27.1	26.6	26.4	26.1	25.7	25.4
Total agricultural output (ten thousand)	501234	424141	408018	396246	302603	307918	311016
Agricultural land (hectare)	23049	17686	13266	10195	7537	9304	11846
Urban land value (thousands)	44411059	61478067	48697333	51785362	51135580	59719960	78852180

Table 3 Statistical Yearbook Data of Xn (n=1, 2, 3, 4, 5) in Tongzhou District from 2015 to 2021

Socio-economic geographic data	2015	2016	2017	2018	2019	2020	2021
X_1	58110.33	38378.81	45021.75	37183.33	42409.68	46461.2	41914.8
X_2	8200.108	8091.661	6937.82	5333.826	3820.728	5109.183	6614.488
X_3	10.35447	10.43696	10.52431	10.61037	10.69625	10.73302	10.81366
X_4	10.02163	10.10663	10.18679	10.26451	10.34187	10.2988	10.4167
X_5	156.0574	228.9473	233.5939	324.3077	332.9779	337.5356	326.4967

2.2.2. Land subsidence data processing

The land subsidence data in Tongzhou District use Sentinel 2 satellite image data. The obtained remote sensing impact data is preprocessed by band fusion, geometric correction, atmospheric correction, image registration, and cropping, and the remote sensing images are supervised, classified, and information extracted, and the ground subsidence monitoring points in Tongzhou District are expanded. The two-year height difference data of all points are gridded by the quadratic fitting method, and the average value of all grid points is the annual subsidence of Tongzhou District.

3. Analysis on the Relationship between Temporal and Spatial Evolution Characteristics of Land Subsidence and Urban Expansion in Tongzhou District

3.1. Time series evolution characteristics of land subsidence in Tongzhou

According to the statistical analysis, the land subsidence of the difference result of the levelling data in Tongzhou District of Beijing from 2015 to 2021 is obtained. The average settlements from 2015 to 2021 are 30.59 mm, 35.65 mm, 42.88 mm, 35.36 mm, 27.74 mm, 17.24 mm, and 12.31 mm respectively. In Figure 2, it can be seen intuitively that the annual land subsidence of Tongzhou District shows that the land subsidence in the northwest is higher than that in the southeast every year, indicating that the urban expansion process is relatively fast. The regional trend of annual subsidence is similar, which is also reflected in the annual subsidence in 2019-2022, and as the years increase, the annual subsidence in Tongzhou District of Beijing shows a slowing down trend.

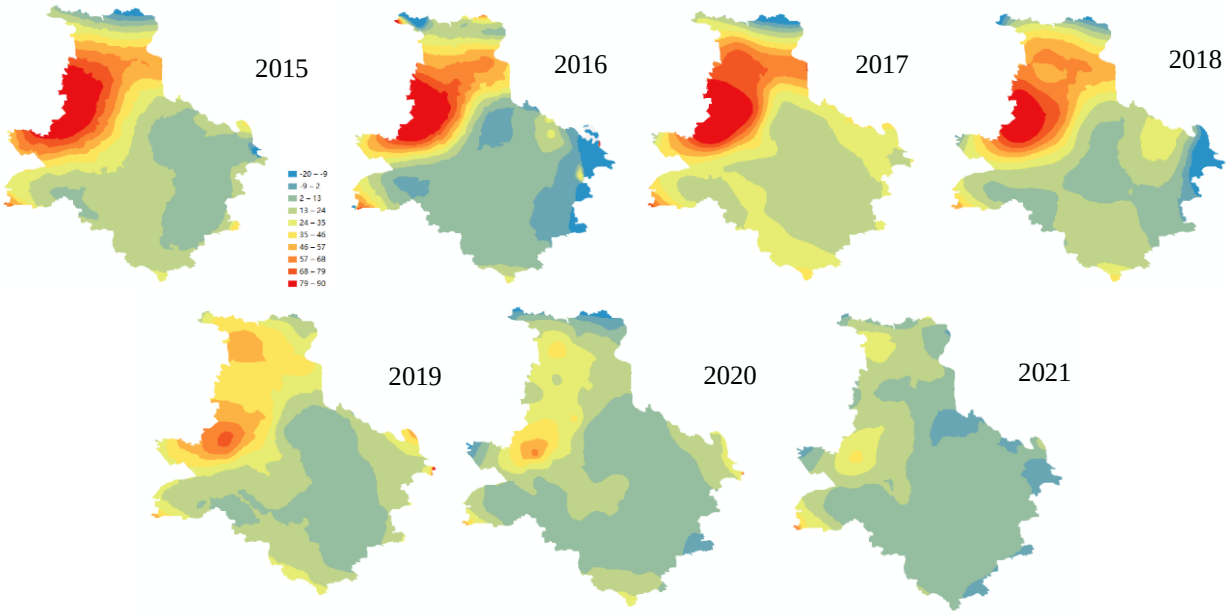

Figure 2 Interpolation results of annual land subsidence in Tongzhou District, Beijing

3.2. Urban expansion process

Based on the urban information extracted from remote sensing images, the Tongzhou District was analyzed, and an annual map of the supervised classification results based on Sentinel-2 satellite data was made to reflect the process of urban expansion. It can be seen intuitively from Figure 3 that during the urbanization expansion process of Tongzhou District, Beijing from 2015 to 2021, the expansion direction is mainly concentrated in the northwest. This result is consistent with the annual subsidence of land subsidence.

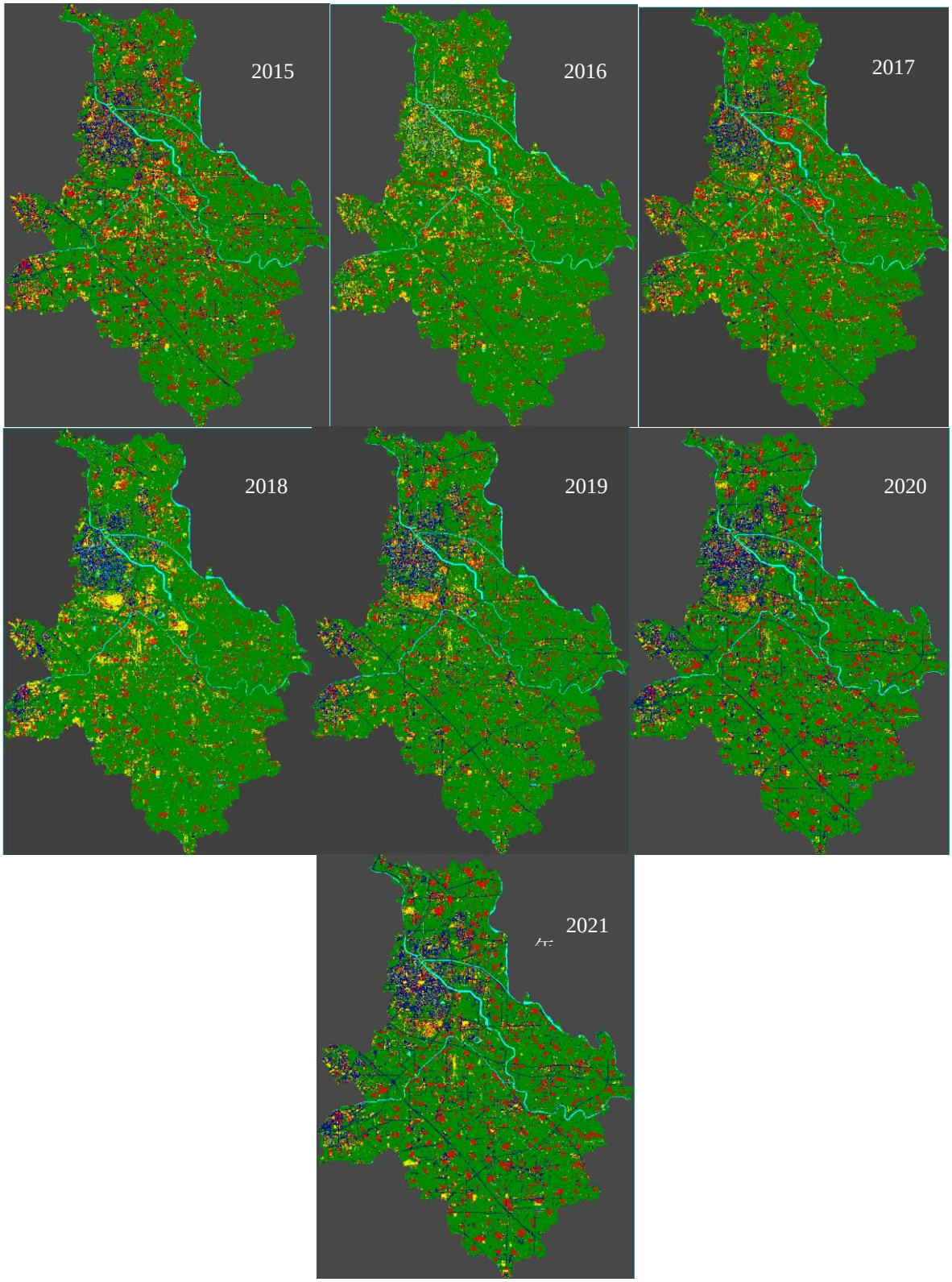

Figure 3 Results of supervised classification based on sentinel-2 satellite data in Tongzhou district, Beijing.

Based on the statistical data in the yearbook of Tongzhou District, Beijing, the Y value is obtained by calculating the annual change of urban land use, see Table 4 for details. It can be seen from Table

4 that the annual change value of land use is increasing continuously, and the process of urban expansion is accelerating, increasing from 9934.8 in 2015 to 16791.5 in 2021. The annual increment of land use change increased from 488 in 2016 to 2660.2 in 2019 and best to 508.3 in 2021. During the period studied in this paper, the annual growth rate of land use change in Tongzhou District of Beijing showed a trend of accelerating and then slowing down. It shows that the urban development in Tongzhou District of Beijing has been very rapid in the past 7 years, and the urban expansion process has shown a trend of speeding up first and then slowing down.

Table 4 Statistical table of annual change of urban land use in Tongzhou District, Beijing

Annual change of land use	2015	2016	2017	2018	2019	2020	2021
Y	9934.8	10422.8	10842.3	12698.8	15359	16283.2	16791.5

3.3. Influence of urban expansion process on land subsidence

In the process of studying the impact of urban expansion on land subsidence, the correlation analysis between the average subsidence and the urban expansion rate from 2015 to 2021 can be carried out. As shown in Figure 4, the average annual subsidence in Tongzhou District of Beijing showed a trend of first increasing and then decreasing. The urban expansion rate increased year by year from 2015 to 2017 and decreased year by year since 2018. And the correlation of the two items gives an R^2 of 0.814. It can be seen that the changes in the process of urban expansion affect the changes in the annual land subsidence. The rapid urban development before 2017 is related to Beijing's policy of building the sub-center of Tongzhou City, which leads to the excessive occupation of other types of construction land in the process of urban development. Land, leading to an increase in the amount of land subsidence. From 2018 to 2021, the speed has slowed down compared with the previous stage, indicating that in the process of urban construction, the control of land has been continuously strengthened, and the scale of urban construction land has been controlled. Urban sprawl slows down.

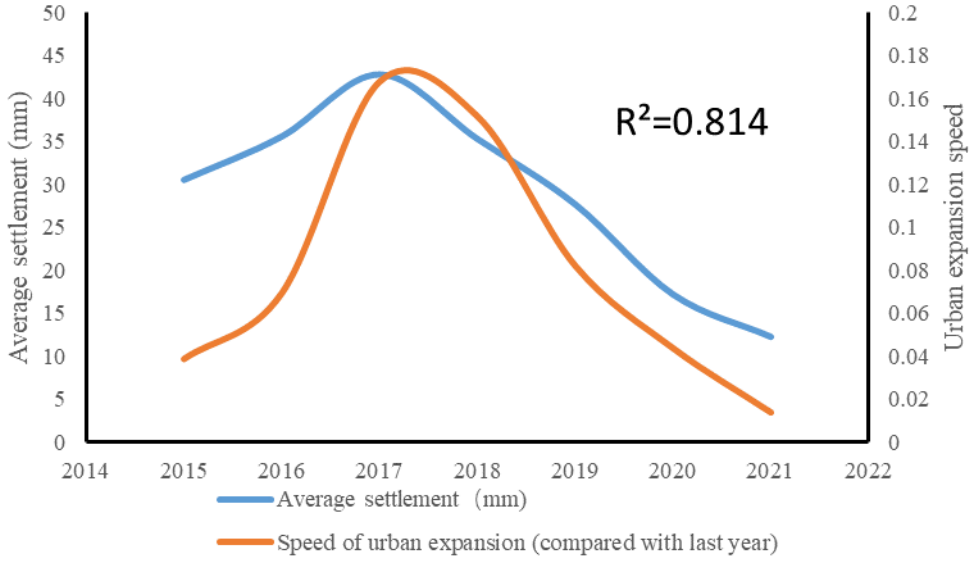

Figure 4 Correlation analysis chart of annual average land subsidence rate and urban expansion rate in Tongzhou District, Beijing.

4. Conclusions

Based on multi-factor socioeconomic data, the urban expansion described by the multivariate linear model and the analysis of the average annual land subsidence rate from 2015 to 2021 found that the land subsidence caused by the urban expansion process in Tongzhou District was caused by the joint action of multiple factors. There is a certain correlation between urban expansion and the rate of land subsidence, and the rapid growth of urban expansion will lead to more serious land subsidence. The process of urban expansion in this paper will affect the rate of land subsidence, which is the same as previous studies. The difference is that the process of urban expansion cannot aggravate land subsidence, but the speed of urban expansion can directly affect the intensification of land subsidence. In this paper, socio-economic factors are mostly used to describe the increment of urban expansion. If more factors such as groundwater exploitation and asphalt usage can be added to the multivariate linear model, the incremental description of urban expansion process will be more accurate and better analyzed.

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