GIS-Based Ecological Sensitivity Analysis and Assessment of the Middle Reaches of the Syr Darya River: Postprint

Authors: Zhang Guangchuang, Wang Jie, Liu Dongwei, Jelili Abduweli

Date: 2020-04-26T00:00:00+00:00

Abstract

Taking the middle reaches of the Syr Darya River as the study area, nine ecological sensitivity indicators—including elevation, slope, aspect, accumulated temperature, precipitation, land cover, vegetation coverage, water buffer zone, and soil—were selected to construct an ecological sensitivity evaluation index system for this region. Combining the Analytic Hierarchy Process (AHP) with GIS spatial analysis, the spatial distribution characteristics of ecological sensitivity in the middle reaches of the Syr Darya River were investigated. The results indicate that ecological sensitivity in the middle reaches of the Syr Darya River generally exhibits a spatial differentiation pattern characterized by high values in the central region and low values in the peripheral areas. The ecological sensitivity of the study area is classified into five levels: extremely sensitive, highly sensitive, moderately sensitive, slightly sensitive, and insensitive, with the areal proportions of each sensitivity zone accounting for 4.39% , 10.48%, 29.97%, 31.26%, and 23.90% of the total area, respectively. The degree of ecological sensitivity in the study area is significantly influenced by vegetation coverage and water body factors, with the extremely sensitive and highly sensitive zones represented by the Chardara Reservoir and the main stream of the Syr Darya River exhibiting the highest ecosystem sensitivity. Climate factors exert a notable impact, with accumulated temperature and precipitation contributing to a certain directionality in the degree of ecological sensitivity. Variations in land cover types and soil types result in diverse degrees of ecological sensitivity across the middle reaches of the Syr Darya River; areas with higher ecological sensitivity are primarily distributed in and around reservoirs and rivers, where farmland constitutes the dominant land cover type and soft gley soil represents the primary soil type. Ecological sensitivity in the middle reaches of the Syr Darya River demonstrates a positive correlation with elevation and slope factors, while showing an aspect-related distribution pattern of higher sensitivity

on south-facing slopes and lower sensitivity on north-facing slopes. The comprehensive evaluation results are presented in map form through overlay statistics of each sensitive zone area, providing a reference for ecological environmental protection and land development and utilization in the middle reaches of the Syr Darya River.

Full Text

Analysis and Evaluation of Ecological Sensitivity in the Middle Reaches of the Syr Darya River Based on GIS

ZHANG Guang-chuang[1], WANG Jie[1], LIU Dong-wei[1], Jilili Abuduwaiti[2] [1]College of Ecology and Environment, Inner Mongolia University, Hohhot 010021, Inner Mongolia, China [2]Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China

Abstract

An ecological sensitivity evaluation index system was constructed for the middle reaches of the Syr Darya River by considering elevation, slope, aspect, accumulated temperature, precipitation, land cover, vegetation coverage, water buffer zone, and soil ecological sensitivity as indicators. By combining this system with the analytic hierarchy process and geographic information system (GIS) spatial analysis functions, evaluation indices were formulated for the middle reaches of the Syr Darya River. Spatial and comprehensive evaluation analyses reveal the spatial distribution characteristics of ecological sensitivity in the middle reaches of the Syr Darya River. The results show that the ecological sensitivity of the middle reaches of the Syr River generally reflects the spatial differentiation characteristics of the central high and low ambient environment. The ecological sensitivity of the study area is divided into five grades: extremely sensitive, highly sensitive, moderately sensitive, mildly sensitive, and insensitive, accounting for 4.39%, 10.48%, 29.97%, 31.26%, and 23.90% of the total study area, respectively. The areas were significantly affected by climatic factors, and the accumulated temperature and precipitation factors resulted in a certain degree of directionality with respect to the ecological sensitivity of the study area. The degree of ecological sensitivity in the study area was affected by vegetation coverage, and the water body factors exhibited considerable influence. The sensitivities of the ecosystems in the extremely sensitive and highly sensitive areas, represented by the Chaldala Reservoir and the main stream of the Syr River, respectively, were observed to be the highest. The degree of ecological sensitivity in the study area can be attributed to differences in land cover and soil types. In land cover types that were primarily farmland, the soil type was primarily soft subsoil. The ecological sensitivity of the study area was positively correlated with elevation and slope factors. The slope direction shows a low distribution pattern toward the south (slope direction) and a high distribution pattern toward the north (slope direction). The comprehensive evaluation

results are based on the superimposed statistics of each sensitive area, which provide a reference for ecological environmental protection, land development, and utilization of the middle reaches of the Syr Darya River.

Keywords: ecological sensitivity; sensitivity analysis; index system; middle reaches of the Syr Darya River; Central Asia

2.2 Data Sources and Preprocessing

The digital elevation model (DEM) data, Landsat 8 OLI imagery, and ArcGIS software were used as primary data sources and analytical tools for this study. The DEM data was processed using ArcGIS spatial analysis functions to derive elevation, slope, and aspect parameters. Landsat 8 OLI imagery was preprocessed using ENVI software for radiometric calibration and atmospheric correction to obtain surface reflectance data. These datasets were subsequently used to calculate vegetation indices and land cover classifications for the ecological sensitivity evaluation. The spatial resolution and temporal coverage of the remote sensing data were selected to match the requirements for regional-scale ecological assessment.

2.3 Ecological Sensitivity Index System

2.3.3 Index Construction and Weighting The ecological sensitivity index system was constructed based on multiple factors including terrain (elevation, slope, aspect), climate (accumulated temperature, precipitation), land cover, vegetation coverage, water buffer zones, and soil characteristics. Each factor was classified into sensitivity levels according to established criteria. The analytic hierarchy process (AHP) was employed to determine the weight distribution for each evaluation index, ensuring that the relative importance of different factors was quantitatively represented in the comprehensive assessment.

2.4 Spatial Analysis Methods

2.4.2 Buffer Analysis Buffer zones were established around water bodies and other sensitive features to quantify their influence on surrounding ecosystems. The buffer distance was determined based on the ecological characteristics of the study area and the specific requirements of sensitivity evaluation. This approach allowed for the assessment of how proximity to water resources affects ecological sensitivity patterns across the landscape.

2.4.4 GIS Overlay Analysis ArcGIS overlay analysis functions were utilized to integrate multiple factor layers and generate comprehensive ecological sensitivity maps. The spatial superimposition of individual sensitivity layers followed the weighted linear combination method, where each factor layer was multiplied by its corresponding weight derived from the AHP process. The final composite map represents the integrated ecological sensitivity index for the middle reaches of the Syr Darya River.

3 Results and Analysis

3.1 Analysis of Evaluation Factors

3.1.1 Elevation Factor Elevation significantly influences ecological sensitivity in the study area. Areas below 3400 m account for 29.62% of the total area and exhibit relatively low sensitivity. The elevation range of 3400-3600 m covers 52.58% of the area and shows moderate sensitivity, primarily due to the distribution of farmland and settlement areas. Higher elevation zones above 3800 m demonstrate increased sensitivity associated with steep slopes and fragile ecosystems. The spatial distribution of elevation-based sensitivity correlates with land use patterns and vegetation types.

3.1.2 Slope Factor Slope gradient directly affects soil erosion potential and ecosystem stability. Gentle slopes (5-9°) covering approximately 30% of the area show low sensitivity and are primarily used for agricultural activities. Moderate slopes (9-14°) exhibit increased sensitivity due to higher erosion risk. Steep slopes (>26°) represent highly sensitive areas where vegetation cover is crucial for preventing soil degradation. The slope factor demonstrates a strong correlation with land cover types and soil conservation requirements.

3.1.4 Temperature Factor Accumulated temperature is a critical climatic factor affecting ecological sensitivity. The study area shows significant spatial variation in thermal conditions, with accumulated temperature decreasing with elevation. Areas with higher accumulated temperature values generally support more diverse ecosystems but may also experience greater anthropogenic pressure. The temperature factor exhibits directional patterns in its influence on ecological sensitivity, with north-facing slopes typically showing different sensitivity levels compared to south-facing slopes due to differential solar radiation.

[Figure 1: see original paper] Survey map of study area

The rating standards and condition of ecological index

Average random one-off index

Weight distribution and coefficient of each evaluation index

References

[1] Ablekim Abdimijit, Ge Yongxiao, Wang Yajun, et al. The past, present and future of the Aral Sea[J]. Arid Zone Research, 2019, 36(1): 7-18.

[2] Zhao Rongqin, Qin Mingzhou. Tempospatial variation of partial carbon source/sink of farmland ecosystem in coastal China[J]. Journal of Ecology and Rural Environment, 2007, 23(2): 1-6.

[3] Ouyang Zhiyun, Zheng Hua, Gao Jixi, et al. Regional Ecological Assessment and Ecosystem Service Zoning[M]. Beijing: China Environmental Press, 2009.

[4] Hu Ruji, Chen Xi, Jiang Fengqing, et al. Threat of human activities to hydrological regime in Central Asia[J]. Arid Zone Research, 2011, 28(2): 189-197.

[5] Qu Ying, Lu Yajing, Liu Ziyu. Research on the weight calculation method based on the AHP-DEMATEL method[J]. Mathematics in Practice and Theory, 2016, 46(7): 38-46.

[6] Wu Q, Li SJ, Liu SQ, et al. AHP method determining the weight of main factors controlling water inrush from coal seam floor and system research and development[J]. Coal Science & Technology, 2017, 45(1): 154-159.

[7] Jiao Yiqing, Liu Yifan. Water resources in Central Asia: crux, impact and prospect[J]. Xinjiang Social Science, 2013, 23(1): 77-83.

[8] Yao JQ, Chen YN. Trend analysis of temperature and precipitation in the Syr Darya Basin in Central Asia[J]. Theoretical and Applied Climatology, 2014, 120: 521-531.

[9] Gong Zitong, Chen Zhicheng, Zhang Ganlin. World reference base for soil resources (WRB): establishment and development[J]. Soils, 2003, 35(4): 271-278.

[10] Kuang Yang, Li Hao, Xia Jun, et al. Impacts of climate change on transboundary water resources and adaptation management framework[J]. Advances in Climate Change Research, 2018, 14(1): 67-76.

[11] Huang Junchang, Liu Wei. The determination of index system of sensitivity factors in ecological sensitivity zoning[J]. Modern Agricultural Science and Technology, 2006, 35(19): 155-156.

[12] Bergengren J, Waliser D, Yung Y. Ecological sensitivity: a biospheric view of climate change[J]. Climatic Change, 2011, 107: 433-457.

[13] Walker N, Reddy GPO, Maji AK, et al. GIS-based multicriteria overlay analysis in soil-suitability evaluation for cotton (gossypium spp.): a case study in the black soil region of Central India[J]. Computers & Geosciences, 2012, 41(2): 108-118.

[14] Zhang Xueqi, Mansur Shabit, Ma Guofei. Effects of climate change on grain production in plain oasis in the Yarkant River Basin[J]. Arid Zone Research, 2018, 35(3): 705-712.

[15] Yin Gelan, Shao Jing' an, Guo Yue, et al. Study of land use change and eco-environmental response in the core area of mid-route of south-to-north water transfer project[J]. Journal of Geo-Information Science, 2017, 19(1): 59-69.

[16] Xu Changlin. Variations in vegetation composition and nutrient characteristics related to alpine meadow in the Northeast margin of the Qinghai-Tibet Plateau[J]. Acta Prataculturae Sinica, 2016, 25(4): 26-35.

[17] Pei Zhilin, Yang Qinke, Wang Chunmei, et al. Spatial distribution of vegetation coverage and its affecting factors in the upper reaches of the Yellow River[J]. Arid Zone Research, 2019, 36(3): 546-555.

[18] Sun Xiangyang. Soil Science[M]. Beijing: China Forestry Publishing House, 2005: 114-124.

Note: Figure translations are in progress. See original paper for figures.