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Study on Temporal and Spatial Variation Characteristics and Influencing Factors of Land Use Efficiency in Xi’an, China

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Abstract: China’s urban land use has shifted from incremental expansion to inventory eradication. The traditional extensive management mode is difficult to maintain, and the fundamental solution is to improve land use efficiency. Xi’an, the largest central city in Western China, was selected as the research area. The super-efficiency data envelopment analysis (DEA) model and Malmquist index method were used to measure the land use efficiency of each district and county in the city from the micro perspective, and the spatial-temporal change characteristics and main influencing factors of land use efficiency were analyzed, which not only made up for the research content of urban land use efficiency in China’s underdeveloped areas, but also pointed out the emphasis and direction for the improvement of urban land use efficiency. The results showed that: (1) The land use efficiency of Xi’an reflected the land use intensive level of the underdeveloped areas in Western China, that is, the overall intensive level was not high, the gap between the urban internal land use efficiency was large, the land use efficiency of the old urban area and the mature built-up area was relatively high, and the land use efficiency of the emerging expansion area and the edge area was relatively low. (2) Like the eastern economically developed areas, the land use efficiency of western economically underdeveloped areas was generally on the rise, while Xi’an showed the U-shaped upward evolution characteristics, and there were four types of changes in the city, that is, highly intensive, medium intensive, high–medium–low-intensive, and intensive–extensive. (3) Various cities should configure resources and optimize mechanism to improve their land use efficiency based on economic and social development. During the study period, Xi’an showed the law of evolution from the south edge area and the emerging expansion area to the main urban area. (4) The improvement of technological progress was the main contribution factor of the land use efficiency in underdeveloped areas of China, and the low-scale efficiency was the main influence factor that caused low land use efficiency. In future urban land use, efforts should be made to optimize and upgrade technology and strictly control the extensive use of land.

Keywords: land use efficiency; change characteristics; influencing factors; Malmquist index; Xi’an

1. Introduction

Over the past 40 years of reform and opening up, China’s urbanization has made great achievements. The urbanization rate increased from 17.92% in 1978 to 59.58% in 2018, with an average annual growth rate of 4%. At the same time, the area of urban built-up areas in China is also accelerating, with an average annual growth rate of 5% [1]. Urban spatial expansion speed is significantly faster than population urbanization speed. Urban sprawl at the cost of excessive consumption of land resources leads to the prominent contradiction between land supply and
demand, and urban diseases are becoming more and more serious. Since the 1990s, with the rapid development of China’s industrialization and urbanization, over-consumption of land resources has become widespread. The problems of extensive expansion, waste of land, and pollution of land are prominent, land carrying capacity has been significantly weakened, and land resource constraints are being increasingly intensified [2]. Land is the carrier of all human activities. Land use efficiency determines the sustainable development ability of cities. The improvement of land use efficiency is not only the fundamental requirement of the special land national conditions, but also the road that must be taken to vigorously promote the construction of ecological civilization and guarantee the long-term sustainable development of the economy and society. At present, China’s urbanization has entered a critical period of transformation and quality improvement, and urban land use has changed from incremental expansion to a stock-tapping era, so the traditional extensive management mode is difficult to sustain. Therefore, the formulation of reasonable land use policies and to effectively improve land use efficiency is an urgent problem that must be solved by the state.

Human use of land on a large scale has existed for thousands of years. In the early days, humans used extensive land use management methods [3]. With the process of urbanization, the increase of population, the rapid development of social economy, and the increasing demand of human for land, most cities currently face the prominent contradiction of land supply and demand [3]. Therefore, the study of urban land use efficiency has become a hot topic in the academic community. From the perspective of research content, domestic and foreign scholars’ research on urban land use efficiency mainly include connotation definition, efficiency evaluation, space–time patterns, and influence mechanisms [4,5].

Based on the input–output relationship of urban land, one kind of research on the connotation of urban land use efficiency in domestic studies considers that urban land use should be highly efficient in land output; the other kind is combined with the idea of sustainable development, emphasizing that land use should pay attention to social, economic, and ecological benefits [6]. As for the evaluation of land use efficiency, most take urban agglomeration, provinces, and city areas as research objects [7,8], set different index systems according to different goals, and use cluster analysis, the analytic hierarchy process (AHP), fuzzy evaluation, the multi-factor comprehensive evaluation method [9,10], the entropy method, and the data envelopment analysis (DEA) method [11–14] to evaluate land use efficiency. In recent years, domestic scholars have begun to pay attention to the temporal and spatial evolution characteristics of land use efficiency, with a small number of studies focused on the temporal and spatial differentiation characteristics of prefecture level cities, urban agglomerations, or regional levels [15–21]. As for the influencing factors and ways to improve the efficiency of land use, the economic level, industrial structure, scientific and technological levels, policies and systems, and the role of the government are the main driving forces that affect the efficiency of land use [15,16,22].

The urbanization and industrialization process of Western countries occurred earlier than other areas, so urban land as an important factor of production has already had some consideration. The classic theory of land use efficiency in western cities is the law of diminishing land returns, which focuses on the rational input of land and pays attention to the law of urban land as a factor of production in the process of economic activity production. The classical theory of early land use efficiency provides an important theoretical basis and practical way for land intensive use [23]. With the continuous expansion of urban space scale, the ecological, environmental, social, and economic problems related to urban land use have become increasingly prominent. Western countries began to combine urban land intensive use with the idea of sustainable development [24–26] to evaluate urban land use efficiency, and there is little difference between the use of technical methods and domestic scholars, such as remote sensing (RS), the geographic information system (GIS), and advanced computer technology. In recent years, foreign scholars have deeply researched the mechanisms affecting land use efficiency. From different perspectives, they put forward the differences and causes of calculations of land use efficiency in relation to different types of land, different cities, and more reasonable methods to improve the efficiency of urban land use [27].
In conclusion, domestic scholars have studied urban land use efficiency and influencing factors from different perspectives, such as provinces and cities, industrial parks, urban agglomerations, etc., measured urban land use efficiency from different perspectives, constructed different index systems and calculation methods, and improved the theory of urban land use efficiency. However, there are many research efforts ongoing regarding the current situation of land use efficiency in China, with few research efforts looking into the long-term spatial-temporal evolution characteristics of a single city. Research on the effective analysis of driving forces by decomposing land use efficiency into two directions of pure technical efficiency and scale efficiency is still limited, with research mainly focusing on urban agglomerations or cities in the east, and less on the underdeveloped areas in the west.

Therefore, this paper selects Xi’an, a typical city in the underdeveloped western region of China, as the research object, analyzes the spatial-temporal change characteristics and influencing factors of urban internal land use efficiency in 2007–2017, and enriches the research results of urban land use efficiency. It includes two specific tasks: First, using the super-efficiency DEA method to calculate the comprehensive efficiency of land use in Xi’an City, and analyzing its temporal and spatial evolution characteristics, and second, decomposing the comprehensive efficiency of land use into pure technical efficiency and scale efficiency, revealing the deep driving force of the change of the efficiency of land use in the city, and providing policy suggestions for the sustainable development of the city.

2. Research Methods and Data Sources

2.1. Study Area

Xi’an, known as Chang’an in ancient times, is one of the three international metropolises built in China, the largest central city in Northwest China, an important national scientific research, education, and industrial base, and a typical city in the underdeveloped areas of Western China. It is located in the middle of Guanzhong Plain and is subordinate to Shaanxi Province (Figure 1). It has 11 districts (Xincheng, Beilin, Lianhu, Yanta, Baqiao, Weiyang, Yanliang, Lintong, Chang’an, Gaoling, Huyi), 2 counties (Lantian, Zhouzhi), 7 national development areas, and one national new area under its administration. Since the proposal of building an international metropolis, the population scale of Xi’an has increased, the built-up area has expanded rapidly, and various investments have increased. With the expansion of scale and the investment of capital, evaluation of the efficiency of land use scientifically and whether the investment of capital was allocated reasonably and efficiently are important problems to be studied and solved in the rapid development of social economy in Xi’an. Therefore, this paper chose 11 districts and 2 counties of Xi’an as the research area, evaluated the land use efficiency, analyzed the temporal and spatial evolution characteristics, and explored the influencing factors of the land use efficiency in order to provide reference for the improvement of the same kind of urban land use efficiency.

![Figure 1. Location map of Shaanxi in China and Xi’an in Shaanxi.](image-url)
2.2. Research Methods

At present, there are many methods for measuring land use efficiency. Most methods have greater subjectivity in the selection of indicators and weight determination, and the reliability of measurement results is consistently questioned. Data envelopment analysis [28] (DEA) has the advantages of strong objectivity and validity in multiple input–output evaluations due to non-subjective weighting, with no need to determine the input–output function relationship and analysis of the influencing factors of the decision-making unit in advance. Therefore, it became the mainstream method of land use efficiency analysis [28]. As DEA continued to improve, many measurement models were derived. Because the super-efficiency DEA model effectively distinguishes the level of land use efficiency, which cannot be distinguished by the traditional DEA model, it is widely used in land use efficiency evaluation. The Malmquist index method analyzes the dynamic changes of land use total factor productivity and the dominant factors affecting land use efficiency.

2.2.1. Super-Efficiency DEA Model Analysis Method

Super-efficient DEA is an improved DEA model proposed by Andersen and Petersen in 1993 [29–31]. Assuming that each district and county is a decision-making unit, and there are n decision-making units (DMUs), each decision-making unit has i kinds of input indicators, s kinds of output indicators, and sets $X_{ij}$ as the $i$-th resource of the $j$-th decision-making unit and $Y_{sj}$ as the $s$-th output of the $j$-th decision-making unit.

For the input-oriented model, the $j$-th decision-making unit has the following super-efficient DEA model [32]:

$$\min \theta - \epsilon \left( \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right)$$

subject to

$$\sum_{j=1}^{n} X_{ij} \lambda_i + s_i^- \leq \theta X_0$$

$$\sum_{j=1}^{n} Y_{j} \lambda_j - s_r^+ = Y_0$$

$$\lambda_i \geq 0, j = 1, 2, \ldots, n, s_r^+ \geq 0, s_i^- \geq 0$$

(1)

where $\theta$ is the efficiency evaluation index, $X$ and $Y$ are the input and output variables respectively, $\lambda_j$ is the weight vector of input and output of each district, $n$ is the number of decision units, and $s_r^+$ and $s_i^-$ are slack variables.

2.2.2. Malmquist Index Analysis Method

The Malmquist index analysis was proposed by Swedish economics and statistician Malmquist in 1953. It is mainly applied to the study of the dynamic trend of land use total factor productivity and influencing factors [33].

Under the condition of constant scale return (CRS), the Malmquist productivity change index is:

$$F(C) = E(C) \times T(C)$$

$$E(C) = \frac{D_{t+1}(x^{t+1}, y^{t+1})}{D_{t}(x^{t}, y^{t})}$$

$$T(C) = \sqrt{\frac{D_{t}(x^{t}, y^{t})}{D_{t+1}(x^{t+1}, y^{t+1})} + \frac{D_{t}(x^{t}, y^{t})}{D_{t+1}(x^{t+1}, y^{t+1})}}$$

(2)

where $F(C)$ is the CRS-based Malmquist productivity change index, $E(C)$ is the CRS-based technical efficiency change index, $T(C)$ is the CRS-based technological progress change index, and $D_t$ is the CRS-based distance function.
Under the condition of variable scale return (VRS), the Malmquist productivity change index is:

\[ F(V) = P(V) \times S(C, V) \]

\[ P(V) = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^0_t(x^t, y^t)} \]

\[ S(C, V) = \frac{D^t(x^t, y^t)}{D^{t+1}(x^{t+1}, y^{t+1})} + \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D_{t+1}^{t+1}(x^{t+1}, y^{t+1})} \]

where \( F(V) \) is the VRS-based Malmquist productivity change index, \( P(V) \) is the VRS-based technical efficiency change index, \( S(C, V) \) is the VRS-based technological progress change index, and \( D_v \) is the VRS-based distance function.

### 2.3. Data Sources

The efficiency evaluation of the DEA model is mainly reflected in the relationship between input and output of factors. The input factors of land use mainly include land, funds, and population. The output factors are mainly the social and economic benefits of the land. Based on the principles of science and operability, and drawing on relevant research experience, this paper selected land area, fixed asset investment, and resident population as the input factors, and selected regional gross domestic product (GDP) and local fiscal revenue to reflect social and economic output. All data from 2007 to 2017 were from the Xi’an Statistical Yearbook. The scope of citation data was based on the administrative divisions of each district and county. The data of each new district and development zone were included in the administrative district to which it belonged.

### 3. Analysis of Temporal and Spatial Changes and Influencing Factors of Land Use Efficiency from 2007 to 2017

#### 3.1. Temporal and Spatial Changes of Land Use Efficiency from 2007 to 2017

With the help of MaxDEA software, the input and output data of 13 districts and counties in Xi’an from 2007 to 2017 were substituted into the super-efficient DEA model, and the land use efficiency values of various districts and counties over the years were calculated and their average values were ranked. Based on the relevant research and the actual situation of Xi’an, the land use efficiency value was graded, and the time variation characteristics of land use efficiency in each district and county of Xi’an were analyzed. The change index was calculated according to the land use efficiency values of each district and county, and the spatial evolution characteristics were analyzed.

#### 3.1.1. Characteristics of Land Use Efficiency Attributes

The land use efficiency values of each district and county were large from 2007 to 2017. The distribution of the value of the highest year (2017) ranged from 0.201 to 1.842, and only a few districts and counties had effective land use efficiency values \((\geq 1)\). The highest efficiency was 46.15%, the lowest was 7.69%, and the overall efficiency was less than 30%, indicating that the land use efficiency of Xi’an urban areas needs to be improved (Table 1).

Overall, the average land use efficiency of Xi’an from 2007 to 2017 was 0.855, and the level of land intensive use needs to be strengthened. The average land use efficiency values of all districts and counties were quite different. The traditional old towns in the urban center and the mature built-up areas in the north were relatively high, while the southern emerging development areas and marginal areas were relatively low. The non-agricultural land was relatively high, while the agricultural land was relatively low. Among the 13 districts and counties, the average land use efficiency of Beilin District (1.659) and Lianhu District (1.088) was greater than 1, the average land use efficiency of 7 districts and counties was lower than the average, and the land use efficiency values of Lantian County (0.596) and Zhouzhi County (0.554) were not optimistic (Figure 2).
Table 1. Land use efficiency values of various districts and counties in Xi’an from 2007 to 2017.

| Names     | 2007     | 2008     | 2009     | 2010     | 2011     | 2012     | 2013     | 2014     | 2015     | 2016     | 2017     | Means    |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Xincheng  | 1.068    | 1.107    | 1.060    | 0.961    | 0.909    | 0.908    | 1.100    | 1.160    | 0.853    | 0.850    | 0.741    | 0.974    |
| Beilin    | 1.476    | 1.695    | 1.725    | 1.655    | 1.626    | 1.530    | 1.559    | 1.553    | 1.817    | 1.769    | 1.842    | 1.659    |
| Lianhu    | 1.097    | 1.195    | 1.118    | 0.927    | 0.933    | 0.930    | 0.936    | 0.969    | 0.958    | 0.987    | 1.040    | 1.008    |
| Baqiao    | 0.743    | 0.792    | 0.854    | 0.812    | 0.733    | 0.813    | 0.782    | 0.649    | 0.575    | 0.497    | 1.117    | 0.761    |
| Weinan    | 1.015    | 1.053    | 1.171    | 0.859    | 0.819    | 0.781    | 0.869    | 0.865    | 0.812    | 0.782    | 0.898    | 0.902    |
| Yanta     | 1.025    | 0.999    | 0.943    | 0.875    | 0.869    | 0.840    | 0.932    | 0.971    | 0.890    | 0.864    | 0.905    | 0.919    |
| Yanliang  | 0.969    | 0.776    | 0.681    | 0.659    | 0.932    | 0.682    | 0.720    | 0.720    | 0.618    | 0.623    | 0.636    | 0.728    |
| Lintong   | 1.313    | 1.123    | 0.998    | 1.080    | 1.207    | 1.038    | 0.924    | 0.791    | 0.325    | 0.485    | 0.427    | 0.883    |
| Chang’an  | 0.594    | 0.583    | 0.705    | 0.686    | 0.785    | 0.692    | 0.679    | 0.588    | 0.469    | 0.459    | 0.585    | 0.620    |
| Lantian   | 0.748    | 0.790    | 0.792    | 0.740    | 0.950    | 0.692    | 0.674    | 0.570    | 0.200    | 0.200    | 0.200    | 0.596    |
| Zhouzhi   | 0.608    | 0.605    | 0.610    | 0.569    | 1.317    | 0.632    | 0.610    | 0.517    | 0.182    | 0.201    | 0.323    | 0.554    |
| Huyi      | 0.839    | 0.811    | 0.796    | 0.708    | 1.001    | 0.732    | 0.875    | 0.839    | 0.296    | 0.363    | 0.293    | 0.687    |
| Gaoling   | 0.809    | 0.791    | 0.767    | 0.773    | 0.854    | 0.831    | 0.974    | 0.925    | 0.779    | 0.736    | 0.788    | 0.821    |
| Means     | 0.946    | 0.948    | 0.940    | 0.869    | 0.995    | 0.854    | 0.895    | 0.855    | 0.675    | 0.678    | 0.747    | 0.855    |
| Effective ratios | 0.461 | 0.385 | 0.308 | 0.154 | 0.308 | 0.154 | 0.154 | 0.077 | 0.077 | 0.231 | 0.154 |

Figure 2. Average values of land use efficiency in various districts and counties of Xi’an from 2007 to 2017.

3.1.2. Time-Varying Characteristics of Land Use Efficiency

At present, there is no uniform standard for the classification of urban land resource intensive use levels. Existing research is determined by combining provincial or local actual conditions with relevant national standards. Combined with the actual situation in Xi’an, this study divided land use efficiency into four grades, namely, extensive, low-intensive, moderately intensive, and highly intensive (Table 2). The extensive classification was based on national standards. Low-intensive, moderately intensive, and highly intensive were based on relevant research experience (Jin, 2014) using the numerical axis method.

Table 2. Classification criteria of land use efficiency grades in various districts and counties of Xi’an.

| Grading of Land Use Efficiency | First Level | Second Level | Third Level | Fourth Level |
|-------------------------------|------------|-------------|------------|-------------|
| Closeness value Utilization degree | [0–0.40) | [0.40–0.70) | [0.70–1.00) | [1.00–] |
| Extensive                    | Low-intensive | Moderately intensive | Highly intensive | |

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According to the land use efficiency value and land use efficiency classification criteria of various districts and counties in Xi’an from 2007 to 2017, the time variation characteristics of land use efficiency in each district and county of Xi’an were analyzed. Overall, from 2007 to 2017, the average land use efficiency of Xi’an fluctuated with time, with the value decreasing from 0.946 to 0.675 then rising to 0.747, showing U-shaped evolution characteristics, that is, from moderately intensive to low-intensive, then to moderately intensive.

The changes in each district and county are presented in the following types (Figure 3).

1. Highly intensive. From 2007 to 2017, the land use efficiency value of Beilin District was between 1.476 and 1.842, which was stable in a highly intensive state.

2. Moderately intensive. From 2007 to 2017, the land use efficiency value of Gaoling District was between 0.736 and 0.974, and it remained stable in a moderately intensive state.

3. High–medium–low-intensive. High–medium intensive fluctuations were initially observed. The land use efficiency value of Lianhu District was greater than 1 from 2007 to 2009, and it was stable above 0.9 in 2010–2016. It reached 1 or more again in 2017, showing characteristics from highly intensive to moderately intensive, then to highly intensive. The land use efficiency value of Xincheng District was greater than 1 from 2007 to 2009, above 0.9 in 2010–2012, to more than 1 in 2013–2014, and to about 0.7 in 2015–2017, showing characteristics from highly intensive to moderately intensive to highly intensive, then to moderately intensive. Yanta District and Weiyang District presented characteristics from highly intensive to moderately intensive, with 2008 and 2010 as turning points, respectively. Next, high–medium–low-intensive fluctuations were observed. From 2007 to 2013, the land use efficiency of Baqiao District was maintained in a moderately intensive state, which fell to 0.497–0.649 in 2014–2016 and rose to more than 1 in 2017, showing a change in characteristic from moderately intensive to low-intensive, then to highly intensive. Then, medium–low-intensive fluctuations were observed. The land use efficiency value of Yanliang District fluctuated between 0.618 and 0.962 during 2007–2017, showing characteristics from moderately intensive to low-intensive to moderately intensive, then from low-intensive to moderately intensive, and then to low-intensive. The land use efficiency value of Chang’ an District fluctuated between 0.459 and 0.785, showing the characteristics from low-intensive to moderately intensive, then to low-intensive.

4. Intensive–extensive. First, high–medium–low-intensive and extensive fluctuations were observed. The land use efficiency of Lintong District was 1.313 in 2007 and dropped to the lowest value of 0.325 in 2015, showing a change in characteristic from highly intensive to moderately intensive, then to highly intensive, from moderately intensive to extensive, then to low-intensive. Second, high–moderately intensive and extensive fluctuations were observed. The land use efficiency of Huyi District was highest in 2011 at 1.001 and lowest in 2017 at 0.293, showing characteristics from moderately intensive to low-intensive, then from moderately intensive to extensive. Third, medium–low-intensive and extensive fluctuations were observed. The land use efficiency value of Lantian County was 0.740–0.950 in 2007–2011, 0.692–0.570 in 2012–2017, and continued to drop to 0.2 in 2015–2017, showing a continuous decline in characteristics from moderately intensive to low-intensive, then to extensive. Fourth, high–low-intensive and extensive fluctuations were observed. The land use efficiency value of Zhouzhi County was around 0.6 in 2007–2010, rising to 1.317 in 2011. It dropped to around 0.6 again in 2012–2014. It continued to drop to around 0.2 in 2015–2017, showing a change in characteristics from low-intensive to highly intensive, then from low-intensive to extensive.
Figure 3. Characteristics of land use efficiency changes in various districts and counties of Xi’an from 2007 to 2017.
3.1.3. Spatial Evolution Characteristics of Land Use Efficiency

From the annual change index, the land use efficiency values of various districts and counties in Xi’an in 2007–2017 decreased in most of the studied years, with the annual proportion about 60% (Figure 4). The largest increase in land use efficiency was observed in Zhouzhi County, which increased by 0.748 from 2010–2011; the largest reduction was also observed in Zhouzhi County, which decreased by 0.686 from 2011–2012. The lowest annual reduction rate was seen in Lianhu District, accounting for 40%; the higher proportions were in 2009–2010, 2011–2012, and 2014–2015, accounting for more than 80%. Among them, the reduction ratio was as high as 92.31% from 2014 to 2015, and the land use efficiency of the Beilin District alone increased by 0.264. The remaining districts and counties showed decreases.

![Figure 4. Annual change index of land use efficiency in various districts and counties of Xi’an from 2007 to 2017.](image)

From the spatial change index, from 2007 to 2017, except for the land use efficiency of Beilin District (0.366) and Baqiao District (0.374), the remaining districts and counties decreased. Among them, Lintong District (−0.887), Lantian County (−0.547), and Huyi District (−0.546) experienced relatively large decreases (Figure 5).

The land use efficiency of the emerging development areas and urban fringe areas on both sides of the city was relatively high, while the land use efficiency of the traditional old towns and mature built-up areas was relatively low. The relatively high changes were seen in Zhouzhi County (1.993), Lintong District (1.625), Huyi District (1.552), Baqiao District (1.246), and Lantian County (1.059). The relatively low changes were seen in Yanta District (0.464), Lianhu District (0.511), Gaoling District (0.585), and Chang’an District (0.702).

The cumulative value added was relatively low in the traditional old cities and individual urban fringe areas, and the emerging development area was relatively high. The highest added value was in Zhouzhi County (0.814) and the lowest was in Yanta District (0.172). The cumulative reduction value of the mature built-up area was relatively low, and the emerging development areas and urban fringe areas on both sides of the east and west were relatively high. The largest reductions were in Lintong District (−1.256) and the smallest was in Beilin District (−0.249).

In different time periods, the districts and counties with improved land use efficiency in Xi’an had different conditions. Over time, the evolution of the southern fringe area and the emerging development area to the main urban area of the city was demonstrated. From 2007 to 2012, the land use efficiency was mainly due to the increase of the southern fringe area and the emerging development area of the city. The added value of Chang’an District (0.099), Baqiao District (0.070), and Beilin District (0.054) was relatively high. The traditional old city, mature built-up area and eastern fringe area were mainly reduced, and the more reduced areas were Yanliang District (−0.280), Lintong District (−0.276) and Weiyang District (−0.235). From 2012 to 2017, the land use efficiency was mainly increased in the
urban main urban area, and the relatively high added value was in Beilin District (0.312) and Baqiao District (0.304). The outer edge area of the main city was mainly reduced, among which Lintong District (−0.611), Lantian County (−0.491), Huyi District (−0.440), and Zhouzhi County (−0.389) were more relatively reduced.

Figure 5. Spatial change index of land use efficiency in districts and counties of Xi’an from 2007 to 2017.

3.2. Factors Affecting the Temporal and Spatial Changes of Land Use Efficiency from 2007 to 2017

In the previous section, the land use efficiency and its changes in 13 districts and counties of Xi’an were analyzed, but the influencing factors of efficiency change were not revealed. According to the Malmquist index, the change of total factor productivity of land use can be decomposed into changes in technological efficiency and technological progress, and technological efficiency changes can be decomposed into pure technological efficiency changes and scale efficiency changes. The effects of various factors on the change of total factor productivity of land use and their changing trends were studied to reveal the main influencing factors of land use efficiency change in Xi’an.

3.2.1. Factors Affecting Land Use Efficiency Change

In order to more fully reflect the influencing factors of land use efficiency change, this section involves a scatter plot of the relationship between the land use total factor productivity change and the technological efficiency and technological progress changes, and a scatter plot of the relationship between the technical efficiency changes and changes in pure technical efficiency and scale efficiency (Figure 6). The results showed the following:

(1) The change in total factor productivity of land use was affected by the combination of technological efficiency, technological progress, pure technical efficiency, and scale efficiency. The scatter plots of the relationship between total factor productivity change and technical efficiency,
technological progress and technological efficiency changes, pure technical efficiency, and scale efficiency change were only had a few scatter points that were coincident with the 45° diagonal, with the vast majority of points located on either side of the 45° diagonal, showing that the change in total factor productivity was affected by the change in technical efficiency and technological progress, and the change in technical efficiency was affected by the combination of pure technical efficiency and scale efficiency.

(2) The overall technical efficiency of land use was greater than the scale efficiency. Compared with the scatter plot of the relationship between technical efficiency change and scale efficiency change, the scatter plot determined by the technical efficiency change and the pure technical efficiency change had more scatter points located in the upper part of the 45° diagonal, and the degree of deviation from the 45° diagonal was also larger, indicating that the pure technical efficiency had reached an effective state over a longer period of time.

(3) The improvement in technological progress was the main contributor to the growth of total factor productivity of land use in all districts and counties of Xi’an. The low scale efficiency was the main influencing factor of the low land use efficiency. Compared with the scatter plot of the relationship between changes in total factor productivity and changes in technical efficiency, the scatter plot determined by the changes in total factor productivity and changes in technological progress had more scatter points close to the 45° diagonal, indicating that technological progress had a greater impact on the total efficiency than technical efficiency. At the same time, compared with the scatter plot of the relationship between changes in technical efficiency and changes in scale efficiency, the scatter plot determined by changes in the technical efficiency and changes in the scale efficiency had more scatter points close to the 45° diagonal, indicating that the impact of changes in scale efficiency on the change in technical efficiency was stronger than the efficiency of pure technology. In addition to introducing advanced technology and upgrading the technical level, all districts and counties involved in future land management should strictly control the extensive use of new land and strive to improve the scale of land management.

![Figure 6](image_url)

**Figure 6.** Factors affecting land use efficiency change in Xi’an from 2007 to 2017.
3.2.2. Temporal and Spatial Trends of Land Use Efficiency Changes

With the help of Distributed Evolutionary Algorithms in Python (DEAP) 2.1 software, the Malmquist index analysis method was used to calculate the land use technical efficiency, technological progress, pure technical efficiency, scale efficiency, and total factor productivity change indexes in Xi’an from 2007 to 2017, and analyze the annual average and spatial change trends. According to the annual average change index of land use efficiency in Xi’an from 2007 to 2017 (Table 3), it was concluded that:

(1) The total factor production efficiency showed an overall growth trend with a growth rate of 5.7%. From 2007 to 2017, the total factor productivity change index of land use in 13 districts and counties of Xi’an was less than 1 and showed a downward trend in the two periods of 2011–2012 and 2013–2014; the rest of the time period showed values greater than 1, with a mean of 1.057.

(2) Changes in technical efficiency, changes in pure technical efficiency, and changes in scale efficiency affected the increase in the index of change in total factor productivity. However, technological advancement contributed the most to the increase in the total factor productivity change index, and the decline in scale efficiency had the greatest impact on the reduction of the total factor productivity change index. From 2007 to 2017, except for the technological progress changes of the two periods of 2011–2012 and 2012–2013, which were less than 1 and showed a downward trend, the rest of the time period showed values greater than 1, with a mean value of 9.7%. This showed that technological progress was the main factor influencing the growth of total factor productivity of land use in Xi’an. The average technical efficiency change was 0.964, which decreased by 3.6%. The mean technical efficiency change averaged 0.997, which fell by 0.3%. These values imply that the allocation and utilization of resource elements in Xi’an need to be further improved. The average change in scale efficiency decreased by 3.4%. Except for the four time periods of 2010–2011, 2012–2013, 2015–2016, and 2016–2017, the other six years showed a downward trend, indicating that the land use in Xi’an needs to increase the scale effect of agglomeration.

### Table 3. Annual change index of land use efficiency in Xi’an from 2007 to 2017.

| Times     | Technical Efficiency | Technological Progress | Pure Technical Efficiency | Scale Efficiency | Total Factor Productivity |
|-----------|----------------------|------------------------|---------------------------|-----------------|---------------------------|
| 2007–2008 | 0.987                | 1.106                  | 1.016                     | 0.971           | 1.091                     |
| 2008–2009 | 1.002                | 1.044                  | 1.017                     | 0.985           | 1.047                     |
| 2009–2010 | 0.948                | 1.062                  | 0.986                     | 0.961           | 1.007                     |
| 2010–2011 | 1.125                | 1.357                  | 1.023                     | 1.100           | 1.528                     |
| 2011–2012 | 0.889                | 0.871                  | 0.975                     | 0.911           | 0.774                     |
| 2012–2013 | 1.040                | 0.977                  | 1.002                     | 1.038           | 1.016                     |
| 2013–2014 | 0.937                | 1.056                  | 0.973                     | 0.964           | 0.990                     |
| 2014–2015 | 0.680                | 1.586                  | 0.961                     | 0.707           | 1.079                     |
| 2015–2016 | 1.035                | 1.026                  | 0.952                     | 1.088           | 1.062                     |
| 2016–2017 | 1.075                | 1.036                  | 1.072                     | 1.003           | 1.114                     |
| Means     | 0.964                | 1.097                  | 0.997                     | 0.966           | 1.057                     |

According to the spatial change index of land use efficiency in Xi’an from 2007 to 2017 (Table 4), it was concluded that:

(1) Except for the downward trends seen in Lintong District, Lantian County, Zhouzhi County, and Huji District, the index of total factor productivity of land use in the remaining nine districts and counties showed an upward trend. Among them, the increased rates on Yanta District, Gaoling District, Weiyang District, Beilin District, and Lianhu District reached 16.5%, 14.9%, 14.4%, 13.9%, and 12.8%, respectively. The rising rates of Xincheng District, Baqiao District, Chang’an District, and Yanliang District were 6.4%, 3.4%, 3%, and 2.5%, respectively.

(2) The change index of land use technology progress in all districts and counties showed an upward trend. The technical efficiency and scale efficiency change indexes of most districts and counties showed a downward trend, and the pure technical efficiency reached a bottleneck. The
technical efficiency and scale efficiency change indexes of Beilin District and Lianhu District remained unchanged during the study period. Except for the rising trend of Baqiao District (upward rate of 3% and 1.6% respectively), the technical efficiency and scale efficiency change indexes of the other 10 districts and counties showed a downward trend. In terms of pure technical efficiency changes, except for the increases of 1.4% in Baqiao District and 5.2% in Lantian County, the remaining 11 districts and counties remained stable or slightly raised and lowered, indicating that the pure technical efficiency of land use in most districts and counties of Xi’an encountered bottlenecks.

Table 4. Spatial change index of land use efficiency in Xi’an from 2007 to 2017.

| Names   | Technical Efficiency | Technological Progress | Pure Technical Efficiency | Scale Efficiency | Total Factor Productivity |
|---------|----------------------|------------------------|--------------------------|-----------------|--------------------------|
| Xincheng | 0.970                | 1.097                  | 1.000                    | 0.970           | 1.064                    |
| Beilin   | 1.000                | 1.139                  | 1.000                    | 1.000           | 1.139                    |
| Lianhu   | 1.000                | 1.128                  | 1.000                    | 1.000           | 1.128                    |
| Baqiao   | 1.030                | 1.004                  | 1.014                    | 1.016           | 1.034                    |
| Weiyang  | 0.989                | 1.157                  | 0.990                    | 0.999           | 1.144                    |
| Yanta    | 0.990                | 1.177                  | 1.000                    | 0.990           | 1.165                    |
| Yanliang | 0.959                | 1.068                  | 1.000                    | 0.959           | 1.025                    |
| Lintong  | 0.918                | 1.054                  | 1.000                    | 0.918           | 0.968                    |
| Chang’an | 0.998                | 1.031                  | 1.000                    | 0.998           | 1.030                    |
| Lantian  | 0.877                | 1.087                  | 0.948                    | 0.925           | 0.953                    |
| Zhouzhi  | 0.912                | 1.086                  | 1.002                    | 0.910           | 0.990                    |
| Huyi     | 0.900                | 1.096                  | 1.007                    | 0.894           | 0.986                    |
| Gaoling  | 0.997                | 1.152                  | 1.003                    | 0.994           | 1.149                    |
| Means    | 0.964                | 1.097                  | 0.997                    | 0.966           | 1.057                    |

4. Discussion and Conclusion

4.1. Discussion

This paper selected Xi’an, the largest central city in Western China, as the research object, measured the land use efficiency of each district and county in the city from the micro perspective, and analyzed the temporal and spatial change characteristics and main influencing factors of land use efficiency, which not only made up the research content of urban land use efficiency in China’s underdeveloped areas, but also pointed out the improvement of land use efficiency in a single city, a problem that most previous research could not solve from the macro perspective.

In recent years, foreign scholars have paid more attention to the relationship between urban economic development and land use efficiency, showing that the urban land use efficiency in economically developed areas was higher than in economically underdeveloped areas and that the urban land use efficiency in large-scale areas is higher than that in small-scale cities [34,35]. This was basically consistent with the characteristics of urban land-use efficiency in different development stages in different regions of China. In terms of space, urban land use efficiency in China is generally high in the east and low in the central and western regions. In the eastern region, there is a phenomenon of high-value agglomeration, and in the central and western regions, there is a pattern of central periphery [36–38]. The conclusion of this study also showed that the large-scale expansion and sprawl of the city led to changes in urban spatial structure and affected the input scale of all kinds of land, thus affecting the land use efficiency, leading to an imbalance in land use efficiency in different areas of the city. Generally speaking, the land use intensive degrees of the old urban area and the central area of the city were high, while the land use intensive degrees of the new area and the edge area were low.

From the perspective of the temporal and spatial change characteristics of land use efficiency, at present, most of the urban land use efficiency in China, regardless of whether it applied to the eastern economic developed areas or in the western economic underdeveloped areas, showed an overall upward trend, but the trend, cycle, range, and land use level of urban agglomerations and their internal
cities all showed different characteristics; overall, there was one characteristic which decreased firstly and then increased [39–42]. The research results of Xi’an city also proved this conclusion. Regarding the process of urbanization in China, there is a serious problem of land imbalance within the city. Each city should develop reasonable resource allocation and optimization mechanisms to improve efficiency according to its own economic and social development and land use efficiency differences.

In this paper, the land area, the whole social fixed assets investment, and the permanent population were used as the input factors, and the gross regional product and the local fiscal revenue were selected as the output factors to measure the land use efficiency of each district and county in Xi’an city. The results were in good agreement with the economic and social development of each district and county, and the research conclusions were also in good agreement with the law of diminishing land returns in western economics. However, the intensive use of land had certain characteristics in relation to the time period. In the 21st century, we should strive for the unity of economic benefits, ecological benefits, and social benefits in land use. However, due to the difficulties in collecting long-term data in different areas of the city, this paper only selected indicators related to economic and social aspects, mainly focusing on the economic efficiency of land use. In a follow-up study, ecological data should be added to further reveal the temporal and spatial evolution characteristics of the comprehensive efficiency of land use in the city, so as to improve the comprehensive efficiency of land use in the era of stock and lay foundations to formulate comprehensive countermeasures.

4.2. Conclusion

Firstly, the level of land use efficiency directly reflected the intensive level of urban land use. From the perspective of space, there were differences between urban land use efficiency areas because of the differences in natural, economic, and social conditions. As the largest central city in Western China, the overall land use efficiency of Xi’an and its districts and counties reflected the intensive level of land use in the underdeveloped areas of Western China. The average land use efficiency of Xi’an city was 0.855, which was in the moderately intensive level as a whole. The average land use efficiency of 13 districts and counties had a large gap, indicating that most districts and counties need to be strengthened. Generally speaking, the land use efficiency of traditional old urban areas in the city center and mature built-up areas in the north was relatively high, while the land use efficiency of emerging expansion areas and marginal areas in the south was relatively low.

Secondly, the intensive use of land was the inevitable trend of urban social and economic development. From the time sequence, urban land use generally experienced a dynamic process of extensive, intensive, scale intensive, and then extensive periods relative to time, and may continue to improve with the progress of economy, society, science, and technology. In different stages of development, different policies should be made and resource allocation should be optimized according to the development needs of different regions and the differences in economic and social development conditions. Therefore, land use efficiency showed different spatial characteristics in different time periods. In the past 10 years, the overall land use efficiency of Xi’an city presented U-shaped evolution characteristics from moderately intensive to low-intensive, then back to moderately intensive. The changes of 13 districts and counties formed four types, namely, highly intensive, moderately intensive, high–moderate–low-intensive and intensive–extensive. As far as the change range is concerned, the land use efficiency of the new development and marginal zones was larger, while that of the traditional old urban areas and mature built-up zones was smaller. From 2007 to 2012, the urban land use efficiency mainly increased in the southern edge of the city and the emerging expansion area, while the traditional old urban area, the mature built-up area, and the eastern edge area decreased. From 2012 to 2017, the land use efficiency in the main urban area mainly improved, while that outside the main urban area mainly decreased.

Thirdly, the change in total factor productivity of land use was affected by changes in technological efficiency, technological progress, pure technological efficiency, and scale efficiency. During the research period, the improvement in technological progress was the main contributing factor to the total factor
productivity growth of land use in Xi’an City, and the low scale efficiency was the main influencing factor on the low efficiency of land use. In most districts and counties, the total factor production efficiency and technological progress change index of land use showed an overall growth trend, the technological efficiency and scale efficiency change index showed a downward trend, and the pure technological efficiency reached a bottleneck. In the future, in addition to the introduction of advanced technology, we should strictly control the extensive use of new land and strive to improve the scale of land management.

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