Research on land use efficiency of Zhongyuan Urban Agglomeration

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Abstract. The improvement of urban land use efficiency is of great significance for achieving high-quality economic growth and environmental sustainability. Based on the SBM-Undesirable model, the land use efficiency of 27 cities in Zhongyuan Urban Agglomeration was measured in 2005 -2016, and the reasons of land use efficiency losses are also analyzed. Considering the status and differences of land use, the environmental-friendly recommendations in the region are put forward. The results show that during 2005-2016, the average land use efficiency of 27 cities in Zhongyuan Urban Agglomeration was 0.79, which was low in general but showed a “W” type fluctuating trend. The development of urban economy should not rely too much on the increase in land input and the expansion of urban boundaries but should turn to the improvement of the efficiency of stock land.

1. Introduction

Since the reform and opening up, the rapid advancement of urbanization and industrialization has generated a large amount of demand for land. At the same time, the dual urban-rural land system and tax-sharing reform have prompted local governments to vigorously promote land finance policy, and these two basic reasons have led to the rapid expansion of urban space. From 1999 to 2014, China’s urban construction land area increased from 15,000 km² to 49,800 km², nearly an increase of 2.32 times. Although urban spatial expansion is conducive to the agglomeration of population and industries, it also brings a series of problems such as low land use efficiency and serious environmental pollution. The inefficient use of land resources has severely restricted sustainable development of urban economy. The Zhongyuan Urban Agglomeration is located in central and eastern China, with Henan Province as the main body. The spatial scope covers five provinces of Henan, Hebei, Anhui, Shandong, and Shanxi, with a land area of 287,000 km² of the main body. The spatial scope covers five provinces of Henan, ns. In China, the Zhongyuan urban agglomeration plays a role in linking east and west, connecting south and north, and is also an important carrier of the strategy of central China’s rise. Since the beginning of the new century, the scale of cities in the Zhongyuan Urban Agglomeration has continued to expand, land use patterns and structures have continued to change, and various problems have continued to appear, such as the excessive expansion of construction land, sharp reduction of arable land, low land use efficiency, and serious soil pollution. Thus, it is an urgent task to excavate the existing land, improve the land use efficiency and realize the endogenous development of the Zhongyuan Urban Agglomeration. First of all, in terms of the connotation of land use efficiency, most scholars measure land use efficiency by comparing input and output or results and consumption [1]; in addition, urban land use is an activity carried out by humans under the social ecosystem. Due to the multi-functionality of land...
resources, the characterization of land use efficiency should include many aspects, such as economic benefits, social benefits and environmental benefits; at the same time, urban land use will not only produce positive benefits, but may also cause damages, which reflecting the ability of the land users [1]. Secondly, in the evaluation of land use efficiency, the research methods used by scholars mainly include parametric analysis and non-parametric analysis. The parametric analysis mainly refers to the random boundary model. The most commonly used non-parametric analysis model is the data envelopment analysis, including the traditional DEA model [2], super-efficiency DEA model [3], SBM model [4]. The advantage of the non-parametric analysis is that it does not need to set the function model in advance, and can realize the calculation of multiple output efficiency. The efficiency measured by this method is not the utilization efficiency of single elements of land, but the utilization efficiency of all elements of the decision-making unit. The research areas are not limited to cities across the country, but also for urban agglomerations. For the research results, urban land use efficiency generally shows a trend of decreasing from southeastern China to northwestern China, and there are obvious gradient changes between regions [5].

In summary, although the existing research has achieved many results, it still has the following shortcomings: First, most of the research areas are limited to the national or provincial areas, and the research on urban agglomerations is mainly concentrated in the Yangtze River Delta, Pearl River Delta, Beijing-Tianjin-Hebei and other regions, and the land use efficiency of other regions is less investigated; second, the environmental benefits of land use are ignored. Existing literature estimates mainly the economic and social benefits of land use, and insufficient investigation of the negative environmental impact of land use has led to the insufficient interpretation of land use efficiency. Based on the existing problems in previous studies, the framework of this paper is as follows. Firstly, the general situation of the study area is introduced, and then the SBM undesirable model is used to calculate and analyze the total factor efficiency of urban land use in the region and analyze the source of efficiency losses.

2. Research methods and data sources

2.1. Land use efficiency measurement method

Data Envelopment Analysis (DEA) can analyze the relative effectiveness of the evaluated objects based on multiple input and multiple output indicators, using linear programming methods. Traditional DEA analysis mainly uses models such as CCR and BBC. However, the traditional method is radial and directional calculation. When there are slack variables, the radiality will overestimate the efficiency, and the directionality cannot simultaneously take into account investment and non-proportionately. In 2001, Tone proposed a non-radial, non-directional SBM model based on slack variables, which solved the problem of ignoring slack variables in radial operations [6]. The SBM-Undesirable model is developed based on the SBM model. It takes into account the undesirable output while taking into account the above two issues. The model is:

\[
\rho^* = \min \frac{1 - \frac{1}{m} \sum_{i=1}^{m} \frac{S_i^*}{x_i}}{1 + \frac{1}{s_1 + s_2} \left( \frac{\sum_{i=1}^{m} \frac{S_i^g}{y_i^g} - \frac{\sum_{i=1}^{m} \frac{S_i^b}{y_i^b}}{r_o} \right) }
\]

Subject to:
\[
x_0 = X\lambda + s^-
\]
\[
y_0^g = y^g\lambda - s^g
\]
\[
y_0^b = y^b\lambda + s^b
\]
\[
s^-, s^g, s^b \geq 0, \lambda \geq +
\]
Among them $\rho^*$ is the total factor land use efficiency value of the evaluated unit, the value range is $[0,1]$, and $\lambda$ is the weight vector. $X$ are inputs, $Y^e$ are expected outputs and $Y^b$ are undesired outputs of each prefecture-level city each year. $s^-, s^e, s^b$ are respectively the input redundancy, the expected output insufficient and the undesired output superscalar. If and only if $\rho^* = 1$ and $s^-, s^e, s^b$ are all 0, the land use of the evaluated unit is effective; when $\rho^* < 1$ and at least one of $s^-, s^e, s^b$ is not 0, it indicates that there is room for improvement in input or output, and land use in the evaluated unit is invalid.

2.2. Index selection

The measurement of construction land utilization efficiency needs to select indicators from the input and output ends. In terms of input indicators, we mainly consider the core driving forces of urban development such as land, capital, and labor, and output indicators mainly include economic indicators, social indicators, and environmental indicators. In accordance with the principles of goal, relevance, simplicity, combined with the research objectives of this article and existing literature, the following input-output indicators are selected (Table 1). The area of built-up area is selected as land input; the number of employees in secondary and tertiary industries is selected as labor input; fixed asset investment is selected as capital input; GDP value of secondary and tertiary industries is selected as economic output; the average wage of employees is selected as social output; green coverage rate of built-up area is selected as environmental output; industrial waste water discharge is selected as the unexpected output.

| Indicators | Unit |
|------------|------|
| Built-up area | km² |
| Number of employees in secondary and tertiary industries | People |
| Fixed assets investment | Ten thousand yuan |
| GDP of secondary and tertiary industries | Ten thousand yuan |
| Average wage of employees | Yuan |
| Green coverage rate | % |
| Industrial waste water discharge | t |

2.3. Data sources

Considering the availability of the research data, this paper selects 27 prefecture level cities in the Zhongyuan urban agglomeration as the research objects, and the research time span is 2005-2016. The index data used are from China Urban Statistical Yearbook and China Urban Construction Statistical Yearbook from 2006-2017. In order to eliminate price-influencing factors, the price indicators of each city-level are uniformly converted into constant prices in 2004 to eliminate the impact of inflation.

3. Results and analysis

3.1. Land use efficiency measurement results

MaxDEA ultra7 was used to calculate the land use efficiency of Zhongyuan Urban Agglomeration from 2005 to 2016. The changing trend of the overall urban agglomeration (Figure 1) and the annual average land use efficiency of each city (Table 2) were obtained. On the level of urban agglomeration, the land use efficiency of 27 prefecture level cities showed a similar “W” type change from 2005 to 2016, with significant fluctuations, but an overall upward trend, with a total average of 0.79. Among them, from 2005 to 2008, the overall land use efficiency was in the rising stage, reaching 0.80 in 2008,
which benefited from the rapid advancement of urbanization and industrialization, and the continuous improvement of urban land economic and social output; from 2009 to 2010, the land use efficiency fell to 0.74 and 0.73, because after the economic crisis in 2008, China’s economic growth fell rapidly, and the government adopted large-scale investment policy in order to stimulate the steady and rapid economic growth, which promotes the rapid growth of land investment, but the extensive factor input makes the land use efficiency decrease. After 2011, the land use efficiency is in a rising and fluctuating state, reaching a peak value of 0.89 in 2016. This is due to the transformation of the mode of regional economic development in this stage changes from blindly pursuing speed to pursuing quality.

![Figure 1. Mean trend of land use efficiency in Zhongyuan Urban Agglomeration from 2005 to 2016.](image)

### Table 2. Land Use Efficiency of Zhongyuan Urban Agglomeration from 2005 to 2016.

| City        | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|-------------|------|------|------|------|------|------|------|------|------|------|------|------|
| Zhengzhou   | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Kaifeng     | 0.44 | 0.53 | 0.57 | 0.64 | 0.64 | 0.47 | 0.47 | 0.48 | 0.54 | 0.55 | 0.64 | 0.44 |
| Luoyang     | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Pingdingshan| 0.50 | 0.51 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Anyang      | 0.51 | 0.56 | 0.57 | 0.57 | 0.57 | 0.60 | 0.60 | 0.73 | 0.54 | 0.77 | 0.83 | 1.00 |
| Hebi        | 0.78 | 1.00 | 0.69 | 0.60 | 0.56 | 0.59 | 0.65 | 0.61 | 0.73 | 0.68 | 0.65 | 0.79 |
| Xinxiang    | 0.44 | 0.51 | 0.50 | 0.47 | 0.42 | 0.41 | 0.56 | 0.47 | 0.54 | 0.59 | 0.51 | 0.78 |
| Jiaozuo     | 0.44 | 0.48 | 0.48 | 0.46 | 0.46 | 0.46 | 0.48 | 0.61 | 0.55 | 0.51 | 0.55 | 0.47 |
| Puyang      | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.57 | 0.56 | 0.41 | 1.00 | 0.75 | 1.00 |
| Xuchang     | 1.00 | 1.00 | 0.63 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.70 | 0.81 |
| Luoho       | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.94 | 1.00 | 1.00 |
| Sanmenxia   | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Nanyang     | 0.39 | 0.40 | 0.41 | 0.41 | 0.38 | 0.39 | 0.65 | 0.46 | 0.56 | 0.63 | 1.00 | 1.00 |
| Shangqiu    | 0.47 | 0.63 | 0.61 | 0.52 | 0.46 | 0.47 | 0.54 | 0.50 | 0.59 | 0.86 | 0.68 | 1.00 |
| Xinyang     | 0.57 | 0.63 | 0.56 | 0.55 | 0.58 | 0.58 | 1.00 | 0.79 | 1.00 | 1.00 | 1.00 |
| Zhoukou     | 0.58 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.64 | 1.00 | 1.00 | 1.00 | 1.00 |
| Zhumadian   | 0.61 | 0.59 | 0.59 | 0.58 | 0.59 | 0.57 | 0.71 | 0.58 | 0.63 | 0.69 | 0.63 | 0.70 |
| Changzhi    | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.74 | 0.83 | 0.79 | 1.00 | 1.00 | 1.00 |
| Jincheng    | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.67 | 1.00 |
| Yuncheng    | 1.00 | 1.00 | 1.00 | 1.00 | 0.54 | 0.52 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Handan      | 0.42 | 0.47 | 0.55 | 1.00 | 0.57 | 0.56 | 1.00 | 0.82 | 0.79 | 0.78 | 1.00 | 0.58 |
| Xingtai     | 0.62 | 0.73 | 0.66 | 0.72 | 0.61 | 0.60 | 0.65 | 0.60 | 0.72 | 0.58 | 0.56 | 0.71 |
| Liaocheng   | 0.69 | 0.76 | 0.76 | 0.70 | 0.78 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Heze        | 0.51 | 1.00 | 0.53 | 0.68 | 0.75 | 0.71 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Huayang     | 0.71 | 0.67 | 0.75 | 1.00 | 0.72 | 1.00 | 0.79 | 0.73 | 0.83 | 0.82 | 0.61 | 0.74 |
| Fuyang      | 0.25 | 0.58 | 0.52 | 0.54 | 0.51 | 0.55 | 1.00 | 0.70 | 0.72 | 0.88 | 0.78 | 0.71 |
| Bozhou      | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Average     | 0.69 | 0.78 | 0.74 | 0.79 | 0.72 | 0.71 | 0.82 | 0.77 | 0.83 | 0.86 | 0.83 | 0.88 |
As far as the city level is concerned, the observation table 2 shows that from 2005 to 2016, the land use efficiency of the 27 cities in the Central Plains urban agglomeration was significantly different, and the land use level was uneven. Among them, Zhengzhou, Luoyang, Luobei, Sanmenxia, Changzhi, Jincheng, and Bozhou have higher land use efficiency values over the years, while the average land use efficiency of Kaifeng, Xinxiang, Jiaozuo, Nanyang, Shangqiu, Zhumadian, Xingtai, and Fuyang lags far behind other cities. Specifically, from 2005 to 2016, the land use efficiency values of Anyang, Puyang, Nanyang, Xinyang, Yuncheng, Handan, Heze, and Fuyang fluctuated greatly. Anyang's land use efficiency value was low before 2012, and gradually increased after 2013 to reach DEA effective; Puyang land use before 2009 was DEA effective, but between 2010 and 2012, the land use efficiency value fell sharply, and in 2013 and It will stabilize at a relatively high level in the future; Nanyang has a low land use efficiency value from 2005 to 2014, but shows a fluctuating upward trend, reaching the DEA effective in 2015; Xinyang fluctuating and increasing during 2005-2010, and stable at a relatively high level after 2011; The land use efficiency of Yuncheng from 2005 to 2008 was valid for DEA, and fell to 0.54 and 0.52 in 2009 and 2010, and resumed to be valid for DEA in 2011; Handan reached DEA valid in 2008, 2011, and 2015, and in other years it showed great fluctuations; Heze’s efficiency value from 2005 to 2010 showed a state of rising volatility, after 2011, it reached the DEA effective, Fuyang reached the highest efficiency value in 2011, and other years fluctuated greatly, showing an overall upward trend.

3.2. Analysis of land use efficiency loss

In order to further reveal the source of efficiency loss in the process of land use in Zhongyuan Urban agglomeration, the degree of input element redundancy, unexpected output excess and expected output insufficiency of land use in 2016 were calculated respectively (Table 3). In table 3, S1 is the redundant part of the built-up area, S2 is the redundant part of the fixed assets investment, S3 is the redundant part of the secondary and tertiary industries, S4 is the insufficient part of the output value of the secondary and tertiary industries, S5 is the insufficient part of the average wage of the employees, S6 is the part of the insufficient green coverage in the built-up area, and S7 is the excessive part of the industrial wastewater discharge. It can be seen than the non-DEA effective cities of Zhongyuan Urban agglomeration all had the common dilemma of input redundancy and insufficient expected output, and some cities also had the problem of excessive unexpected output.

In terms of input indicators, the built-up area of Jiaozuo, Xingtai, Liaocheng, Fuyang and other cities has certain redundancy, and Fuyang has the most redundancy, reaching 49 km². Compared with land investment redundancy, the situation of fixed asset investment and labor input redundancy is more common. Kaifeng, Zhumadian, Handan, Liaocheng, Fuyang have redundancy problems in fixed assets investment, of which Handan has the largest investment redundancy, reaching 12633.97 million yuan; Kaifeng, Hebi, Jiaozuo, Zhumadian, Handan, Xingtai, Huaibei and Fuyang have labor input redundancy, and among them, Jiaozuo has the most serious labor redundancy with 78711 people. In terms of the expected output index, there is no shortage of economic output in each city, but there is a problem of insufficient social output and environmental output. Kaifeng, Hebi, Xinxiang, Jiaozuo, Xuchang, Zhumadian, Handan and Huaibei cities have significant problems of insufficient average wages of employees. Meanwhile, Kaifeng, Xinxiang, Jiaozuo, Xuchang, Handan and Huaibei have obvious problems of insufficient green coverage in built-up areas. In terms of unexpected output, Xinxiang, Huaibei and Xingtai have a significant excess of industrial waste water discharge. Therefore, measures should be taken to effectively reduce environmental pollution in the process of economic development.

| Cities     | Efficiency value | Input redundancy | Expected output insufficiency | Unexpected output excess |
|------------|------------------|------------------|-----------------------------|--------------------------|
| Zhengzhou  | 1.00             | 0                | 0                           | 0                        |

Table 3. Reasons for land use efficiency loss in Zhongyuan Urban Agglomeration in 2016.
### 4. Conclusion and suggestions

This paper takes 27 prefecture-level cities in the Zhongyuan Urban Agglomeration from 2005 to 2016 as the research objects, uses the SBM-Undesirable model to measure urban land use efficiency and explores its temporal and spatial evolution trends. It shows from 2005 to 2016, the annual average value of overall land use efficiency of the Zhongyuan Urban Agglomeration was 0.79; the overall level was low but showed an upward trend of “W” like changes. The development of cities should shift from extensional development to intensional development. The development of the urban economy should not rely too much on the increase in land input and the expansion of urban boundaries, but should turn to the improvement of the efficiency of the use of stock land. The improvement of land use efficiency can start from two aspects which are improving technical efficiency and promoting technological progress. Specific measures to improve the efficiency of land use technology include formulating a reasonable urban development plan, optimizing land use structure, promoting industrial structure adjustment and upgrading, and improving labor quality; specific measures to promote technological progress include increasing scientific research investment and vigorously introducing high-tech talents, and combine the scientific research advantages of the universities of the Zhongyuan Urban Agglomeration with the industrial production advantages of enterprises to realize the transformation and application of scientific research results.

In recent years, the efficiency of land use in Zhongyuan Urban Agglomeration has been improved, but the urban economic growth still depends on the increase of land input in the long term. Therefore, it is necessary to maintain the dynamic attention to urban land use and increase the control of the disordered expansion of construction land.

| City       | Year | Population | Land Use | Labor | Capital | Efficiency |
|------------|------|------------|----------|-------|---------|-------------|
| Kaifeng    | 0.59 | 0          | 482170   | 64358 | 0       | 32185       |
| Luoyang    | 1.00 | 0          | 0        | 0     | 0       | 0           |
| Pingdingshan | 1.00 | 0     | 0        | 0     | 0       | 0           |
| Anyang     | 1.00 | 0          | 0        | 0     | 0       | 0           |
| Hebi       | 0.79 | 5        | 47117    | 0     | 7055    | 0           |
| Xinxiang   | 0.78 | 0        | 0        | 0     | 13775   | 10          |
| Jiaozuo    | 0.64 | 26       | 78711    | 0     | 15475   | 10          |
| Puyang     | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Xuchang    | 0.81 | 6       | 0        | 0     | 13454   | 17          |
| Luhe       | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Sanmenxia  | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Nanyang    | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Shangqiu   | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Xinyang    | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Zhoukou    | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Zhumadian  | 0.70 | 4        | 380834   | 68417 | 0       | 10683       |
| Changzhi   | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Jincheng   | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Yuncheng   | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Handan     | 0.58 | 0        | 1263397  | 30796 | 0       | 51057       |
| Xingtai    | 0.71 | 20       | 47872    | 0     | 0       | 1           |
| Liaoqiang  | 0.87 | 15       | 279385   | 0     | 0       | 2           |
| Heze       | 1.00 | 0        | 0        | 0     | 0       | 0           |
| Huaiyang   | 0.74 | 0        | 15501    | 0     | 17575   | 9           |
| Fuyang     | 0.71 | 49       | 1051449  | 6465  | 0       | 11          |
| Bozhou     | 1.00 | 0        | 0        | 0     | 0       | 0           |
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