Study on Ecological Security Evaluation Index System of the Yellow River Basin

Yuxin TIAN [1], Meirong TIAN [2,*], Chaoyang FENG [2], Xitong NIU [2], Mengfei LIU [2]

[1] School of Ecology and Environment, Zhengzhou University, Zhengzhou 450001, China
[2] State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China

Abstract. As an important energy base and ecological barrier in China, the ecological security of the Yellow River Basin has a very important strategic position in the pattern of high-quality development, but it is threatened by human activities and climate change. In order to evaluate the degree of ecological security in the Yellow River Basin and clarify the influencing factors of ecological security, this paper discusses the advantages and disadvantages of the existing ecological security assessment methods and models. On this basis, the system dynamics model is used to describe the process of ecological security threats, identify the key factors that threaten ecological security, and then sort out the ecological security assessment indicators. The ecological security assessment model composed of pressure(P), state(S), hidden dangers(D), response(R) and management (M) (PSDRM) indicators is constructed, and the ecological security assessment methods and processes are improved to provide theoretical guidance and technical support for improving the ecological security assessment of the basin.

1.Introduction

The Yellow River Basin is an important ecological security barrier in China, which plays an important ecological role in water supply, climate regulation, water storage and flood regulation. The Yellow River Basin is located in the arid and semi-arid area, and the desertification area accounts for about 44.2 % of the national desertification area. At the same time, as an important energy base in China, The Yellow River Basin has long been subjected to high-intensity human development and construction, resulting in prominent ecological and environmental problems. The average annual ecological water loss is 2 billion m^3, and the wetland shrinks by 402.2 km^2 . According to statistics, in 2020, the grassland, wetland and forest ecological damage loss in the nine provinces along the Yellow River is about 321 billion yuan. How to improve the ecological security of the Yellow River Basin has become the focus of government management and research scholars. Ecological security is an important part of national security, and watershed ecological security assessment is an important prerequisite for watershed ecological protection. At present, the ecological security assessment method has little consideration in ecological management and ecological risk. In order to further improve the ecological security assessment technology and method of the Yellow River Basin, this paper screens the ecological security assessment indicators of the Yellow River Basin based on the system dynamics method. On the basis of the pressure state response model, the two factors of ecological management and potential ecological risk are integrated to construct the ecological security assessment index system, which provides technical support for the ecological security assessment of the Yellow River Basin.

2. Main methods of ecological security assessment in watershed

2.1. Ecological footprint method

Ecological footprint refers to the regional space that sustainably provides resources or is biologically productive and consumes wastes [9]. Ecological footprint method is mainly used to measure ecological sustainability, and can also be used to compare resource production and consumption in a certain area to determine whether it exceeds the ecological bearing range [10]. It can effectively represent the pressure brought by the development of human society on the ecological environment [11], so it is introduced into the field of ecological security assessment.

2.2. Ecological risk determination method

Ecological risk refers to the risk borne by an ecosystem under the interference of natural or human activities, which adversely affects the structure and function of the ecosystem [14]. The higher the ecological risk, the lower the ecological security degree. Therefore, ecological risk assessment method is used to analyze ecological risk from the perspective of risk sources and risk receptors [15], and grade scoring method is used to quantify risk sources and

*Corresponding author: hntianyuxin@163.com

ecological environment. After calculating relative risk value, ecological security is determined [16], and ecological security pattern is constructed on this basis.However, the ecological risk method currently lacks complete evaluation guidelines, and there are many intrinsic factors involved in ecological risk, so the universality of evaluation indicators needs to be further verified.

2.3. Model evaluation method

Ecological security assessment models mainly include mathematical model, ecological model, landscape ecological model and digital ground model [17]. At present, the mathematical models widely used are as follows: Pressure-State-Response (PSR) [18], Driving forces-State-Response (DSR) [19],Pressure-State-Function-Response (PSFR) [20], Driving forces-Pressure-State-Impact-Response (DPSIR) [21], and the improved model proposed on the basis of these models. The advantages and disadvantages of each research model are shown in Table 1.

Table 1. Ecological security evaluation model

Model	Advantages	Disadvantages
PSR	It can better reflect the causal relationship of environmental degradation caused by external environmental pressure , emphasize the source of environmental pressure, and is often used to evaluate a wide range of environmental objects.	When the index of non-environment variable is represented, the concept of criterion layer is easy to be confused.
DSR	It can better reflect the causal relationship between human and environment and emphasize the social factors that increase or decrease environmental pressure.	When driving force is directly substituted for pressure, the flexibility of driving force cannot be fully reflected.
PSFR	It can accurately reflect the degree of human comprehensive interference.	At present, it is in the development stage, and the method of constructing index system and dividing evaluation unit needs to be improved.
DPSIR	It has the characteristics of strong comprehensiveness, complete and clear logic, and the circular closed structure formed by it can effectively measure the running state of the ecosystem.	It cannot fully reflect the diversity dimension of environmental and socioeconomic causal relationship, and the state of ecosystem security cannot be comprehensively evaluated.

Because the model method can clearly express the interaction between human activities and ecological environment, and has the characteristics of integrity, comprehensiveness, systematicness and flexibility, it has become the main method of ecological security assessment. However, the existing research models ignore the potential threat of ecological disaster to ecological security, and the research on ecological management, the last line of defense to ensure ecological security, is relatively weak.

3.The system construction of watershed ecological security evaluation indexes

The construction of evaluation indexes system is very important in watershed model assessment. In recent years, relevant scholars have established different watershed index evaluation systems according to the characteristics of the studied watershed. The ecological security of Daqing River Basin was evaluated by 23 indicators which were constructed from 10 criteria layers such as population, economy, land use and water resources utilization, based on the DPSR model(SIMA wenhui et al., 2021) [22]. The ecological security of the Huaihe River Basin was evaluated by 20 indicators based on the model of Pressure-State-Response(RUAN jun et al., 2021) [23]. The ecological security of the Taolai River Basin was evaluated by 10 indicators which were constructed from the criterion layer of contribution, vitality, organization and resilience(PAN jinghu et al., 2021) [24]. Although several evaluation index systems have been constructed for watershed ecological security, the classification of evaluation indicators is complicated and there is no clear standard. It is necessary to carry out targeted research based on the natural, economic and social characteristics of the study area.

3.1. The thought of index system construction

The factors within the ecosystem are interrelated. And the interaction can be expressed by causal feedback loop. The Yellow River Basin is a complex ecosystem integrating nature, economy and society. The core of river basin index system construction is to clarify the complex relationship between watershed ecological environment and human economy and society[25]. The selection of indicators follows the principles of comprehensiveness, representativeness, independence, and accessibility[26]. And the indexes need to fully reflect the main factors affecting the ecological security of the basin, which are vegetation degradation, soil desertification, water resources distribution, etc. Then, according to the dynamic and preventable characteristics of river basin ecological security, the ecological security of the Yellow River Basin can be studied based on the PSR model and PSDRM(Pressure-State-Hidden Danger-Response-Management) model which is added ecological security risks and management module. The relationships between multiple ecological indicators need to be analyzed according to the theory of system dynamics, and it is important to highlight the core management role of people in the watershed ecosystem, so as to ensure the ecological security of the basin through multiple departments and economic interests such as government and market.

The evolution process of ecological security lies in the triggering or development of hidden danger factors which are the potential factors for the deterioration of ecological security status or mutual security relations. The greater the hidden danger, the greater the possibility of deterioration of ecological security[27]. The hidden danger emphasizes the occurrence of ecological security problems at the watershed scale and the transfer process between watersheds, and analyzes the evolution mechanism of watershed ecological security.

Ecological security management is a powerful guarantee measure for human beings actively intervene and restore ecology. However, it is difficult to achieve the ideal ecological restoration effect, only relying on the voluntary or diversified cooperation of various management departments and environmental supervision. So the efficient management is required to make multi-sectors and interest groups work together to restore the ecological environment.

3.2. Threat factors analysis of watershed ecological security based on system dynamics

The system dynamics model emphasizes the interaction, connection and dynamic evolution process between watershed ecosystems[28]. The research problem is described by a causality diagram consisting of interconnected feedback loops[29]. The evaluation index of watershed ecological security was research from the perspective of system dynamics to define the potential impact factors that threaten the ecological security of the basin within a certain spatio-temporal window. Therefore, it is necessary to abstract the objects that threaten the ecological security according to the ecosystem, and decompose them by layers to find the bottom direct threat unit. The direct results and relationships of resources exploitation , vegetation coverage, land desertification, water conservation function, water resources, geology and geomorphology, soil erosion, sediment deposition, river connectivity, landscape fragmentation, natural disasters, biodiversity, the proportion of secondary industry, GDP, environmental protection investment, environmental protection technicians and environmental pollution control in the basin are simulated by analyzing the causal relationship of their interactions and establishing causal effect diagram. On this basis, the main factors affecting ecological security are recognized (Table 2). The influence mechanism of each index on ecological security is analyzed to construct the possible risk causal feedback loop diagram of the Yellow River Basin (Fig.1), which lays a foundation for combing the ecological security evaluation index.

Table 2. Analysis of ecological security threat factors in the Yellow River Basin

Serial number	Potential risk factors	Remarks (Determine parameters according to ecological status and human activities)	Subordinate unit
1	The weight of industy	The secondary industry in the Yellow River Basin largely determines its economic focus. The improvement of GDP can promote investment in environmental protection which can be used to train a large number of environmental technicians. By improving the sewage treatment rate and the comprehensive utilization rate of solid waste, environmental pollution can be reduced and the threat to ecological security can be reduced.	Pressure layer, response layer, management layer
2	Population density	The increase of population promotes GDP growth, but aggravates the adverse impact of human activities on the ecological environment, and the personal average resources are reduced.	Pressure layer,
3	Resource exploitation	Destruction of surface vegetation, resulting in land desertification, water conservation function decline, is detrimental to the storage of water resources. The destruction of geological landforms causes soil erosion. The gob area caused by resource exploitation destroys topography, which induces soil erosion, causes sediment deposition, destroys river connectivity, induces natural disasters, and threatens biodiversity.	Pressure layer, state layer, hidden danger layer
4	The Yellow River diversion water	The unreasonable development and utilization of water resources, Ecological water is occupied and biodiversity is declining.	Pressure layer, hidden danger layer, response layer

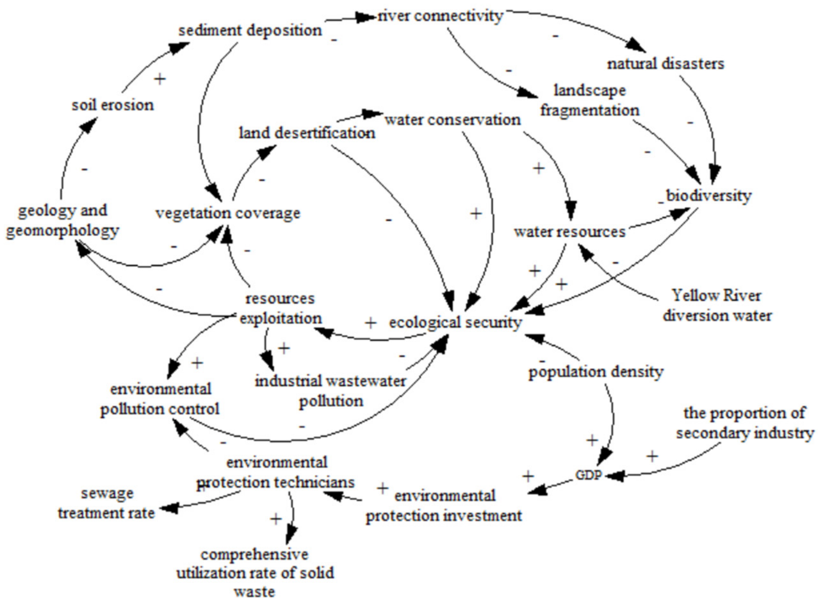

Fig.1. Causal feedback loop diagram of risk in the Yellow River Basin

3.3. The design of Index system framework

The index system constructed by PSDRM model covers social economy, ecological environment, threat hidden danger, government behavior, management regulation and so on, which can fully and accurately reflect the impact of human activities and natural factors on the ecological security of the basin. The pressure module is the direct cause of changes in the degree of ecological security. Ecological security pressure is analyzed from social, economic and environmental aspects. The state indicator module includes the consumption and impact of pressure indicators on natural resources and the environment. Therefore, the ecological security status of the basin is analyzed from resources and environment. The Ecological security risks discussed in this article are induced by the main threat factors of resource development and fragile ecological environment in the Yellow River Basin, which are controllable or semi-controllable. Ecological security risks are analyzed from three aspects of the Yellow River watercourse and its environment and biology. Response refers to a series of corresponding countermeasures made by human owing to the stress of the river basin. The ecological security management of the Yellow River Basin is carried out from two aspects: behavioral measures and economy. Countries or regions adopt relevant ecological security strategies and actions and use relevant professional knowledge to design appropriate control methods.

Based on the thought of PSDRM model, combined with the ecological security threat factors of the Yellow River Basin, a four-level ecological security evaluation index system for the Yellow River Basin was established. The ecological security index of the Yellow River Basin as the first layer represents the comprehensive status of ecological security in the Yellow River Basin, that is, the target layer (V). The second layer is the criterion layer (A), which is used to establish the "pressure-state-hidden danger-response-management" framework. The third layer is the factor layer (B), which classifies the factors affecting the criterion layer[12]. The fourth layer is the index layer (C). The positive index value is proportional to the ecological security, and the negative index value is inversely proportional to the ecological security. Specific as Table 3.

Table 3. Evaluation Index System of Ecological Security in the Yellow River Basin

The target layer（V）	The criterion layer（A）	The factor layer（B）	The index layer（C）	Indicator direction
Ecological security of the Yellow River Basin	Pressure	Social pressure	Urban population density	（-）
		Economic pressure	Per Capita GDP	（+）
			Energy consumption per GDP	（-）
			Water consumption per GDP	（-）
		Environmental pressure	Industrial wastewater emissions	（-）
			Industrial solid waste emissions	（-）
			Water intake of Yellow River diversion	（-）
			Coal production	（-）
	State	Environmental state	Annual mean precipitation	（+）
			Landscape fragmentation	（-）
			The proportion of days with air quality greater than level 2	（+）
			Soil and water conservation capacity	（+）

Hidden danger	Resource state	Water quality composite score	（+）
		Per capita water resources	（+）
		Per capita public green space area	（+）
	River hazards	River connectivity	（+）
		Riparian zone vegetation coverage	（+）
	Environmental hazards	Soil erosion rate	（-）
		Land use type transformation coefficient	（-）
	Biological hazards	Bio-diversity	（+）
Response	Government response	Reformation area	（+）
		Sewage treatment rate	（+）
		Comprehensive utilization rate of industrial solid waste	（+）
		Water resources utilization ratio	（+）
Management	Measures management	Number of technician	（+）
	Economic management	The proportion of education investment in GDP	（+）
		Second industry ratio	（-）
		The proportion of environmental protection investment in GDP	（+）

4.Conclusion and suggestion

4.1. Conclusion

(1) PSDRM model is a continuous improvement of PSR model, which is composed of five factors including pressure, state, hidden danger, response and management. In other words, on the basis of PSR framework, ecological security hidden danger and management are added, and the index system is more systematic and comprehensive, and makes up for the deficiencies of static indicators of PSR.

(2) In terms of index selection, indicators with characteristics of the Yellow River basin are selected, such as water resource exploitation and utilization rate, raw coal production, water consumption of ten thousand yuan GDP, vegetation coverage of riparian zone, etc., which can better reflect the interaction between human society and ecological environment and reflect the importance of ecological security management of the Yellow River Basin.

(3) Compared with the traditional ecological security research model, this paper determines the hidden ecological security indicators according to the threat factors, in order to take measures to control the adverse development trend before the evolution of ecological security, and to manage the ecological security from the source, so as to lay the foundation for the regional differential control of the Yellow River Basin.

4.2. Suggestion

(1) At present, no unified evaluation method has been developed for ecological security evaluation standards, which is also a major difficulty in ecological security research. Most scholars adopt certain dimensions for evaluation indicators based on existing research results, conduct quantitative processing for participating index factors, and use standardized methods to convert standardized values and comprehensive index values of indicators into grade values, so as to conduct quantitative classification. The subjectivity is strong, so it is necessary to consider the threshold values of multiple unbalance states in the basin ecosystem, and the quantification classification based on the threshold value is more objective. However, the ecological security threshold is dynamic in time and space, which needs to be determined according to specific spatio-temporal conditions. Therefore, the quantitative research of ecological threshold value should be strengthened.

(2) With the continuous development of remote sensing technology, image classification technology and computer technology, remote sensing image is more convenient for calculation and interpretation. Therefore, geographic information system software can be used to realize ecological security assessment at different time and space scales. However, due to the lack of relevant index system, standards and assessment guidelines for ecological security assessment, ecological security assessment service has not been fully realized. Therefore, it is suggested to compile guidelines for ecological security assessment in different areas such as mines, sensitive areas, water erosion and wind erosion areas, and key functional areas, so as to realize operational ecological security assessment and provide technical support for natural resource assets leaving office audit.

References

1. Yang W., Zhou L., Sun D. Ecological vulnerability assessment of the Yellow River Basin based on partition − integration concept. Remote Sensing for Natural Resources, 33(03): 211-218(2021).
2. Xiao F., Xu Y., Huang D., et al. Impact of climate change on ecological security of the Yellow River Basin and its adaptation countermeasures[J]. Yellow River, 3(01): 10-14+52(2021).

3. Zhang H. Ecological protection and high-quality development in the Yellow River Basin are guaranteed by scientific management methods[J]. Yellow River,42(05):1-7+12(2020).
4. Qiu Z., Mao D.,Xiang H., et al. Patterns and changes of wetlands in the Yellow River Basin for 5 periods[J]. Wetland Science, 19(04): 518-526 (2021).
5. Mou X., Zhang X., Wang X., et al. Ecological change assessment and protection strategy in the Yellow River Basin[J]. Strategic Study of CAE, 24(01): 113-121 (2022).
6. Ren B., Zou Q. The evaluation of environmental carrying capacity in Yellow River Basin and the policy orientation for further ascension[J]. Journal of Northwest University(Natural Science Edition, 51(05): 824-838 (2021).
7. Wang Y., Chen Y., Wang H., et al. Ecosystem change and its ecohydrological effect in the Yellow River Basin[J]. Bulletin of National Natural Science Foundation of China, 35(04): 520-528 (2021).
8. Tan Y., Yang M. On the profound connotation of Xi Jinping's concept of ecological security[J]. Socialism Studies, (05): 89-95 (2021).
9. Wu B., Yu Q., Lin H. Basic concepts and theoretical system of eco-security[J]. Forestry Economics, 38(07): 19-26 (2016).
10. Yan B., Lv S., Zhao M., et al. Advances in the research on assessment methods of grassland ecological security[J]. Chinese Journal of Grassland, 41(05): 164-171 (2019).
11. Zhang K., Lin N., Xu D., et al. Research advance on ecological security in China: assessment models and management measures[J]. Journal of Ecology and Rural Environment, 34(12): 1057-1063 (2018).
12. Xie G. Research on the farmland ecological safety in Guangzhou[J]. Guangdong Agricultural Sciences, 38(22): 152-154 (2011).
13. Ying L., Kong L., Xiao Y., et al. The research progress and prospect of ecological security and its assessing approaches[J]. Acta Ecologica Sinica, 42(05): 1679-1692 (2022).
14. Peng J., Dang W., Liu Y., et al. Review on landscape ecological risk assessment[J]. Acta Geographica Sinica, 70(04): 664-677 (2015).
15. Wan H., Wang S., Chen B., et al. Ecological risk assessment and spatial threshold analysis of wetlands in the Sanjiang plain[J]. Acta Ecologica Sinica, (16): 1-12 (2022).
16. Zhang T., Wang T., Huang Q., et al. Ecological risk assessment of Lhasa River Basin on the Tibetan Plateau[J]. Acta Ecologica Sinica, 38(24): 9012-9020 (2018).
17. Rao L., Zhou L., Xu C., et al. Connotation, method and practice of the quality assessment on ecoenvironment[J]. Subtropical Soil and Water Conservation, 32(03): 37-41+54 (2020).
18. SU S, LI D, YU X, et al. Assessing land ecological security in Shanghai (China) based on catastrophe theory[J]. Stochastic Environmental Research and Risk Assessment, 25(6): 737-746 (2011).
19. Tan Y., Yu Z. An ecological security evaluation of Huaihe river based on DSR[J]. Journal of Anhui Agricultural University(Social Sciences Edition) , 21(05): 35-39 (2012).
20. Liu X., Shao Y., Cui S., et al. Ecological security assessment in Dongjiang lake watershed based on PSFR model[J]. Resources and Environment in the Yangtze Basin, 24(S1): 197-1205 (2015).
21. PIRRONE N, TROMBINO G, CINNIRELLA S, et al. The Driver-Pressure-State-Impact-Response (DPSIR) approach for integrated catchment-coastal zone management: preliminary application to the Po catchment-Adriatic Sea coastal zone system[J]. Regional Environmental Change, 5(2-3): 111-137 (2005).
22. Sima W., Hu X., Shen Z., et al. Water ecological safety valuation index system of Daqing river basin[J]. Water & Wastewater Engineering, 57(01):90-95+102 (2021).
23. Ruan J., He G., Wang Y. Dynamic assessment of regional ecological security based on ideal point-unascertained measurement theory[J]. Science Technology and Engineering, 21(16):6951-6957 (2021).
24. Pan J., Wang Y. Ecological security evaluation and ecological pattern optimization in Taolai River Basin based on CVOR and circuit theory[J]. Acta Ecologica Sinica, 41(07): 2582-2595 (2021).
25. Wu D., Liu Y., Liu Y., et al. Progress on ecological security evaluation of cultivated land[J]. Chinese Journal of Eco-Agriculture, 23(03): 257-267 (2015).
26. Kang H., Li X., Chen X., et al. Evaluation method and its application of river ecological security in Fujian province[J]. Hydraulic Science and Technology, (03): 1-6(2019).
27. Wang G. Ecological security mechanism and assessment method based on potential danger factors-the case study of liaohe river watershed[D]. Dalian: Dalian University of Technology, (2007).
28. Han S., Zhang L., Chen Y. Fallow scale of major grain producing areas in Jiangsu Province under food security and ecological safety constraints[J]. Transactions of the Chinese Society of Agricultural Engineering, 2021, 37(23): 247-255 ().
29. Zhu B., Tang J., Jiang M., et al. Simulation and regulation of carbon market risk based on system dynamics[J/OL]. Systems Engineering-Theory & Practice: 1-21.