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Land Use Scenario Simulation under the Ecological Restriction: A Case Study of Zhengzhou-kaifeng Metropolitan Area in China

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Abstract: Amid China's effort to push forward urbanization, the ecological space is largely occupied, and thus the regional ecosystem service is on a worsening and declining trajectory, putting the regional ecological security in danger. In this connection, how to optimize the land resources utilization holds the key to land use planning. Against this background, this study focused on the comprehensive index, namely index on water security, biodiversity conversation and natural recreation, in Zhengzhou-kaifeng metropolitan area, and identified ecological significance. Given ecologically important land as constraints, MCE (Multi Criteria Evaluation) and CA-MARKOV model were employed to simulate how the land use pattern would evolve in the scenarios of natural development and ecological priority in 2019. The findings showed that ecologically important lands occupied 553.77km2, and accounted for 18.49% of the total Zhengzhou-kaifeng metropolitan area while, in the context of ecological priority and natural development, new construction lands occupied 0km2 and 16.64 km2 of the ecologically important lands respectively. Thus, against the backdrop of ecological priority, the ecologically important lands were well-protected while the landscapes tended to be fragmented.

Keywords: *GLand use, Ecological significance, Ecological constraint, CA-MARKOV model, Zhengzhou-kaifeng metropolitan area*

1. Introduction

As China now pursues economic boom and urbanization, cities sprawl with expanding land use and speedy traffic network constructions, taking up massive ecological spaces. As a result, the regional ecosystem service deteriorates and directly endangers the regional ecological security. Ecological significance means how important ecosystems or land spaces are to the regional ecosystem's service. Therefore, to evaluate the ecological significance aims to identify ecological infrastructure's role in keeping the regional land safe and sound. Then, the essay concluded that ecological infrastructure served as the hard-and-fast limits for the land development and expansion, a basic guarantee to sustain the ecosystem service and a vital way to balance the development and protection [1]. Among all evaluation methods about ecological significance, the comprehensive evaluation method based on GIS is widely used. Nowadays, it is most popular with the current land-use study to focus on how to keep the steward of ecological security and land use in balance and how to integrate ecological constraint conditions with the optimal simulation of land use pattern, which becomes much easier thanks to the application of the model. The common models include system dynamics model [2], CA model [3, 4], multi-agent system [5] and driving model (such as CLUE-S model [6]). Based on the existing research results [1,7,8], this article first opted for Zhengzhou-kaifeng metropolitan area as the case study area on the ground these cities registered the fastest economic growth yet the most vulnerable ecosystem. Then, the evaluation on the ecological importance was conducted from the perspective of ecosystem service function and regional importance. Beyond that, based on CA-MARKOV model, the results of evaluation on the ecological significance were regarded as the ecological constraint conditions, and then had an optimized simulation on the future land use pattern in the case-study area. In this connection, this study tended to provide the technological support and decision-making reference for land-use and urban planning in areas featuring ecological priority.

2. Study area

The territory of Zhengzhou-kaifeng metropolitan area, at the central-north part of Henan province, lies between latitudes 34°26' N and 34°58' N, and longitudes 113°26' E and 114°30' E along the southern shore of lower reaches of Yellow River, covering a total area of 2994.76km^2. The area is mainly featured by plains with the south-west part high and the north-eastern low while its climate is dominated by temperate continental monsoon with abundant hydrothermal resources and outstanding location advantages. Zhengzhou-kaifeng metropolitan area in this study include Zhengzhou city (yet excluding Shangjie District in Zhengzhou city in a bid to keep the studied-area continuous), and the downtown in Kaifeng city and Zhongmu county. Thanks to the speedy socioeconomic growth, these picked cities will represent the overriding growth pole and pilot area for reform and development. More than that, Zhengzhou-kaifeng new area, part of the studied regions, would be home to the largest industrial agglomeration and modern-complex new district in the central-western China. Additionally, this new area, a would-be environment-friendly and livable service center, would be built into a pilot site for balancing rural and urban reform and development. More importantly, the efforts to push forward the construction of "five districts and one center" would further speed up the development of Zhengzhou-kaifeng metropolitan area and make these cities integrated more quickly. Therefore, it can be predicted that great changes would be brought to the landscape ecology and land use. The detailed location of Zhengzhou-kaifeng metropolitan area can refer to Figure 1.

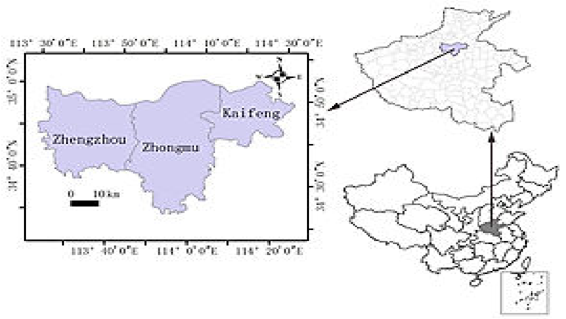

Figure 1:*Location of Zhengzhou-kaifeng metropolitan area*

3. Data Sources and Processing

In the study, the cognition software was employed for further interpretation on the second-phase ETM remote-sensing images with 30m resolution in 2009 and 2014. Besides, based on the Category of Land Use(GB/T 21010-2007), the land use in Zhengzhou Kaifengmetropolitan area could fall into construction land (urban construction land, rural residential land), cultivated land (irrigated land, paddy field, dry land), woodland, waters (river, reservoir, pond) and beach. In addition, the DEM data with 30m resolution from the applied environment center of the Chinese academy of sciences were used to generate the gradient information. Other data mainly sourced from statistical yearbook in related cities, Zhengzhou-kaifeng new city master plan (2009-2020), Kaifeng city master plan (2008-2020), Zhengzhou city master plan (2010-2020), the master plan for general land use from relevant cities (2006-2020), etc.

4. Methodology

4.1 Water Security importance (WSI)

Water security, from the perspective of the whole valley in Zhengzhou-kaifeng metropolitan area, setting aside wetlands and river buffer to regulate, stagnant and store flood, and giving flood the space to unleash itself [9].The evaluation on the significance of water security picked up the surface water security, the type of flood storage and the importance of water conservation to have a comprehensive assessment on the water security in the studied area[1]. To make it more specific, the surface water security was based on the river and lake distribution map, and was selected through the distance analysis from the ARCGIS 10.0 software. Then, as for the type of flood storage, the area within the Yellow River levee was picked up as the center of flood storage on the grounds that the Yellow River beach has played a constructive role in stagnating and preventing flood and protecting the dam [10]. Beyond that, this flood storage center also included flood detention areas such as Hou Sun and Miao Hou Ma in zhongmu county; lastly, the index of the importance of water conservation were finalized in accordance with the land use type in the studied area in reference to the ecosystem service system of XIE Gaodi [11]. At the end, water security importance index value was obtained through the extraction operation on the superposition of grid to calculate the maximum surface water security on each grid.

Table 1: *Evaluation Factors and Classification Criterion of Water Resource Security Importance*

Factors	Extremely important	Moderately important	Generally important	Not important
Grading assignment	4	3	2	1
Flood regulation and storage areas	core areas	buffer areas	peripheral areas	Other areas
Surface water security(Distance to a river or a lake)	≤50m	50-100m	100-150m	≥150m
Water conservation	water	woodland	cultivated land	Other lands

4.2 Biodiversity conservation importance (BCI)

Biodiversity protection means a way to identify the key process and the spatial pattern of biodiversity protection regionally and landscape-wise, thus keeping the habitats and ecosystem sound and integrated[12]. Generally, the well-functioned ecosystem biodiversity can offer an enabling biological habitat conditions because, according to researches available, the habitat types (mosaics) and size would have a certain effect on biodiversity [13]. Therefore, this research adopted the ecological function areas and biodiversity service value equivalent double factors to make the evaluation. Here, the ecological function area meant the minimum standard area to keep its biodiversity and was categorized on the basis of many iterations topology analysis [14,15] (detailed in Table 2) while the biodiversity service equivalent was decided upon the finalized China's biodiversity service value equivalent [11]. Biodiversity conservation importance index calculation formula was defined as:

$BCI=n_i \times m$(1)

In this formula: BCI meant importance index for biodiversity protection, ni meant ecosystem services equivalent corresponding to the land use type, m meant revised protection level, including 1.5 as modified ecological function areas index , 1 as non-ecological function areas. The formula (1) calculated the biodiversity conservation importance index of each grid, and, based on natural fracture method, divided the level into extremely important, moderately important, generally important and not important, assigning levels with 4, 3, 2, 1 respectively. The method also employed the cut-off point from optimization method of statistical jenk , which made it possible for the internal sum of the variance at all levels to be the most minimum.

Table2: *Classification criterion to identify the ecological functional areas*

Code	Land use types	Size(ha)
C1	Paddy land	≥50
C2	Natural wetland	≥50
C3	Irrigated and Dry cultivated land	≥50
C4	woodland	≥25
C5	mosaic of cultivated land and woodland	≥25
C6	mosaic of Paddy field and natural wetland	≥30
C7	Irrigated and Dry cultivated land, woodland, paddy yield and natural wetland	≥30

4.3 Natural recreation importance (NRI)

The recreation from the nature means the residents' enjoyment and active engagement in nature. In this study, the importance of recreation from the nature meant those natural landscape and land space which played a critical role in enhancing people's recreational experience and mainly include scenic spots, forest parks, agricultural parks and its ecological spaces with possibility to be livable [16]. By and large, the more recreational and more cultural the area's ecosystem is, the better this area is to serve residents. Besides, the recreation and culture value of equivalent for different land use types were finalized in accordance with the land use type in reference to the recreation and culture value of equivalent of XIE Gaodi[11]. Then according to the level of recreation, specific calculation formula was as follows:

$NRI=n_i \times m$(2)

In this formula: NRI meant importance index for natural recreation, n_i meant ecosystem services equivalent corresponding to land use type, *m* meant revised recreational level, including 1.5 as the Yellow River scenic area, 1.4 as the forest park, 1.3 as the scenery tourist area, 1.2 as relics park, 1 as other areas. The classification method was tantamount to BCI (Biodiversity conservation importance).

4.4 Ecological importance index (EI)

The above-mentioned single factors of ecological importance index could only reflect the importance of a single factor. After getting the maximum from the superposition of the importance of evaluation diagram, the composite index of the ecological importance of each grid would be obtained in the following formula:

$EI=max(WSI, BCI,NRI)$(3)

In the formula: EI meant the composite index of the ecological importance; WSI meant importance index for water security; BCI meant biodiversity conversation index; and NRI meant natural recreation index.

4.5 The ecological importance of land use spatial structural identification:

The identification of spatial structure of ecological importance was based on the evaluation on ecological importance. In accordance with the composite index of ecological importance, the ecological importance of land use in the studied area could be divided into four levels, namely extremely important, moderately important, generally important and not important. Among four levels, the extremely important land-use area was critical to the ecosystem service function.

CA-Markov model consists of Markov chain, multi-criteria evaluation and CA[17,18]. To be specific, Markov chain is used to generate transition probability and the transferred areas' matrix of each type of land use; MCE general constraint conditions and influencing factors create the suitability diagram of land use transfer. CA-Markov model of operation can be done by IDRISI software while this paper adopted IDRISI 17.0[19]. The basic steps of this model were as follows:

(1) Scenario setting. This study set two scenarios, namely the ecological priority and the natural development. Ecological priority scenario assumed the preference to safeguard key land-use space with important ecosystem services. Then, based on the evaluation on ecological importance, the extremely important land-use space would be regarded as the ecological constraint conditions, and be integrated into the simulation on how the land use would be impacted naturally, socially and culturally in 2019. The difference between these two scenarios was whether ecological constraint conditions were taken into consideration.

(2) Convert the data. Under the auspices of ArcGIS10.0 software, the land use maps in 2009 and 2014 could be converted into IDRISI- supporting RST format.

(3) Create the transfer matrix of land use. CA-MARKOV transition probability matrix and the

transferred areas' matrix could be obtained by superposition of land use maps in 2009 and 2014 through MARKOV module in IDRISI.

(4) Create the suitability diagram for each type of land's conversion [20]. This study adopted fuzzy membership functions from the multi-criteria evaluation (MCE) to specify the suitability and location of Conversion pixel. Based on MCE (multi-criteria evaluation) module in IDRISI 17.0, the suitability diagram for each type of land's conversion was gained through the weighted linear combination of constraining conditions and influencing factors.

1) Take the construction land under the context of ecological priority as an example; the following steps were needed to obtain this suitability diagram: first, specifying the constraint conditions and influencing factors. The constraint conditions were essential to the evaluation on the ecological significance while influencing factors include slope distance, the distance to traffic trunks, the distance to towns and the distance to river reservoirs and the spatial classification of ecological importance. Secondly, the standardization of suitability. Limiting factors used a boolean (0 and 1) to represent its suitability, in which 0 meant unsuitability (restricted areas, namely areas that would have no conversion), and 1 meant suitability (namely areas that were open to conversion). The allocation of the boolean value depended on the ASSIGN modules in IDRISI 17.0. In this IDRISI 17.0 software, 0-255 were used to represent the standardization of suitability of influencing factors, in which 0 meant the least suitable, and 255 meant the most suitable.

2) IDRISI software used FUZZY module to standardize the suitability of influencing factors. For instance, the general idea is that the nearer to the traffic trunk, the more suitable for construction land. Thus, J-shaped curve which showed that longer distance to the traffic trunk would decrease the suitability was used to have this standardization. For the rest of influencing factors, Sigmoidal curve (water distance), Linear curve (slope, distance to towns and the classification of ecological importance) were employed to have the standardization of suitability. Thirdly, to make the suitability diagram. The suitability diagram of construction land would be gained through the weighted linear combination of influencing and limiting factors with the use of MCE module of IDRISI 17.0. Following the above-mentioned steps, the suitability diagram of conversion for other types of land was obtained. Finally, the suitability diagrams of conversion for all types of land were gained through the collection editor in Zhengzhou-kaifeng metropolitan area.

(5) Land use scenario simulation. CA-MARKOV module in IDRISI 17.0 was loaded to simulate different land-use spatial distribution under two different scenarios of natural development and ecological priority. The CA iterations were set at 5, with 5×5 neighboring filter. That meant 5×5 matrix space composed of original cell around each center would have significant effect on the state of the original cell.

5 Results

5.1 The spatial structure identification of ecological importance

ArcGIS 10.0 software was used for the single factor of ecological importance and comprehensive spatial structure identification with the specified results shown in Figure 2 and Table 3.

From table 3, the area rated as the extremely-important one in terms of water security covers 439.84km2, accounting for 14.69% of the total studied area. The extremely-important water security area is quite essential to flood storage and hydrology regulation. As to biodiversity protection, the area rated as the extremely-important one covers 208.57 km2, accounting for 14.69% of the total studied area. In regard to recreation from the nature, the area rated as the extremely-important one covers 101.99 km2, accounting for 3.41% of the total studied area. As to ecological importance, the area rated as the extremely-important one covers 553.77 km2, account for 18.49% of the total studied area, while the area rated as the important one covers 272.11 km2, account for 9.09%. Thus, these extremely-important land-use spaces played a critical role in safeguarding regional ecosystem service and ecological security, and needed to be integrated into off-limits for developers. Thus, the most strictly protective measures should be adopted.

Table 3: *Space recognition results of ecological factors and comprehensive importance*

Factors	Classification	Area/km^2	Proportion /%
Water security	Not important	723.40	24.16%
	Generally important	1471.29	49.13%
	Moderately important	360.23	12.03%
	Extremely important	439.84	14.69%
Biodiversityc onservation	Not important	964.76	32.21%
	Generally important	1677.64	56.02%
	Moderately important	144.33	4.82%
	Extremely important	208.57	6.96%
Natural recreation	Not important	2638.64	88.11%
	Generally important	238.38	7.96%
	Moderately important	15.75	0.53%
	Extremely important	101.99	3.41%
Ecological importance	Not important	723.40	24.16%
	Generally important	1445.48	48.27%
	Moderately important	272.11	9.09%
	Extremely important	553.77	18.49%

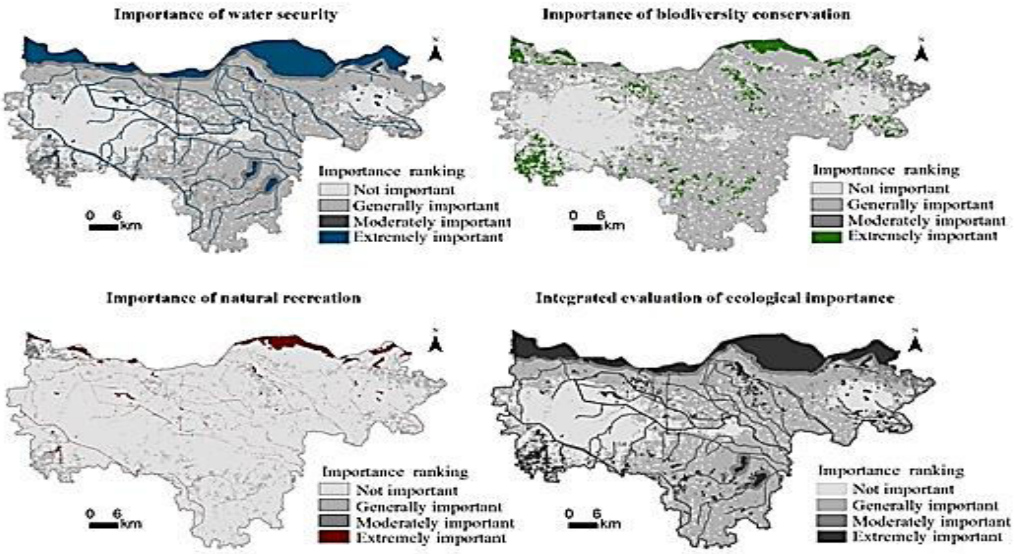

Figure 2: Results of evaluation of ecological importance in Zhengzhou-Kaifeng metropolitan area

5.2 Land use simulation scenario

5.2.1 The accuracy verification of land use simulation

The land-use graph obtained by remote sensing in 2009 was regarded as the initial state of land use while the land graph in 2014 was the final state. The MARKOV module was used to obtain the transfer matrix of land use from 2009 to 2014, and then to generate the suitability diagram for all types of land in 2009. Furthermore, CA-MARKOV model was employed to simulate the land use in 2014. Then, making the comparison between the simulation results of land use in 2014 and land-use graph by remote sensing in 2014, Kappa coefficient was 0.82, meaning a high-level consistency.

5.2.2 Comparing land-use simulation results under two different scenarios

The land-use diagram by remote sensing in 2014 was regarded as the initial state of land use. Then, the land-use transition probability matrix from 2009 to 2014 was the transfer matrix to simulate the land use under two different scenarios of natural development and ecological priority with the results shown in Figure 3.

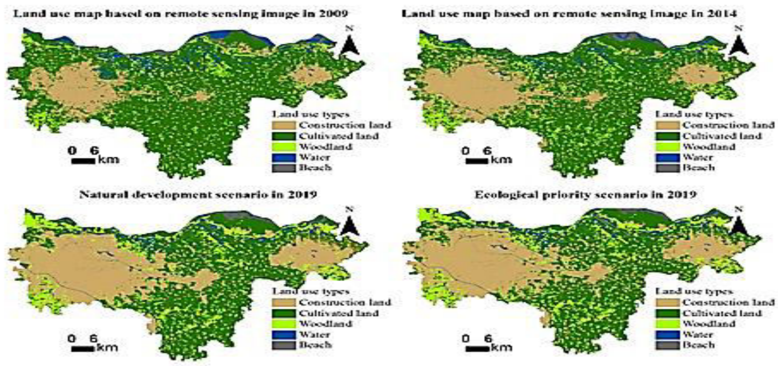

Figure 3: Land use maps based on remote sensing images and simulation results of Zhengzhou-Kaifeng Metropolitan area in 2019 under different scenarios

Under two scenarios, ecological importance at all levels taken by new construction lands is demonstrated in Table 4. Ecological priority highlights the protection of extremely-important ecological space. In detail, the new construction lands covered 0 km2 of the total extremely-important land-use area while the natural development footprints accounted for 16.64km2. Under the context of ecological priority, the occupied secondary-important ecological space decreased 5.09km2 while the occupied important land space increased 21.73km2 in comparison with natural development.

Consequentially, it could be concluded that the new construction lands occupied the extremely-important ecological lands, thus effectively protecting the ecological space.

In a bid to further compare the landscape pattern under two scenarios, the number of patches (NP), contagion (CONTAG), aggregation index (AI), Shannon diversity index (SHDI) among other landscape index were selected to have the evaluation[21,22]. In detail, CONTAG index meant the extending trend of different types of patches in landscape. Secondly, aggregation index (AI) reflected how nonrandom and aggregated different patches were in landscape. Finally, Shannon diversity index (SHDI) reflected the landscape heterogeneity. The results as shown in table 4 told us that in comparison with natural development, the number of patches (NP) was on increase while the landscape tended to be more fragmented under the context of ecological priority. Possibly, the expansion of construction land refrained from the ecological extremely-important land-use space, thus tending to be more fragmented. Against the backdrop of these two scenarios, SHDI remained consistent due to the equal spaces for all types of land use. On the other hand, the fact that CONTAG and AI were on decrease meant that patches tended to be more fragmented under the ecological priority, which did with the fragmented expansion of construction land.

Table 4:*Ecological space protection effect under the two scenarios in 2019*

Items	Evaluation indexes	2019	
		Natural development scenario/km^2	Ecological priority scenario/km^2
New construction land footprints	Extremely important	16.64	0
	Moderately important	19.23	14.14
	Generally important	297.43	319.16
	Not important	0	0
Landscape pattern	NP (Number of patches)	5688	6320
	CONTAG	55.8699	55.5892
	AI (Aggregation index)	94.5679	94.3168
	SHDI (Shannon's diversity index)	1.1618	1.1618

6. Conclusion

Based on the evaluation of ecological importance, this study set up natural development and ecological priority scenarios, and built up CA-MARKOV model featuring the development of land-use pattern in Zhengzhou-kaifeng area, and simulated how the land-use pattern would evolve in 2019 in different scenarios with the following major conclusions:

1. The evaluation on the ecological importance in Zhengzhou-kaifeng metropolitan area concluded that the extremely- important land-use spaces covered 553.77km2, accounting for 18.49% of the total area. These extremely-important land-use spaces played a critical role in safeguarding regional ecosystem service and ecological security, and needed to be integrated into off-limits for developers. Thus, the most strictly protective measures should be adopted.
2. The land-use simulation results for 2019 Zhengzhou-kaifeng metropolitan area displayed that under the context of ecological priority, the extremely-important and moderately-important land-use spaces occupied by the new construction lands covered 0 km2 and 14.14 km2 respectively. On the other hand, against the background of natural development, the extremely important and moderately important land-use spaces occupied by the new construction lands covered16.64 km2 and 19.23 km2respectively. Thus, in comparison, the extremely-important ecological space was well-protected.
3. Thanks to the limits from key ecological spaces, the expansion of construction land tended to be more fragmented under the scenario of ecological priority whereas NP, AI and CONTAG of landscape were onincrease which showed landscapes tended to be more fragmented under the scenario of natural development.

As the metropolitan areas speed up its urbanization, man-made factors, especially decision-making governments, will transform the land use down the road.

The next priority for the study is that a land-use evolution model balancing natural, man-made and social roles will be in place if individual or governmental decision-making activities can be combined with the CA-MARKOV model.

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