Comprehensive identification of ecologically important areas in Zhengzhou, China

Manshu Liu[1], Zhen Shi[1], Guifang Wang[1], Yang Yang[1], László Kollányi[1]
[1]*Institute of Landscape Architecture, Urban Planning and Garden Art, Hungarian University of Agriculture and Life Sciences*

Abstract

Ecosystem services include the direct and indirect contributions of ecosystems to human well-being and survival, which are important factors that maintain and influence the ecological environment of humans, animals, and plants. Identification of ecological source areas is the first step for mapping high-quality ecological networks, ensuring urban ecological security, and improving the ecosystem service functions. Zhengzhou City is located in the central region of China, and is the core transportation hub of the country. In recent decades, Zhengzhou has accumulated a series of ecological problems in the dramatic urbanization development, such as the destruction of natural resources, environmental pollution, and biological species reduction. Ecological conservation is an urgent need for Zhengzhou. Based on the ecosystem services theory, we selected biodiversity maintenance function, habitat quality, water conservation, and soil conservation as key ecological impact factors to comprehensively evaluate the ecosystem service functions of the study area. By using GIS spatial analysis tool, the InVEST habitat quality model, and spatial connectivity analysis, we can implement the integrated identification of ecological source areas on a large scale. After superimposing the evaluation of ecological factors, the results show that the most important source areas are primarily distributed in the southwest of Zhengzhou. The proportion of ecological sources in Zhengzhou is relatively small, with an area of about 711.16km2, accounting for only 9.3% of Zhengzhou. Most of them have already been protected as forest parks or nature reserve by the government, while some sources like sections of Yellow River which are close to main urban area are facing development pressure. The ecological corridors in the urban area mostly are based on water system like Jinshui river, Xiliu Lake, and Longzi Lake that can connect green open space in the main urban area and natural green space outside.

Introduction

The ecological source is the central point of the outward expansion of ecological energy, which can maintain regional species diversity. It is the most important ecological area of the "source-corridor-node" ecological network (Zhang et al. 2021). The protection of ecologically important sources is the cornerstone in maintaining urban ecological security, building a complete ecological network, improving ecosystem service functions, and promoting sustainable landscape development. It has become a hot topic in related research fields. In recent years, China's urbanization process has continued to accelerate, and a series of environmental problems and ecological threats have gradually emerged. Alleviating the ecological security problems caused by urbanization has become the focus of national development. Therefore, identifying and protecting ecologically important areas is the key step to ensuring ecological security and maintaining biodiversity and ecosystem stability. In 2014, the Ministry of Environmental Protection of China first issued the “National Ecological Protection Red Line---Technical Guidelines for the Delineation of Ecological Function Baselines (Trial)”, which pointed out the concept of "ecological red line". The area delineated by the red line means the most important ecological land that is inaccessible to human activities, with high-value ecological service potential. This guideline emphasized the key protection of important ecological function areas, ecologically sensitive areas, and ecologically fragile areas (Zheng and Ouyang 2014). Therefore, the identification of ecologically important area is of great significance for promoting the sustainable development of current urban ecology.

This paper mainly studied the ecological environment assessment and important ecological resource distribution in Zhengzhou, a city in central China. Combined with ecological functionality, regional connectivity, and existing ecological protection policies, using multi-aspect evaluation of regional ecosystem services to comprehensively identify the most important ecological areas and delineate ecological red lines. This study lays the foundation for building the regional ecological network and improving ecosystem services.

Background and Literature Review

Since the Earth system entered the Anthropocene, the global environment has changed significantly due to human activities (Steffen et al. 2007). Especially after the Industrial Revolution, the number of human beings had increased significantly, population migration and industrialization had resulted in the rapid expansion of urban land, and the urbanization process has been accelerating. Under global urbanization, China's urban development rate in recent decades is particularly prominent, showing a dramatic increase. Since China's reform and opening-up in 1978, the urbanization rate has increased from 17.92% in 1978 to 63.89% in 2020. This growth is huge. Due to the continuous expansion of urban construction areas, the surrounding ecological land such as forests, water bodies, wetlands, and agricultural land has been occupied in large areas. The destruction of natural resources has led to the loss of some ecological corridors and the fragmentation of the ecological landscape pattern (Grimm et al. 2008). A series of ecological threats has become an urgent problem to be solved in the current urban development. Protecting important ecological sources, strengthening the connection between source patches, and establishing ecological corridors can effectively protect ecologically important areas from being eroded, enhance the regional landscape connectivity, and improve the overall ecosystem service function and ecological security (Wang et al. 2021).

Research on the evaluation and identification of ecological sources has become more and more mature, but there have not formed unified methods. Some only directly delineate large areas of forest land, nature reserves, and forest parks with the good ecological environment as ecological source areas (Ma et al. 2022); some build relevant evaluation indicators based on ecosystem service functions to evaluate ecologically important areas(Tong and Shi 2020); Some identify ecological sources through ecological importance and vulnerable areas (Zhou et al. 2015). However, most evaluation methods pay more attention to the functionality of ecological patches themselves, lack the analysis of connectivity between ecological patches within the entire region, and ignore the relationship between a single ecological patch and the surrounding environment, as well as its structural importance in matrix landscapes. This study combines the ecosystem service function and the importance of regional connectivity to comprehensively identify the ecological sources from multiple aspects, which is more scientifically meaningful for future ecological planning.

This research object is Zhengzhou City in Henan Province, where the urbanization rate has increased from 32.4% in 1978 to 74.58% in 2019 ('Population over the Years - Zhengzhou Municipal Bureau of Statistics' n.d.). The urban expansion there is significant, and it is representative in studying the impact of urbanization of large-scale cities on the ecological environment in China.

Method and Data

1. Study area

Zhengzhou is in the central region of China. It is the capital city of Henan Province (34°16′-34°58′ North Latitude, 112°42′-114°14′ East Longitude), with 5 small cities, 1 county, and 6 districts under the jurisdiction of Zhengzhou. The city's total area is about 7657km^2, of which the urban area is 1010km^2. It occupies an important geographical position in China and is the core node city of China's "Belt and Road". Zhengzhou is adjacent to the Yellow River in the north, there are 124 rivers in the territory, which belong to the Yellow River Basin and the Huai River Basin. The western mountainous area consists of the Songshan scenic area and the Dengfeng State-owned Forest to form a large forest land with a high coverage rate. The hilly area has a large area of shrub forest and grassland, which constitutes various mountain natural resources conditions.

2. Data source

According to research needs and actual data acquisition, the basic data used in this paper include Zhengzhou Landsat-8TM image data, Zhengzhou 2018 land classification data, DEM elevation data, soil data, meteorological data, roads data, and Zhengzhou statistical yearbook data, etc. The above data are from the USGS official website (http://earthexplorer.usgs.gov/), the Chinese Academy of Sciences Resource and Environment Science Data Center (http://www.resdc.cn/), and the Geospatial Data Cloud website (http://www.gscloud.cn/), Cold and Arid Regions Scientific Data Center (http://westdc.westgis.ac.cn/), China Meteorological Data Network (http://data.cma.cn/) and OpenStreetMap official website (http://www.openstreetmap.org), etc.

3. Methods

3.1 Identification of ecological sources based on ecosystem service

Ecosystem services refer to the benefits that humans can obtain from ecosystems, and Millennium

Ecosystem Assessment (MA) divides them into four different types: provisioning services, supporting services; regulating services; cultural services (Alcamo et al. 2003). So, this study based on ecosystem services, from the perspective of regional ecological conditions and functions of ecological patches, we select multiple ecological indicators such as biodiversity maintenance function, habitat quality, water conservation, and soil and water conservation (Table 1) to analyze the ecological conditions of Zhengzhou and comprehensively identify the ecological source areas.

Table 1. Selection of ecosystem service indicators

Ecosystem service types	Indicators	Formula	Introduction
Supporting services	Biodiversity maintenance	$EVS_{xj} = \frac{NDVI_{xj}}{NDVI_j} \times EVS_{jD}$	Using ecosystem service value and NDVI to calculate biodiversity maintenance ability.
	Habitat quality	$Q_{xj} = H_j \left(1 - \left(\frac{D_{xj}^Z}{D_{xj}^Z + k^Z}\right)\right)$	Using InVEST to evaluate the ability to provide an environment for the sustainable development of the species.
Provisioning services	Soil conservation	$A = R \times K \times LS \times (1 - C \times P)$	Using the universal soil loss equation (USLE) to calculate soil conservation capacity.
Regulating services	Water conservation	$TQ = \sum_{i=1}^{j} (P_i - R_i - ET_i) \times A_i \times 10^3$	Using the water balance equation to calculate the ability of the area to retain and conserve water.

Based on the above ecosystem service factors analysis, the classification method of natural discontinuity points is used to divide it into 5 grades. The higher the grade, the higher the regional ecological importance. In superposition analysis of different factors, using the grid factor maximum statistical method (if it is a very important area in any single factor, it will become the comprehensive ecological source area) to generate a comprehensive ecologically important source area.

3.2 Regional connectivity analysis

To maintain the stability of the ecosystem, in addition to the protection of important sources, ecological corridors are also required to enable the energy of ecological sources to expand outward, and species can also migrate between important habitats through ecological corridors. It is an important factor in solving landscape fragmentation and maintaining regional ecological stability. There are some resistances that need to be overcome in the process of expanding energy flow from the source to the outside. Therefore, it is necessary to analyze the comprehensive spatial resistance in the ecological process. By combining the source and spatial resistance, the minimum cumulative resistance model (MCR) can be used to identify the path with the least cost for species movement and build the best ecological corridor, which is widely used in the construction of an ecological network.

Firstly, natural factors and human activity factors are selected to construct a comprehensive spatial resistance surface. This paper selects resistance factors including slope, land use types, vegetation coverage, and distance from the roads and rivers. Different weights are assigned according to the Analytic Hierarchy Process (AHP). Then superimpose these factors to establish a comprehensive space resistance surface. Finally, using the Linkage Mapper tool, based on the ecologically important sources, the ecological corridors can be identified through the principle of the least-cost path, and the connection between the sources is established.

The above methods can comprehensively analyze and evaluate the ecological patches functions and regional connectivity of important sources from the perspective of the entire study area. They can more directly express the ecological conditions of Zhengzhou and determine the importance of ecological sources.

Results

1. Identification of ecologically important area

Through the above methods, the analysis of different ecological factors in Zhengzhou is shown in Figure 1. Overall, each ecological factor in the region shows that the level of ecological service in the western mountain forest area is higher than the level of ecological service in the eastern urban plain area. The areas with high biodiversity maintenance functions are mainly distributed in Songshan Mountains in the west, Daxiong Mountains, and Juci Mountains in the south. The three county-level cities of Gongyi, Dengfeng, and Xinmi undertake the main function of maintaining biodiversity in Zhengzhou. The habitat quality level in a large area centered on the main built-up area of Zhengzhou is poor, and the habitat degradation is severe, resulting in a significantly higher degree of habitat degradation in the eastern plains than in the western mountainous areas. Zhengzhou city's water conservation capacity and soil conservation also show a higher level in the western mountainous areas, mainly due to the influence of the microclimate near the large forest land in the mountainous area, the precipitation is much more, and the evapotranspiration is small there. It reflects the importance of ecosystem services of forest land in terms of rainfall, surface water, and groundwater conservation.

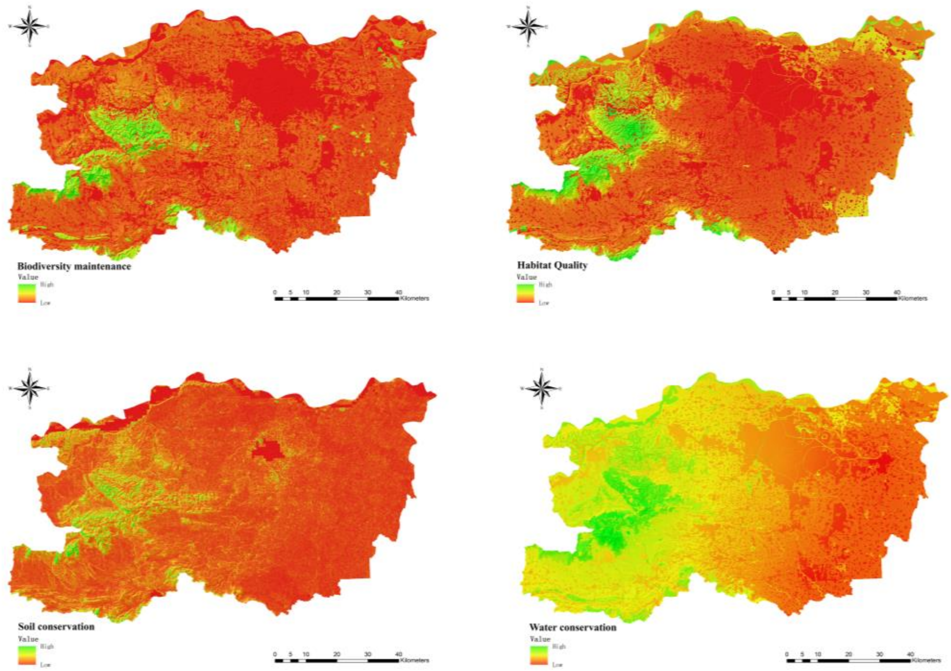
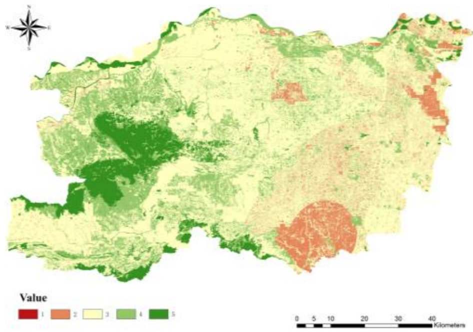


Fig 1. Zhengzhou ecological condition analysis map
(Biodiversity maintenance, Habitat quality, Soil conservation, Water conservation)

Equal weight superimposition of different ecological factors to obtain the comprehensive ecological assessment of Zhengzhou (Fig 2), which is divided into 5 grades. The higher the value, the higher the ecologically important value, which requires critical protection. From a spatial aspect, the most important core patches (5) are mostly distributed in the Song Mountains, state-owned forest farms, southern mountainous areas, and some rivers. General important patches (3) are mainly distributed in cultivated land with relatively gentle terrain. The ecological sources were finally determined to be 711.16 km^2, accounting for 9.3% of the study area, mainly distributed in the Song-Fuxi Mountains in the west, the Daxiong Mountain-Juci Mountains in the south, the Yellow River Nature Reserve in the north, the section of Yiluo river in Gongyi city, as well as Baisha Reservoir, Zhifang Reservoir and Ying River in Dengfeng. Compared with the distribution of nature reserves and forest parks, these sources include the Yellow River Nature Reserve, Song-Fuxi Mountain Scenic Area, Daxiong Mountain Forest Park, Xinmi Forest Park, Juci Mountain Forest Park, Qinglong Mountain Forest Park, and Yanming Lake Wetland Park.



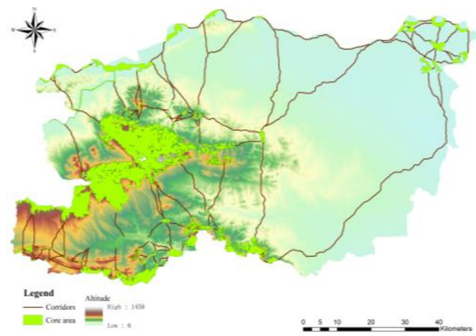


Fig 2. Zhengzhou comprehensive ecological level classification

Fig 3. Identification of ecological sources and corridors in Zhengzhou

2. Ecological connectivity analysis

As shown in Fig 3, the connectivity between the mountainous areas in the southwest is pretty good, forming a relatively dense ecological network structure. In comparison, there are fewer ecological sources in the eastern plains, only the wetlands and ponds in the northeast. The agricultural areas in the southeast are extremely lacking in ecological sources, and the ecological network is more discrete. The overlay analysis of the corridors and satellite images shows that the ecological corridors that connect through the city are all rivers. Jinshui River is connected to Ruyi Lake, Long Lake, and rivers near Longzi Lake in the east; Xiliu Lake Park is connected to Yellow River, a small river that flows through the village in the southeast. Some reservoirs in the south of Xinzheng city, the Xingyang River in the north of Xingyang city, and the canals near ponds in the northeast, all of them are essential ecological corridors.

Discussion and Conclusion

In 2017, the Ministry of Environmental Protection of China completed and issued the "Guidelines for the Delineation of Ecological Protection Red Lines" based on the trial version in 2014 as mentioned before. In terms of methodology, the ecological red lines are identified by the importance of ecological functions and ecological sensitivity. Considering the environmental conditions of Zhengzhou City, this study selected the most influential ecological factors according to the government guidelines. In addition, connectivity analysis was added to improve the protection of ecological land from the overall ecological network construction. Compared with the “ecological space control plan” in the “Zhengzhou Metropolitan Area Master Plan (2012-2030)”, there are cooccurrence areas between the ecological red line areas identified in this study and the ecological land areas in the “Plan” (Fig 4). Most of cooccurrence areas are ecological forests, wetland reserves, scenic areas, and forest parks, which belong to the “Prohibited construction areas” in the “Plan”. The disturbance of human activities in these areas should be reduced to maintain the ecological naturalness of the environment.

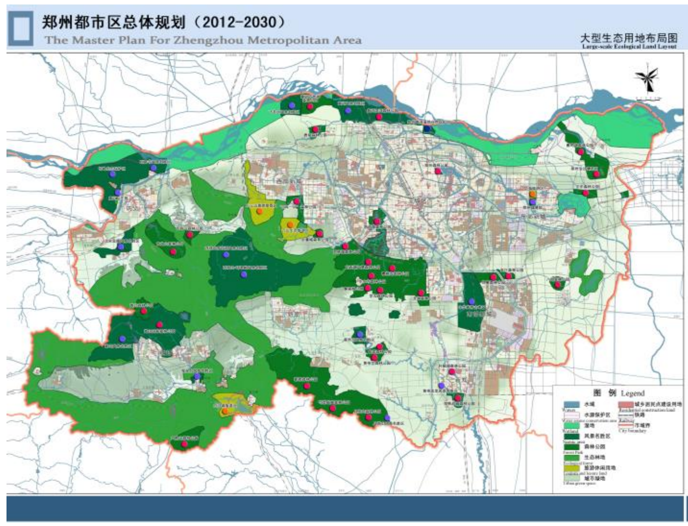


Fig 4. The Master Plan of Zhengzhou Metropolitan Area (2012-2030)

The Yellow River in the north has important ecosystem service function, but only some sections of the river are identified as ecological source areas with strong ecological functions. Because other sections are too close to the main urban area and are greatly affected by human activities, the original ecological conditions have been destroyed to a certain extent. Therefore, the protection and development of rivers close to the city face greater pressure and become the focus of ecological environment improvement. In recent years, the local government has established relevant ecological restoration projects dedicated to improving the overall ecological environment of the Yellow River, setting up wetland reserves, and enriching the green belt construction along the Yellow River.

From the identified ecological corridors, the natural ecological patches in the large-scale city can be connected by the river ecological patches in the main urban area, like Jinshui River, Xiliu Lake, Ruyi Lake, and Longzi Lake in the urban area. They are all important ecological corridors and should be protected. In the future, by improving the ecological level of river wetlands, building greenways in the urban area, Zhengzhou can realize an overall ecological network of green open spaces in the urban area and natural spaces outside the urban area.

Zhengzhou is in the transition zone between mountains and plains, and there has a large area with abundant mountain and river resources. Due to the continuous acceleration of urbanization and the expansion of the construction area, the ecological condition, climate, and rainfall in different regions are quite different. For such environmental characteristics, relevant ecological factors can better represent the differences in ecological levels in different regions. This study uses satellite remote sensing images and model simulations to analyze regional ecological conditions, selects ecosystem service factors according to the environmental conditions of Zhengzhou metropolitan area, and pays more attention to large-scale evaluation and planning. For other countries and regions, it could be adjusted appropriately on the basis of the site scope and ecological conditions. This study could provide reference value for related ecological evaluation and planning.

Acknowledgement

This research is financed by China Scholarship Council and the Stipendium Hungaricum scholarship programme.

References

Alcamo, Joseph, Elena M. Bennett, and Millennium Ecosystem Assessment (Program), eds. 2003. *Ecosystems and Human Well-Being: A Framework for Assessment*. Washington, DC: Island Press.

Grimm, Nancy B., Stanley H. Faeth, Nancy E. Golubiewski, Charles L. Redman, Jianguo Wu, Xuemei Bai, and John M. Briggs. 2008. 'Global Change and the Ecology of Cities'. *Science* 319 (5864): 756–60. https://doi.org/10.1126/science.1150195.

Ma, Binbin, Zhu-an Chen, Xiaojian Wei, Xiuquan Li, and Liting Zhang. 2022. 'Comparative Ecological Network Pattern Analysis: A Case of Nanchang'. *Environmental Science and Pollution Research*, March. https://doi.org/10.1007/s11356-021-17808-5.

'Population over the Years - Zhengzhou Municipal Bureau of Statistics'. n.d. Accessed 6 February 2022. http://tjj.zhengzhou.gov.cn/ndsj/3134558.jhtml.

Steffen, Will, J. Crutzen, and John R. McNeill. 2007. 'The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?' *Ambio* 36 (8): 614–21. https://doi.org/10.1579/0044-7447(2007)36[614:taahno]2.0.co;2.

Tong, Hua-li, and Pei-ji Shi. 2020. 'Using Ecosystem Service Supply and Ecosystem Sensitivity to Identify Landscape Ecology Security Patterns in the Lanzhou-Xining Urban Agglomeration, China'. *Journal of Mountain Science* 17 (11): 2758–73. https://doi.org/10.1007/s11629-020-6283-0.

Wang, Shuang, Maoquan Wu, Mengmeng Hu, Chen Fan, Tao Wang, and Beicheng Xia. 2021. 'Promoting Landscape Connectivity of Highly Urbanized Area: An Ecological Network Approach'. *Ecological Indicators* 125 (June): 107487. https://doi.org/10.1016/j.ecolind.2021.107487.

Zhang, Haozhe, Qingyuan Yang, Huiming Zhang, Lulu Zhou, and Hongji Chen. 2021. 'Optimization of Land Use Based on the Source and Sink Landscape of Ecosystem Services: A Case Study of Fengdu County in the Three Gorges Reservoir Area, China'. *Land* 10 (11): 1242. https://doi.org/10.3390/land10111242.

Zheng, Hua, and Zhiyun Ouyang. 2014. ‘Practice and Consideration for Ecological Redlining’. *Bulletin of Chinese Academy of Sciences* 29 (04): 457-461+448. DOI 10.3969/j.issn.1000-3045.2014.04.008

Zhou, Rui, Xinjun Wang, Hailong Su, and Yilai Lou. 2015. ‘Identification and Security Pattern of Ecological Land in Pingdingshan Newly Developed Area’. *Acta Ecologica Sinica* 35 (06): 2003–12. DOI: 10．5846 / stxb201305241169