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The Influence of Land Use Change on Ecological Carrying Capacity in Wuhan Urban Agglomeration

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Abstract. Obtaining the land use change and ecological carrying capacity change accurately and understanding the specific impact of land use change on biocapacity is of great significance for sustainable development. This study analyzed the influence of land use change on ecological carrying capacity, aimed at providing technical support for regional development planning. Land use change models are adopted to evaluate the dynamic change of land use in Wuhan Urban Agglomeration from 2000 to 2015, whose land use information is extracted from Landsat images. Ecological carrying capacity is calculated with 4 driving factors. The obtained results indicate that the trend of land use degree change is consistent with that of ecological carrying capacity. The relative change rates of different land use types in different cities also affect their biocapacity. We can effectively use the ecological resources, but the demand of human's development for resources is also growing rapidly.

Introduction

People live in a complex Earth System with human-environment interaction, and their all activities are dependent on nature. This ecological principle means that if the mankind wants to develop sustainably, they must live within the carrying capacity of nature[1]. Studies on the ecological carrying capacity as one of the core tools for measuring the sustainable development, has been attention of scholars both at home and abroad. The ecological footprint model proposed by Canadian scholar Mathis Wackernagel[2] is a widely used method. It evaluates a region's sustainable development by measuring the gap between people's demand for natural ecological service and the service that nature can provide.

In the ecological footprint model, the key factors are land use types, population, equivalence factors and yield factors, and the land use type is the main driving factor. At present, most of the land use information data, used to calculate biocapacity, comes from the administrative regions' statistical data, with lagging time, deficient data, low accuracy and spatial scales difficult to unify. In recent years, remote sensing technology has become an important way to obtain accurate and timely information. Some studies used high-resolution images to evaluate the impact of land use change on ecological carrying capacity. Peng Zi et al.[3] used remote sensing data to analyze the impact of land use change on biocapacity in the Dongjiang watershed from 1989 to 2009. However, they focused on the comparisons of the upper, middle and lower reaches while the dynamic change model is relatively simple. Gukangkang et al.[4] gave more consideration to the characteristics of coal-based cities when analyzing the ecological carrying capacity of Huainan City and introduced the index of socio-economic system development for amendment.

In 2002, Wuhan, Huangshi and other cities jointly held the Economic Cooperation and Coordination Forum for Wuhan and the Surrounding Cities. At the end of 2007, the State Council approved the Wuhan City Circle to be a state comprehensive supporting reforms pilot area for building a resource-efficient and environment-friendly society[5]. Wuhan Urban Agglomeration experienced rapid population growth, urban expansion and socioeconomic development in recent decades and the land use situation has undergone drastic changes[6]. This study took Wuhan Urban Agglomeration as the research object, took advantage of the land use information extracted from Landsat images, and studied the dynamic changes of land use types in Wuhan Urban Agglomeration from 2000 to 2015. Further evaluate the impacts of land use change on biocapacity, aimed at providing theoretical and technical support for regional development planning.

Study Area

Wuhan Urban Agglomeration is a regional economic association composed of Wuhan, Huangshi, Ezhou, Xiaogan, Huanggang, Xianning, Xiantao, Tianmen and Qianjiang. The area is located in eastern Hubei Province and the middle reaches of the Yangtze River. Affected by the subtropical monsoon climate, there are adequate light, plentiful precipitation and desirable hydrothermal conditions. The excellent natural environment establishes the foundation for the economic and social development. Since its establishment, the urbanization has been getting faster and faster. The economy grows at an annual rate of 15.56% and GDP amounted to 2.01 trillion yuan in 2016.

Study Method

Data. Cloudless Landsat images of Wuhan City Circle in 2000, 2005, 2010 and 2015 were obtained from Geospatial Data Cloud site. The data of each year include 7 images, the imaging time is autumn and the spatial resolution is 30m. In addition, we performed atmospheric and geometric correction on the data and collected Wuhan Urban Agglomeration boundary vector data and socio-economic data.

Land Use Classification and Image Processing. The land use are divided into five types: forest, primary cropland, water, build-up land and unused land. After mosaicking and cropping the remote sensing images, the classifier choose the maximum likelihood. Finally, the confusion matrix is used to evaluate the accuracy. The classification accuracy of each years is above 90%, and the Kappa coefficients is greater than 0.85. The thematic map is as shown in Fig. 1.

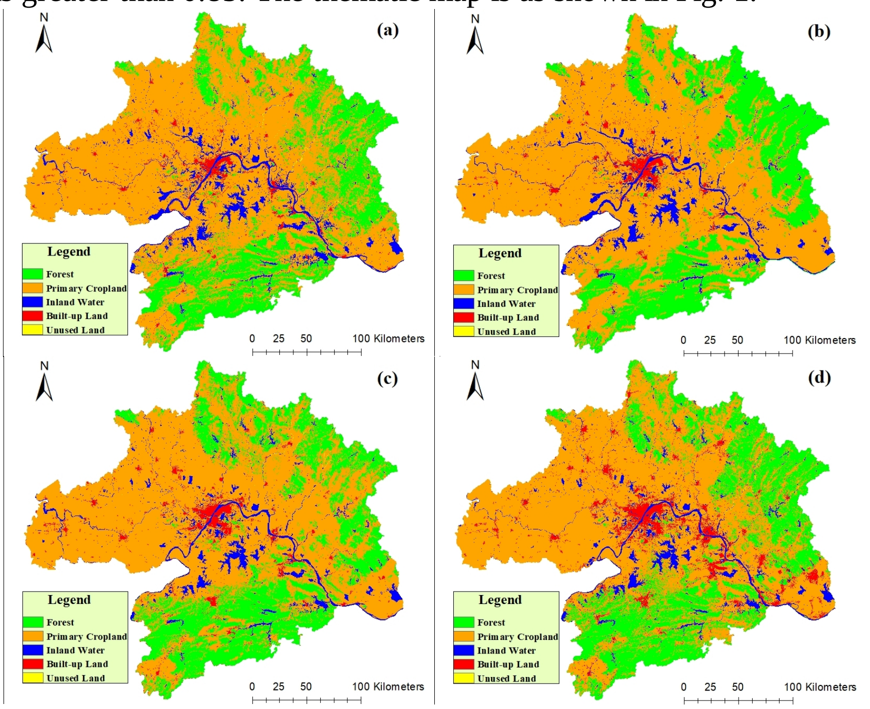

Fig. 1 Land Use Classification of Wuhan Urban Agglomeration (a:2000, b:2005, c:2010, d:2015)

Dynamic Changes of Land Use. The measurement models of land use degree change and the regional differences are as follows to reflect the land use change in the study area.

Land Use Degree Change Model. The land use degree mainly reflects the breadth and depth of land use. Liu Jiyuan et al.[7] proposed the grading standard of land use degree under ecological consideration, and divided it into four levels (Table 1).

Table 1 Land Resource Utilization Type Hierarchy

Types	Unused land level	Forest, grass and water level	Agricultural land level	Urban settlement level
Land use type	Unused or hard to use	Forest, grass and water	Cropland, garden and artificial grassland	Towns, settlements, mining land and transport land
Classification index	1	2	3	4

The land use change variation and rate within a certain period in a certain area can be expressed as:

$$\Delta L_{b\text{-}a} = L_b - L_a = 100 \times \left(\sum_{i=1}^{n} A_i \times C_{ib} - \sum_{i=1}^{n} A_i \times C_{ia} \right) \tag{1}$$

$$R_c = \frac{\sum_{i=1}^{n} \left(A_i \times C_{ib} \right) - \sum_{i=1}^{n} \left(A_i \times C_{ia} \right)}{\sum_{i=1}^{n} \left(A_i \times C_{ia} \right)} \tag{2}$$

In the Eq. 1 and Eq. 2, $\Delta L_{b\text{-}a}$ is the comprehensive index of land use degree during the study period; R_c is the change rate of land use degree; L_b and L_a are comprehensive indexes of land use degree at time ***b*** and time ***a***; A_i is the grade index of *i*th level land use degree; C_{ib} and C_{ia} are the area percentage of *i*th level land use degree at time b and time a. If $\Delta L_{b\text{-}a} > 0$ or $R_c > 0$, the land use of the study area is in the development period, otherwise it is in the adjustment period or the recession period.

Regional Difference of Land Use Change Model. There are significant regional differences in land use change. The relative change rate of some land use types in each region can be used to reflect the change of regional difference of land use change. A particular type's relative change rate of land use in a certain region within a certain study period can be expressed as:

$$R_r = \left(\frac{K_b}{K_a} \right) \div \left(\frac{C_b}{C_a} \right) \tag{3}$$

In the Eq. 3, Rr is the relative variational rate in a certain region within a certain study period; K*a* and K***b*** represent the area of a particular land use type in a certain region within the study area at the beginning of the study period and the end; C*a* and C***b*** represent the area of the whole study area at the beginning of the study period and the end. If the relative variational rate of a particular type in a certain region is greater than 1, it indicates that the land use type change in this region is larger than that in the whole research area.

Ecological Carrying Capacity. Biocapacity refers to the maximum of ecological productive land under certain natural environment and social economy. When calculating ecological carrying capacity, yield factors and equivalence factors are used for adjustment, so that different types of productive land are converted into the land with the same productivity[8]. This paper uses the ecological footprint method to measure the ecological carrying capacity:

$$\mathrm{EC} = N \times ec \tag{4}$$

$$\mathrm{ec} = \sum_{i=1}^{n} S_i \times R_i \times Y_i \tag{5}$$

In the Eq. 4 and Eq .5, EC is the total ecological carrying capacity; ec is the carrying capacity per capita; S_i is the area of ecologically productive land actually owned by the per capita; R_i is the equivalence factor that converts the area of different land-use types into the equivalent area under the average world biological productivity according to their average world yield; Y_i is the yield factor, which is the ratio of the national average output to the world average output.

The equivalence factors used in this study are given in "National Footprint Accounts Methodology 2008"[9], which are 1.33 for forest, 2.64 for primary cropland, 0.4 for water and 2.64 for build-up land. The yield factors used the Chinese value measured by Liu Moucheng et al[10]. The value of the factors are 0.86 for forest, 1.74 for primary cropland, 0.74 for water and 1.74 for build-up land. Unused land's factors are zero.

Results and Analysis

Evaluation of Dynamic Changes of Land Use. According to the classification results in Wuhan Urban Agglomeration (Table 2), primary cropland and forest are the main land use types, followed by water, build-up land and unused land. Cropland, as the most important land use type, accounted for more than two-thirds of the total area, but both the proportion and the area from 2000 to 2015 showed a downward trend. The total area of forest increased during 2005-2010. The area of water decreased significantly from 2000 to 2010 and remained stable by 2015. The area of build-up land increased slightly in the first ten years and the proportion remained stable with a sharp increase in expansion from 2010 to 2015. The unused land is gradually decreasing, especially from 2000 to 2010.

Table 2 Wuhan Urban Agglomeration's Land Use Area [hm^2] of Each Types

Year	Forest	Primary Cropland	Inland Water	Built-up Land	Unused Land
2000	1328116.95	4009218.84	340390.26	126189.00	8003.34
2005	1393962.75	3967702.65	322861.41	126628.83	5704.74
2010	1514901.96	3855358.44	279134.73	162275.94	3906.81
2015	1501535.43	3701525.76	278330.04	327303.09	3839.31

Land Use Degree Change. The range of comprehensive index of land use degree is 100-400. According to the classification, the comprehensive index of Wuhan urban agglomeration are 273.19 in 2000, 272.4 in 2005, 271.84 in 2010 and 274.88 in 2015. The land use degree from 2000 to 2015 are all above 270, in an intermediate level.

According to the land use change data from 2000 to 2015 in Wuhan Urban Agglomeration (as shown in Table 3), the change variation of land use degree and the change rate from 2000 to 2005 and from 2005 to 2010 are all less than 0, indicating that land was in the adjustment or recession period. From 2010 to 2015, the change variation and rate in the study area are all greater than 0, indicating that the land use in the five years was in a period of development. However, the change variation and rate from 2000 to 2015 are both greater than 0, which highlights the rapid development of land use and the improvement of land use level from 2010 to 2015. Generally speaking, land use in Wuhan Urban Agglomeration is in a development period.

Table 3 Wuhan Urban Agglomeration's Change Variation and Rate of Land Use Degree

Change time	2000-2005	2005-2010	2010-2015	2000-2015
Change variation of land use degree	-0.72	-1.79	4.09	1.57
Change rate of land use degree	-0. 26%	-0. 66%	1.51%	0. 58%

Regional Difference of Land Use Change. Wuhan City Circle contains 9 cities, of which Wuhan is the center city, and Huangshi is the sub-center. According to the relative land use change rate as shown in Fig. 2, the forest in Wuhan varied greatly from that in the whole area from 2000 to 2015. Unused land changed least and the other stabled at the average level. Huangshi, the fourth largest city in Hubei Province, has 1.12% of the total cultivated land in the province. From 2000 to 2015, the relative change rate of cropland is located in the upper reaches of the entire area. Unused land basically unchanged and the other were around the average.

By implementing the strategy of "one zone and two belts", Huanggang endeavors to build a modern manufacturing base. Its overall land use has relatively changed greatly, especially for build-up land. Due to the small area of Ezhou, the change rates of land use except unused land are high, especially for forest and build-up land. Xianning and Xiaogan's land use except unused land are maintained at an average level.

The land use type in Tianmen and Xiantao which changes obviously relative to the entire city is unused land, followed by cropland. Qianjiang, the smallest city in the study area, has the most obvious type change. The area of forest increased sharply from 2005 to 2010. Cropland was kept at an average level. The decrease of water was alleviated from 2005 to 2010 and area reduced to a minimum from 2010 to 2015. The build-up land increased significantly from 2005 to 2010, and then remained unchanged. Unused area is very small.

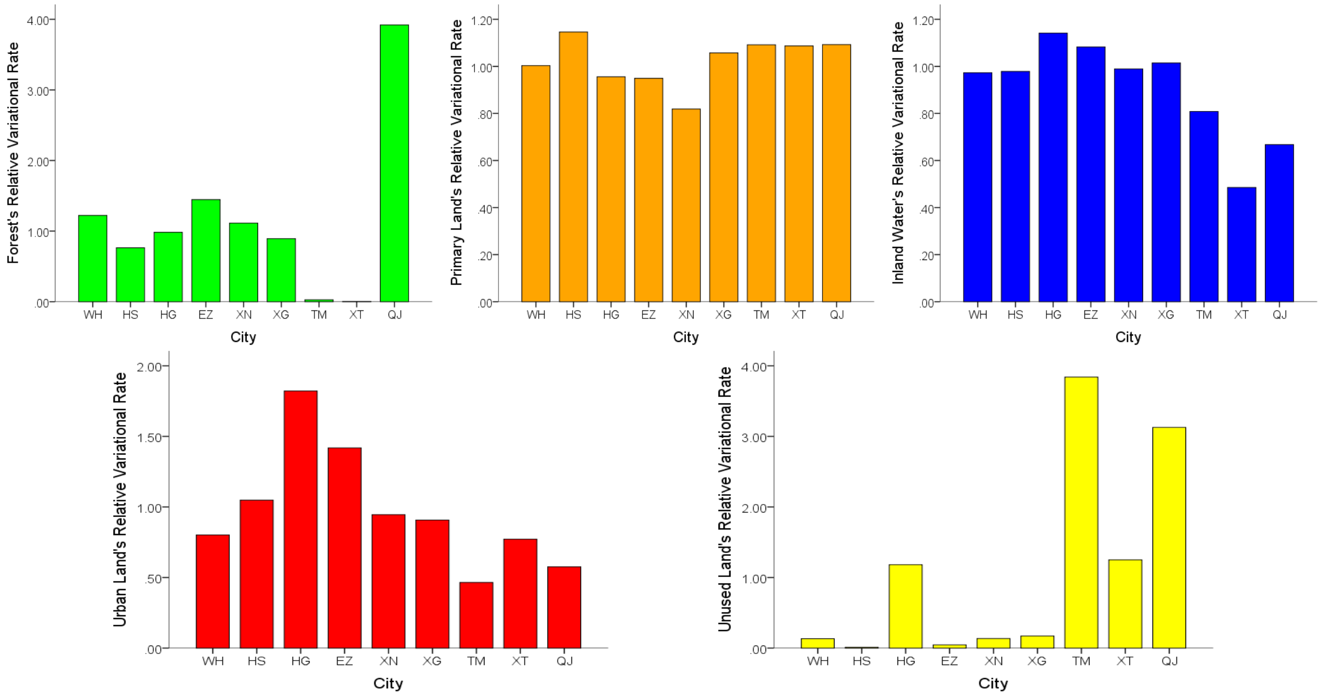

Fig. 2 Relative Variational Rate of Each Land Use Type of Each City in Wuhan Urban Agglomeration(WH, Wu Han; HS, Huang Shi; HG, Huang Gang; EZ, E Zhou; XN, Xian Ning; XG, Xiao Gan; TM, Tian Men; XT, Xian Tao; QJ, Qian Jiang)

Evaluation of Ecological Carrying Capacity.

The Trend of Overall Ecological Carrying Capacity. From 2000 to 2015, the overall ecological carrying capacity showed a slight increase after a slight decrease. From 2000 to 2005, in preparation for the establishment, the biocapacity decreased from 20.61 million hm^2 to 20.50 million hm^2. In the formally established five years, the biocapacity decreased faster, down by 1.97% and slightly increased in the next five years, from 20.09 million hm^2 to 20.31 million hm^2.

Regional Difference of Ecological Carrying Capacity. As shown in Table 4, the ecological carrying capacity ranking of cities in the Wuhan Urban Agglomeration from 2000 to 2015 is: Huanggang> Xiaogan> Wuhan> Xianning> Huangshi> Tianmen> Xiantao> Qianjiang> Ezhou, of which 2010 Tianmen Ecological carrying capacity is greater than Huangshi.

Table 4 Ecological Carrying Capacity [hm^2] of each City in Wuhan Urban Agglomeration

City	2000	2005	2010	2015
Wuhan	3325819.03	3376018.66	3387341.22	3369924.34
Huangshi	1354310.35	1482222.49	1150624.36	1469058.23
Huanggang	5672183.79	5310944.59	5861261.97	5478337.47
Ezhou	600240.75	609109.99	592161.68	598031.98
Xianning	2787268.54	2843068.34	2486655.77	2451361.51
Xiaogan	3685078.60	3662838.36	3566353.66	3700651.22
Tianmen	1171510.49	1176237.87	1172225.37	1183916.64
Xiantao	1120559.84	1120942.63	1145478.40	1143377.84
Qianjiang	892016.42	905894.92	890793.65	908667.68

Ecological Carrying Capacity and Land Use Dynamic Change Analysis. The four key factors affecting biocapacity are land use type, population, equivalence factor and yield factor. The larger proportion of land use types with higher factors, the higher the biocapacity. Unused land's equivalence and yield factors are the smallest, 0; cropland and forest's factors are larger.

The study analyzed the impact of land use on the spatial and temporal biocapacity changes of Wuhan Urban Agglomeration from 2000 to 2015, from three aspects: change rate, degree and regional differences.

Impact of Land Use Degree Change on Ecological Carrying Capacity. The degree change of land use promotes the improvement of regional development ability. As an important indicator of regional development, ecology's affected by the depth and breadth of development. As shown in Fig.3, the trends of the comprehensive index and biocapacity of the Wuhan Urban agglomeration from 2000 to 2015 are the same, showing a slight rebound after the decline. The reason is that from the proposed co-construction plan to the establishment, it is in a period of rapid development now. In the rapid and unripe process of urbanization, the biocapacity will also be affected.

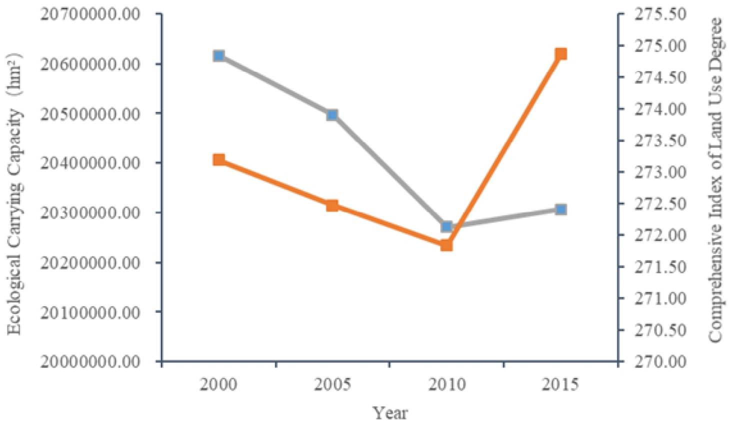

Fig. 3 Land use level composite index and ecological capacity change trend line chart

Impact of Regional Differences in Land Use Change on Ecological Capacity. According to the land use structure of each region, land in Huanggang and Xiaogan is mostly used for cropland and forest, accounting for more than 90% of the total area. Therefore, the biocapacity has always been the best. As the capital city of Hubei province, Wuhan, compared with other cities, has increased land for urban construction year by year. Its ecological carrying capacity is relatively high. As a city close to Wuhan, Ezhou has similar land use structure. Due to its large build-up land and high population density, Ezhou has low ecological carrying capacity. Xianning has mountain and small population, and the population also showed a downward trend, so that the biocapacity is at a high level. Cropland in Huangshi is relatively small and its ecological carrying capacity is in the middle and lower reaches. In

Xiantao and Qianjiang, the cropland covers up to 95% of the total area. The overall ecological carrying capacity is in the middle and lower reaches. The comparison results show that the ecological carrying capacity varies greatly in different districts, land use structure and different changes.

Conclusions and Discussion

The period of Wuhan Urban Agglomeration from 2000 to 2015 is divided into the preparatory, establishment and development phase. There was obvious decrease in unused land during the preparatory phase. However, due to the decrease of cropland and water and the increase of build-up land, the overall biocapacity decreased slightly. In the establishment phase, the change rate was large. During the development stage, the urbanization rate reached a new high. Even though the area of water started to increase, the biocapacity rebounded slightly. The optimal control measures for land use types have been initially reflected, but urbanization is an inevitable process of development. With the continuous expansion of urban population, the protection and optimization of environment are still hard to keep up with the increase of people's demand for resources. The urbanization process suggests it should be reasonably arranged to avoid rapid urbanization.

The urban land resources and environmental conditions of 9 cities are different. The establishment not only provides policy support for its economic exchange, but also takes into account the utilization of ecological environment and the distribution of protection tasks so as to realize the healthy and coordinated development. As the central city, Wuhan has highly concentrated and growing population. Although its water area is large and its ecological resources are abundant, it's still in short supply. Relocate the metropolitan disease of Wuhan by shifting heavy industries to Xianning, a resource-rich and relatively densely populated city. The relatively small cities such as Qianjiang and Xiantao should focus on the agricultural economy.

The following conclusions are drawn from the study:

(1) The trend of land use degree change is consistent with that of ecological carrying capacity. The relative change rates of different land use types in different cities also affect their biocapacity, which reflects the close relationship between ecological carrying capacity and land use change.

(2) From 2000 to 2015, the overall biocapacity of Wuhan Urban Agglomeration decreased slightly and then rose slightly. Through the regulation and control of land use type, we can effectively use the ecological resources. But the human development demand for resources is also growing rapidly. The situation in short supply reflects the importance of rational use of ecological resources.

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