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Flood Risk Identification of Zhengzhou Metropolitan Area Based on Invest Model

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Abstract: Rainstorm and urban flood are always one of the most serious natural disasters in China due to the change of ecological environment, terrain conditions and climate change. Rainstorm and flood disasters seriously threaten the security and development of regional economy and society. Therefore, how to identify the high-risk areas of flood disasters is an important issue to be solved in the prevention of flood disasters. Taking Zhengzhou metropolitan area as the research object, based on the Urban Flood Risk Mitigation module of InVEST model, the vulnerability of flood disaster, the supply capacity of flood regulation service and the supply-demand ratio of ecosystem service in the study area are obtained through analysis, and the areas vulnerable to flood disaster in the study area are identified. The results show that : (1) The flood regulation service supply capacity is mainly manifested in the spatial distribution pattern of high in the west and low in the east. The northern Jiaozuo, northern Xinyang, western Zhengzhou and western Xuchang have higher supply service levels. (2) Affected by factors such as population density, economic development level and land use development degree, there are also obvious spatial differences in the spatial distribution of flood regulation service demand. The high demand area of flood regulation service is concentrated in the central urban area. (3) In areas with low population density and high vegetation coverage, the high supply and low demand of flood regulation services lead to a higher service supply-demand ratio. In the central urban area of the city, due to the large proportion of construction land and dense population, the supply and demand of services is relatively low.

Keywords: InVEST model; flood regulation services; supply-demand ratio; zhengzhou metropolitan area; flood risk.

1. Introduction

The rapid development of the city has significantly improved the material living standards and quality of human beings, but the high-intensity and disorderly land development has also destroyed the ecological space[1]. The deterioration of the ecological environment has significantly affected the regional hydrological cycle process, making the city more prone to floods in the face of heavy rainfall, and urban floods are facing new challenges[2]. More than two-thirds of the country 's land is threatened by floods, and more than two-thirds of the cities have experienced varying degrees of rainstorms and floods. Since 1949, floods have become China 's highest frequency of occurrence, the largest scope of impact and the most losses. Natural disasters, China has different degrees and ranges of floods every year, which have a significant impact on people 's lives and property. From July 17,2021 to July 20,2021, affected by abnormal atmospheric circulation and typhoon, Henan Province suffered a rare heavy rainstorm in history, especially Zhengzhou City suffered heavy casualties and property losses. Therefore, it is necessary to identify areas susceptible to flood disasters and take certain flood control measures to protect the safety of people 's lives and property.

Mastering the supply and demand of regional ecosystem services and protecting regional ecological security are of great significance for improving human well-being[3]. Based on the Urban Flood Risk Mitigation module of InVEST model, this paper obtains the runoff and runoff retention of the study area, and uses the runoff to represent the exposure intensity of the study area, so as to characterize the vulnerability of flood disaster[4]. The higher the vulnerability, the greater the demand for flood regulation services. Runoff retention is used to represent the supply capacity of flood regulation services in the study area. The greater the runoff retention, the stronger the service supply capacity. The ratio of supply and demand of ecosystem services is used to characterize the risk of flood disaster in the study area. The larger the supply-demand ratio is, the stronger the ability to resist flood disaster is, the smaller the risk is, and the smaller the supply-demand ratio is, the greater the possibility of flood disaster is. Identify the areas vulnerable to floods in the study area, and provide scientific support for the construction of regional ecological network pattern and ecological security pattern[5].

2. Study Area and Data

2.1. Overview of the study area

The Zhengzhou metropolitan area mainly includes five prefecture-level cities, Zhengzhou, Kaifeng, Xinxiang, Jiaozuo and Xuchang, with an area of 31,000 square kilometers. It is a temperate continental monsoon climate with four distinct seasons. It is dry and less rainy in spring, hot and rainy in summer, cool in autumn and dry and cold in winter. And the rainfall in summer mostly appears in the form of rainstorm. From July 17 to 20,2021, extreme heavy rainfall occurred in Zhengzhou City, and the rainfall depth reached 617.1mm from 20 : 00 on July 17 to 20 : 00 on July 2021.This extreme rainfall caused serious urban waterlogging, serious water accumulation in the affected areas, heavy casualties and heavy economic losses. Based on the background of severe flood disasters caused by extreme rainfall, it is necessary to carry out risk assessment of flood disasters in Zhengzhou metropolitan area.

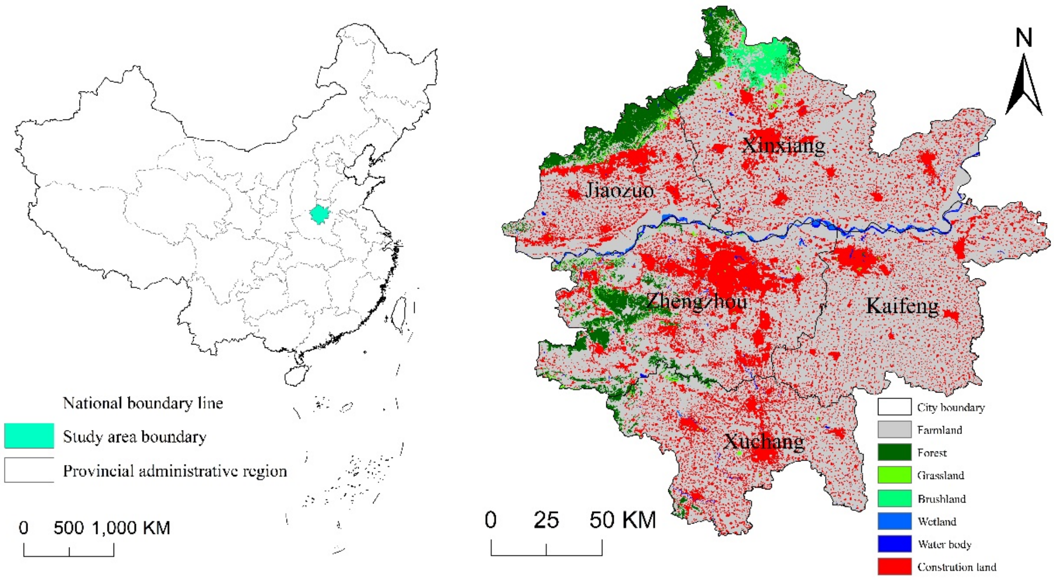

Figure 1. Study area location map

2.2. Data source and processing

The main sources of data are shown in Table 1.ArcGIS software is used to process the raster data into spatial resolution of 30m × 30m, WGS-1984-UTM-Zone-49N coordinates, and the data are clipped according to the boundary of the study area.

Table 1. Data source.

Date	type	Data source
Land use	Grid	Ministry of Natural Resources of China http://globallandcover.com/
DEM	Grid	NASA https://earthdata.nasa.gov/
Soil hydrologic group	Grid	ORNL DAAC https://daac.ornl.gov/
Rainfall depth	Number(mm)	617.1mm (2021.7.17,20:00-2021.7.20,20:00，three days of rainfall in Zhengzhou)

3. Research Ideas and Methods

3.1. Research ideas and logical framework

This paper takes Zhengzhou metropolitan area as the research object, and obtains the runoff and runoff retention of the study area through the Urban Flood Risk Mitigation module of the InVEST model. The runoff represents the exposure intensity of the study area[6], thus characterizing the vulnerability of flood disaster. The higher the vulnerability, the greater the demand for flood regulation services. Runoff retention is used to represent the supply capacity of flood regulation services in the study area[7]. The greater the runoff retention, the stronger the service supply capacity. The ratio of supply and demand of ecosystem services is used to characterize the matching state of supply and demand of ecosystem services and the ability of ecosystem to provide ecosystem services sustainably. The larger the supply-demand ratio is, the stronger the ability to resist flood disasters is, and the smaller the supply-demand ratio is, the greater the possibility of flood disasters is.

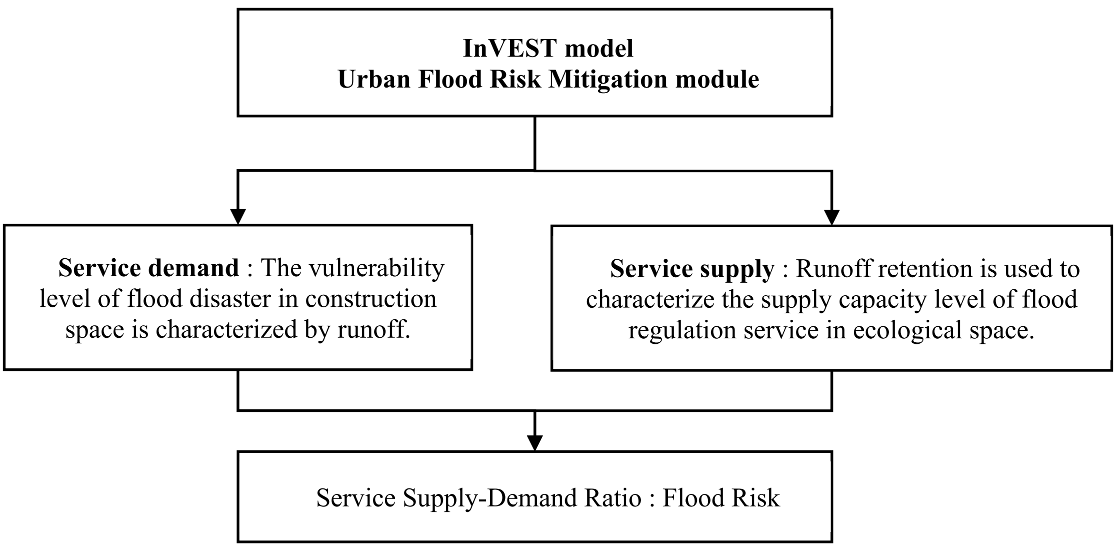

Figure 2. Research idea diagram

3.2. Research methods

3.2.1. Assessment of flood regulation service supply

The supply of ecosystem services is the quantity and quality of ecological services provided by natural ecosystems to humans within a certain time and space. It is a complete collection of non-biological and biological components in the ecosystem that can provide various services[8]. The supply of flood regulation services is calculated using the Urban Flood Risk Mitigation module of the InVEST model. The InVEST model is a land use ecosystem service evaluation model jointly developed by Stanford University and other institutions, which uses land use and other data to evaluate ecosystem services. The spatial distribution characteristics are obtained, and the calculated runoff retention R_i is used as the supply of flood regulation services (m^3). The calculation principle of the module is shown in the formula.

$$R_i = \left(1 - \frac{Q_i}{P}\right) \times P \times Area_i \times 10^{-3} \quad (1)$$

$$Q_i = \begin{cases} \left(P - \lambda S_{max_i}\right)^2 & P > \lambda S_{max_i} \\ 0 & otherwise \end{cases} \quad (2)$$

$$S_{max_i} = \frac{25400}{CN_i} - 254 \quad (3)$$

In the formula, R_i is the runoff retention on the pixel i, which represents the supply of flood regulation services (m^3) ; Q_i is the runoff on the pixel i ; P is the rainstorm depth, 617.1mm (2021.7.17,20 : 00-2021.7.20,20 : 00, three days of rainfall in Zhengzhou) ; $Area_i$ is the area of pixel i ; S_{max_i} represents the possible maximum retention (mm) ; λ is a regional parameter ($0.1 \le \lambda \le 0.3$) ; λS_{max_i} is the rainfall depth required to trigger runoff. According to the model manual and literature, the CN value is determined.

3.2.2. Flood regulation service demand assessment

The demand for ecosystem services mainly refers to the amount of service functions that humans consume, use, or need and expect[9]. Different service needs have different quantitative evaluation methods[10]. The demand for flood regulation services is quantified by vulnerability[11], and the exposure intensity of the study area is represented by runoff, thus characterizing the vulnerability of flood disasters. The higher the vulnerability, the greater the demand for flood regulation services. The calculation method of runoff see formula (4):

$$Q_i(\mathrm{m}^3) = \begin{cases} \left(P - \lambda S_{max_i}\right)^2 & P > \lambda S_{max_i} \\ 0 & otherwise \end{cases} \times Area_i \times 10^{-3} \quad (4)$$

Q_i is the runoff on the pixel i ; P is the rainstorm depth, 617.1mm (2021.7.17,20 : 00-2021.7.20,20 : 00, three days of rainfall in Zhengzhou) ; $Area_i$ is the area of pixel i ; S_{max_i} represents the possible maximum retention (mm) ; λ is a regional parameter ($0.1 \le \lambda \le 0.3$) ; λS_{max_i} is the rainfall depth required to trigger runoff. According to the model manual and literature, the CN value is determined.

3.2.3. Quantification of supply and demand ratio of flood regulation service

The supply-demand ratio of ecosystem services can characterize the matching state of supply and demand of ecosystem services and the ability of ecosystems to provide ecosystem services sustainably[12]. The formula is calculated as follows:

$$ESDR = \frac{S-D}{(S_{max}-D_{\max})/2} \quad (5)$$

In the formula, $ESDR$ is the supply-demand ratio of ecosystem services ; S and D are the supply and demand of ecosystem services, respectively. S_{max} and $D_{\max}$ represent the maximum supply and demand of ecosystem services, respectively. The benefits obtained by human beings from ecosystem services to meet their own needs are defined as the well-being provided by ecosystems to human beings[3]. The greater the ESDR, the better the service demand is satisfied, and the more the demand is satisfied. The more well-being we think, the less likely the flood disaster will occur.

4. Result

4.1. Analysis of flood regulation service supply

The higher the runoff retention, the higher the supply capacity of flood regulation services, the higher the level of flood risk, and the lower the flood risk[13]. It can be seen from the figure that the supply capacity of flood regulation service is mainly manifested in the spatial distribution pattern of high in the west and low in the east. Among them, the supply service level in the north of Jiaozuo, the north of Xinyang, the west of Zhengzhou and the west of Xuchang is higher, mainly due to the high vegetation coverage and large forest land distribution area in the west of the study area, while the green space area in the east is less.

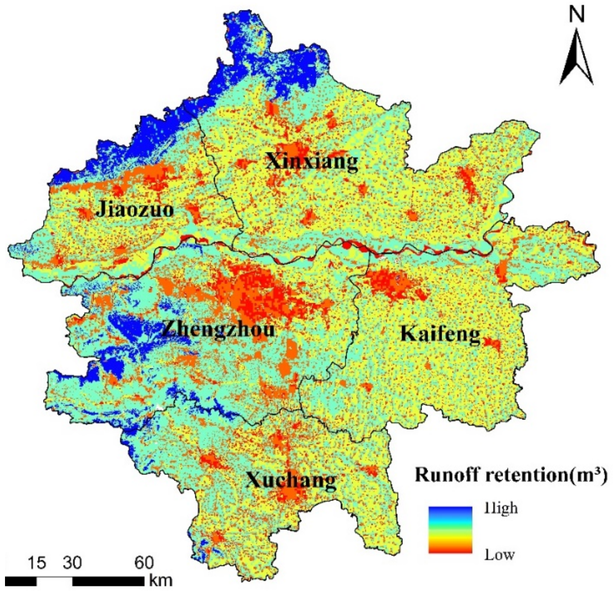

Figure 3. Flood regulation service supply diagram

4.2. Flood regulation service demand analysis

Affected by factors such as population density, economic development level and land use development degree, the spatial distribution of flood regulation service demand also has obvious spatial differences[14]. The high demand area of flood regulation service is concentrated in the central urban area of the city. The main reason is that the density of construction land in urban areas is high and the water network is developed. The rainstorm causes large runoff in this area, high vulnerability of flood disaster and high risk of flood.

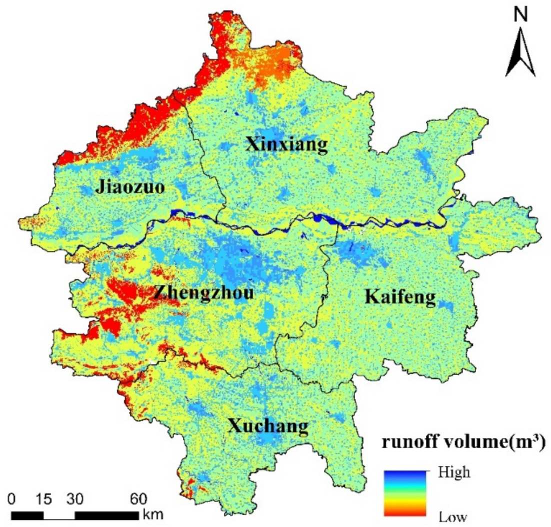

Figure 4. Diagram of flood regulation service demand

4.3. Flood risk analysis

The supply-demand ratio of ecosystem services also showed significant spatial differences. In areas with low population density and high vegetation coverage, the high supply and low demand of flood regulation services lead to a higher ratio of service supply to demand. In the central urban area, due to the large proportion of construction land, dense population, and low service supply and demand, the flood risk in the central urban area is high.

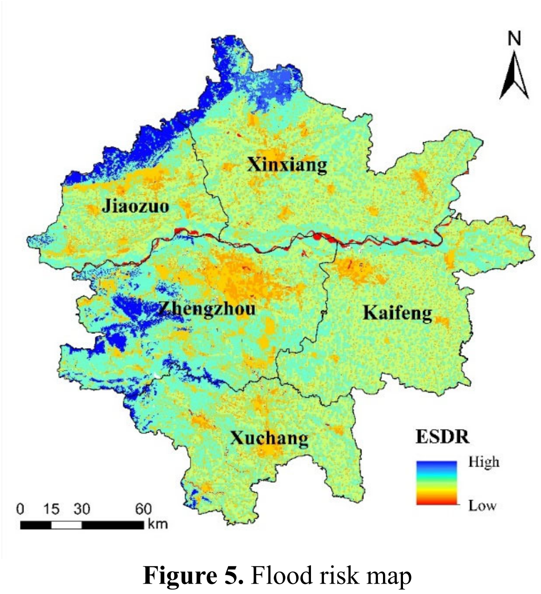

Figure 5. Flood risk map

5. Conclusion

Based on the balance between supply and demand of flood regulation services, this paper analyzes the flood risk of Zhengzhou metropolitan area. The main conclusion is that due to the large proportion of construction land and dense population in the urban center, the flood risk is high. In areas with high vegetation coverage, the risk of floods is low because vegetation can control floods. For the urban center with high flood risk, some measures can be taken to improve its flood control capacity.

References

[1] Jiake Shen, Xiaolu Guo, and Yuncai Wang. 2021. Identifying and setting the natural spaces priority based on the multi-ecosystem services capacity index. Ecol. Indic. (2021), 107473. DOI 10.1016/j.ecolind.2021.107473

[2] Chinh Luu and Jason von Meding. 2018. A Flood Risk Assessment of Quang Nam, Vietnam Using Spatial Multicriteria Decision Analysis. Water-Sui. (2018), 461. DOI 10.3390/w10040461

[3] Stoyan Nedkov and Benjamin Burkhard. 2012. Flood regulating ecosystem services—Mapping supply and demand, in the Etropole municipality, Bulgaria. Ecol. Indic. (2012), 67-79. DOI 10.1016/j.ecolind.2011.06.022

[4] Shuoliang Jiang and Xiansheng Chen. 2022. Urban resilience assessment and obstacle factors analysis under flood scenarios. Statistics and Decision (2022), 63-67. DOI 10.13546/j.cnki.tjyjc.2022.24.012

[5] Matthias Schröter, Roy P. Remme, and Lars Hein. 2012. How and where to map supply and demand of ecosystem services for policy-relevant outcomes? Ecol. Indic. (2012), 220-221. DOI 10.1016/j.ecolind.2012.03.025

[6] Ralf-Uwe Syrbe and Ulrich Walz. 2012. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. Ecol. Indic. (2012), 80-88. DOI 10.1016/j.ecolind.2012.02.013

[7] Yi-Wen Ji, Lang Zhang, Jie Liu, Qicheng Zhong, and Xinxin Zhang. 2020. Optimizing Spatial Distribution of Urban Green Spaces by Balancing Supply and Demand for Ecosystem Services. J. Chem.-NY (2020), 1-8. DOI 10.1155/2020/8474636

[8] Benjamin Burkhard, Franziska Kroll, Stoyan Nedkov, and Felix Müller. 2012. Mapping ecosystem service supply, demand and budgets. Ecol. Indic. (2012), 17-29. DOI 10.1016/j.ecolind.2011.06.019

[9] S. Wolff, C. J. E. Schulp, and P. H. Verburg. 2015. Mapping ecosystem services demand: A review of current research and future perspectives. Ecol. Indic. (2015), 159-171. DOI 10.1016/j.ecolind.2015.03.016

[10] Yishao Shi, Donghui Shi, Liangliang Zhou, and Ruibo Fang. 2020. Identification of ecosystem services supply and demand areas and simulation of ecosystem service flows in Shanghai. Ecol. Indic. (2020), 106418. DOI 10.1016/j.ecolind.2020.106418

[11] Jiake Shen and Yuncai Wang. 2021. Allocating and mapping ecosystem service demands with spatial flow from built-up areas to natural spaces. Sci. Total Environ. (2021), 149330. DOI 10.1016/j.scitotenv.2021.149330

[12] Brendan Fisher, R. Kerry Turner, and Paul Morling. 2009. Defining and classifying ecosystem services for decision making. Ecol. Econ. (2009), 643-653. DOI 10.1016/j.ecolecon.2008.09.014

[13] Benjamin Burkhard, Franziska Kroll, Stoyan Nedkov, and Felix Müller. 2012. Mapping ecosystem service supply, demand and budgets. Ecol. Indic. (2012), 17-29. DOI 10.1016/j.ecolind.2011.06.019

[14] Neele Larondelle and Steffen Lauf. 2016. Balancing demand and supply of multiple urban ecosystem services on different spatial scales. Ecosystem Services (2016), 18-31. DOI 10.1016/j.ecoser.2016.09.008