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Analysis of Spatial-Temporal Changes in Ecological Sensitivity and Driving Forces in the Han River Basin

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Abstract: *Research on ecological sensitivity can help protect ecosystems, guide ecological restoration, assess disaster risk, and promote sustainable development. By combining the entropy weight method with geographic information system (GIS) and remote sensing (RS) methods, 13 index factors were selected and treated at the grid scale, and quantitative models of soil erosion sensitivity, habitat sensitivity, geohazard sensitivity and ecological protection sensitivity were constructed to assess the comprehensive ecological sensitivity of the Han River basin. At the same time, the geographic probe model is used to analyze each indicator factor to reveal its variability and interaction in spatial and temporal evolution. The results show that: (1) the area of highly and extremely sensitive areas in the study area decreased significantly from 2000 to 2020, and a large number of moderately sensitive areas were transferred to lightly sensitive areas, and the ecological environment was improved. only less than 1% of the highly and extremely sensitive areas in 2020, and the proportion of lightly and moderately sensitive areas accounted for 97.44%.(2) The driving force analysis shows that the overall larger share of erosion sensitivity is attributed to the larger share of soil erosion, and the future ecological protection can focus on erosion control.*

Keywords: *Geodetector; Han River Basin; Entropy method; Ecological sensitivity*

1. Introduction

Ecological sensitivity is the adaptability of ecological factors to external pressures or external disturbances without loss or reduction in ecological quality [1]. In recent years, global and regional environmental problems have become increasingly prominent due to high urbanization levels, unreasonable resources, and human activities, and ecological and environmental problems such as environmental pollution, resource shortage, and ecosystem degradation have become important bottlenecks limiting socioeconomic development. [2-4] It is important to conduct ecological sensitivity studies for regional ecological environmental protection and management. Translated with www.DeepL.com/Translator (free version)Ecological sensitivity is not only a key topic of research in the field of global geography, ecology and environmental science, but also a hot spot in the current research on ecological restoration and construction and achieving sustainable development [5]. Numerous studies have shown that ecological sensitivity is a valid and comprehensive indicator of ecosystem self-regulation and resilience under stress[6-8]. In order to explore how to better promote the harmony between human and nature and avoid environmental damage caused by social development and human activities, it is important to evaluate the ecological sensitivity of the region.

Most of the current studies have focused on ecological sensitivity using traditional subjective weighting methods, which are complex and subjective in their calculation. The entropy weight method is widely used [9-11], the data used in this method is a decision matrix, and the determined attribute weights reflect the discrete degree of attribute values, which is in accordance with the mathematical meaning, and the calculation process is simple and avoids the interference of human factors on the weights [12]. Most ecological sensitivity studies have been conducted at the regional, municipal, and provincial scales [13-14], but less at the watershed scale. The upper reaches of the Han River basin have towering mountains, many canyons, and rich vegetation landscapes, and the Danjiangkou Reservoir is the midline water source area for the South-North Water Diversion; the Hanjiang river Plain in the middle and lower

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reaches is an important crop production area in central China [15], and the urban outgrowth process is obvious. Ecological sensitivity evaluation allows the identification of potential ecological problems in the current natural environment and the matching of various types of problems to specific spatial areas [16]. The current research trend is gradually transforming from static to spatio-temporal dynamic evolution [17-18], and the long series of data can more intuitively reflect the dynamic changes for the sensitivity of the region, which is of guidance for better rational development and utilization of land and environmental protection and restoration.

2. Materials & Methods

2.1 Study Area Overview

The Han River basin is located in central China and is one of the tributaries of the Yangtze River. It is located between the Qinba Mountains and the Jianghan Plain, and belongs to the subtropical monsoon region with a mild and humid climate and an average annual precipitation of 972mm, which is relatively abundant. However, the distribution is uneven within the year, and the runoff from May to October accounts for about 75% of the year, with large interannual variations, making it the most variable river among the major tributaries of the Yangtze. Since ancient times, it has played an important role in ecological environment and economic and social development. The Han River basin is also an important water connotation area and ecological barrier area for the South-North Water Transfer Project [19] .More than 85% of the Han River basin is hilly and mountainous, and most of the areas have high and concentrated rainfall, which, combined with unreasonable human activities, has led to soil erosion of varying degrees throughout the basin.

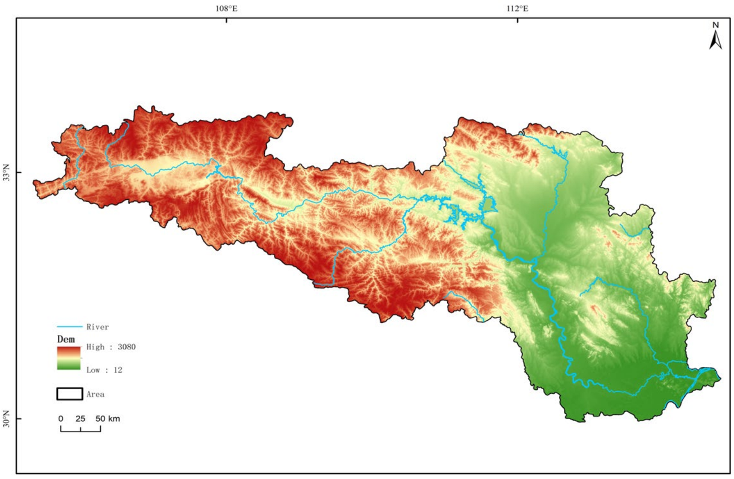

Figure 1: Location of study area

2.2 Data source and processing

Table 1: Ecological sensitivity evaluation index system of Hanjiang River Basin

Indicator layer	Indicator Factors	Data source
Soil erosion sensitivity	Average annual rainfall (mm)	China Weather Data Network
	Type of landform	National Geomatics Center of China
	Land Use Type	Resource and Environment Science and Data Center
	Soil erosion level (T/ (km^2-a))	
Habitat sensitivity	Degree of landscape fragmentation (%)	Fragstats
	Distance from road (m)	Open Street Map
	Population density	NASA World Grid Population Dataset
	DEM (m)	Geospatial Data Cloud
Geological hazard sensitivity	Slope	
	NDVI	
	Geological disaster vulnerability	Geographic remote sensing ecological network platform
Ecological protection sensitivity	Distance from the river system (m)	National Geomatics Center of China
	Distance from the protected area (km)	Geographic remote sensing ecological network platform

Sensitivity evaluation should clarify the type and likelihood magnitude of major ecological and

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environmental problems occurring in the region. In this study, based on the principles of scientificity, rationality and operability, 13 indicators were selected from the local characteristics of the Han River basin to construct the ecological sensitivity evaluation system of the Han River basin. (Table 1)

2.3 Entropy method

The entropy method is a comprehensive evaluation method dedicated to multiple objects and multiple indicators. The core principle is to determine the importance of each indicator in the assessment based on its dispersion, i.e., objective weighting. Typically, if an indicator has a low information entropy, this implies that it is more discrete and therefore provides richer information, allowing it to play a more important role in the overall assessment, which gives it a greater weight. Relatively, if the information entropy of an indicator is high, this means that it is less discrete, provides less information, is relatively less important in the overall assessment, and therefore its weight is relatively less. Table 2 shows the weights of the factors.

Table 2: Weight value of single factor ecological sensitivity grade

	2000 year			2005 year			2010 year			2015 year			2020 year		
	information entropy value(e)	Information utility value(d)	weight (%)	information entropy value (e)	Information utility value(d)	weight (%)	information entropy value(e)	Information utility value(d)	weight (%)	information entropy value (e)	Information utility value(d)	weight (%)	information entropy value(e)	Information utility value(d)	weight (%)
patch density	0.997	0.003	0.334	0.997	0.003	0.377	0.997	0.003	0.324	0.997	0.003	0.352	0.994	0.006	0.633
reserve	0.952	0.048	5.49	0.952	0.048	5.12	0.952	0.048	5.189	0.954	0.046	4.932	0.949	0.051	5.173
road	0.929	0.071	8.164	0.925	0.075	8.025	0.929	0.071	7.716	0.93	0.07	7.491	0.934	0.066	6.666
landform	0.969	0.031	3.587	0.968	0.032	3.422	0.969	0.031	3.39	0.97	0.03	3.194	0.968	0.032	3.281
dem	0.942	0.058	6.605	0.943	0.057	6.175	0.942	0.058	6.243	0.945	0.055	5.864	0.941	0.059	6.01
rain fall	0.991	0.009	1.052	0.978	0.022	2.371	0.975	0.025	2.657	0.978	0.022	2.347	0.996	0.004	0.421
slope	0.922	0.078	8.907	0.92	0.08	8.645	0.922	0.078	8.421	0.926	0.074	7.97	0.919	0.081	8.231
pop	0.862	0.138	15.80	0.819	0.181	19.52	0.833	0.167	18.08	0.798	0.202	21.652	0.793	0.207	21.039
water	0.947	0.053	6.036	0.948	0.052	5.624	0.947	0.053	5.705	0.949	0.051	5.488	0.945	0.055	5.56
landuse	0.93	0.07	7.973	0.932	0.068	7.306	0.93	0.07	7.558	0.932	0.068	7.242	0.928	0.072	7.325
erosion	0.785	0.215	24.61	0.79	0.21	22.62	0.779	0.221	23.91	0.783	0.217	23.252	0.752	0.248	25.143
calamity	0.901	0.099	11.32	0.901	0.099	10.68	0.901	0.099	10.70	0.906	0.094	10.074	0.898	0.102	10.362
ndvi	0.999	0.001	0.128	0.999	0.001	0.119	0.999	0.001	0.106	0.999	0.001	0.143	0.998	0.002	0.157

2.4 GeoDetector

The geographic detector model can test the spatial dissimilarity of univariate variables and also detect logical relationships between two variables, and is widely used in analyzing spatial dissimilarity characteristics, etc. [20-22] The core idea of this paper is that if a factor is spatially significant and consistent with ecological sensitivity, it is decisive for ecological sensitivity.

(1) Divergence and factor detection

The spatial heterogeneity of ecological sensitivity Y is detected, as well as the detection of how much a certain factor X explains the spatial heterogeneity of attribute Y, and is measured by the q-value, with a larger q-value indicating a stronger explanatory power of the independent variable X for attribute Y and vice versa.

(2) Interaction Detection

To identify the interaction between different risk factors Xs, i.e. to assess whether factors X1 and X2 together increase or decrease the explanatory power of the dependent variable Y, or whether the effects of these factors on ecological sensitivity Y are independent of each other. The formula is as follows:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{1}$$

$$SSW = \sum_{h=1}^{L} N_h \sigma_h^2 \tag{2}$$

$$SST = N\sigma^2 \tag{3}$$

h=1,..., L is the stratification of dependent variable Y or independent variable X; Nh and N are the number of cells in stratum h and the whole area, respectively; σh2 and σ2 are the variances of Y values in stratum h and the whole area, respectively. SSW and SST are the sum of within-layer variance and the

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total variance of the whole region, respectively. The value of q ranges from 0 to 1. The higher the value, the stronger the explanatory power of the independent variable X on the dependent variable Y. The interaction detector identifies whether there is an interaction between two single factors and information about the strength, linearity or nonlinearity of the interaction by comparing the magnitude of the qx values after the interaction of two single factors x1 and x2 with that of the qx values when the two single factors act alone [23].

3. Results and Discussion

3.1 Ecological sensitivity analysis of the Han River basin

According to the sensitivity index obtained after using the weighted superposition method the ecological sensitivity index is divided into 5 categories(Figure 2), non-sensitive areas (1-2), mildly sensitive areas (2.1-3.5), moderately sensitive areas (3.6-6), highly sensitive areas (6.1-7), and extremely sensitive areas (7-9). The distribution of ecological sensitivity in the Han River basin has significant spatial differences, with highly sensitive and extremely sensitive areas mainly concentrated in the western and central areas at higher elevations, while mildly sensitive and insensitive areas are mainly distributed in the southeastern low elevation areas. Moderately sensitive areas are more evenly distributed. The areas with large rates of change are mainly located in the middle and lower reaches of the Han River basin, with significant changes from 2015 to 2020, with most of the moderately sensitive areas turning into mildly sensitive areas, which is closely related to the strengthening of ecological protection by local governments.

From 2000 to 2020, the overall condition of ecological sensitivity in the Han River basin is mainly improved, and the overall proportion of sensitivity in each year in the Han River basin is mainly mildly sensitive and moderately sensitive areas. Among them, the highly sensitive and very sensitive areas are significantly reduced, the moderately sensitive areas are reduced by 60,140 km², and the mildly sensitive areas are increased by 64,329 km²(Table 3). The years of overall ecological sensitivity reduction are concentrated in the period from 2015 to 2020.

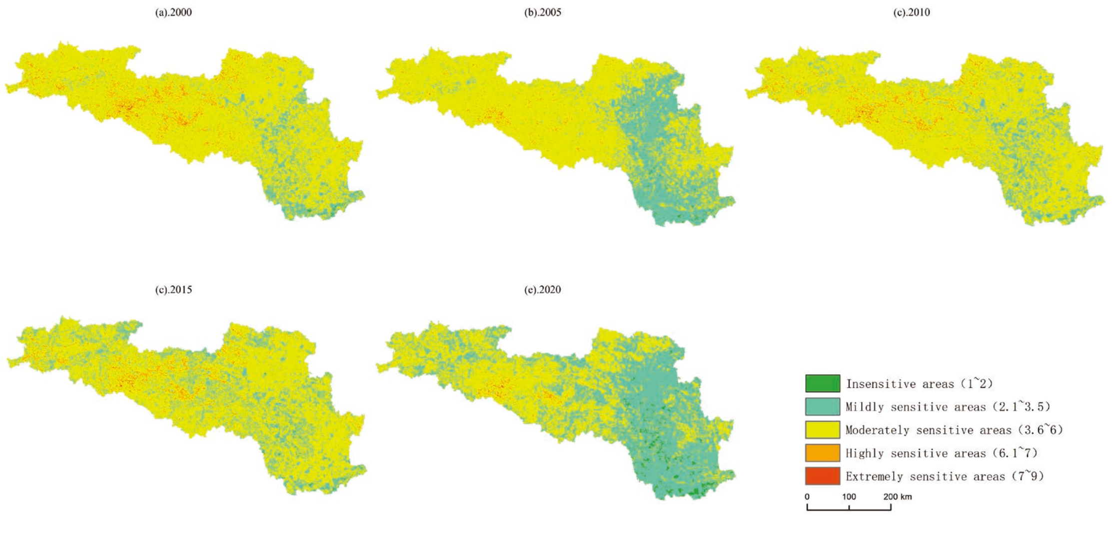

Figure 2: Zoning map of ecological sensitivity grade change in Hanjiang River Basin

Table 3: Comprehensive ecological sensitivity of Hanjiang River Basin

ecological sensitivity	grading standard	2000year area /km²	2000year proportion/%	2005 year area /km²	2005year proportion/%	2010 year area/km²	2010year proportion/%	2015year area/km²	2015year proportion/%	2020year area/km²	2020year proportion/%	2000~2020 yearchange rate/%
insensitivity	1~2	340	0.21	501	0.30	337	0.20	494	0.30	2910	1.77	755.88
slightly sensitive	2.1~3.5	18485	11.22	48095	29.20	21881	13.29	31769	19.29	82814	50.29	348.01
moderately sensitive	3.6~6	137796	83.67	114337	69.43	136677	82.99	127478	77.41	77656	47.15	-43.64
highly sensitive	6.1~7	7828	4.75	1723	1.05	5625	3.42	4808	2.92	1225	0.74	-84.35
very sensitive	7~9	239	0.15	32	0.02	168	0.10	139	0.08	83	0.05	-65.27

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3.2 Driving Factor Analysis

Using the ecological sensitivity index calculated by the entropy method as the dependent variable, a geographic probe was used to construct models for the years 2000, 2005, 2010, 2015, and 2020 in order to explore the changes in the drivers for each period. The results of the study clearly indicate that four elements such as soil erosion rate, geohazards, altitude, and slope (except in 2015) play the largest role in terms of environmental impact, and they all reach significance levels ($P<0.05$). In contrast, the effects of river, landscape fragmentation, and NDVI on sensitivity were relatively small. In the temporal dimension, there were differences in the effects of each time period on ecological sensitivity. The most significant was the difference in population density in 2015 ($p=0.135$), which indicates the extent to which human activities exacerbated ecological sensitivity in that year. In contrast, the weaker annual variation and smaller effect (0.02) was for the factor of proximity to the river, suggesting that for the effects of dependent variables, the factor of proximity to the river was relatively weak.

Interaction detection can be performed when an interaction between two factors is detected, and the definition of interaction detection is the explanatory power for the dependent variable when factors X1 and X2 act together, and this definition of interaction detection is the explanatory power for factors X1 and X2 jointly affecting dependent variables. The main goal of interaction detection is to identify those combinations of factors that have significant interaction effects in order to gain a deeper understanding of the complexity of geographic phenomena. The detection of interactions between the factors showed that the superposition of any two factors enhanced their individual explanatory power for the ecological sensitivity of the area, and most of this enhancement was non-linear. This suggests that ecological sensitivity is often influenced by more than a single factor, but is the result of multiple factors acting together. For example, in 2000, the interaction between soil erosion and altitude was most significant (soil erosion ∩ altitude 0.695), implying that higher altitudes significantly enhance the explanatory power of soil erosion as an independent variable for the spatial distribution of ecological sensitivity.

4. Conclusion

In this paper, we comprehensively used GIS related analysis tools to process and extract 13 index factors of Han River basin, calculated the weight values of each evaluation index in 2000, 2005, 2010, 2015 and 2020 according to the entropy value method, and then weighted superposition to get the ecological sensitivity of Han River basin in these 5 years, and analyzed the driving of ecological environmental impact in different years based on the geographic probe model The changes of the q-values of the factors and the detection of the interaction factors in different years were analyzed based on the geodetector model, and the following conclusions were drawn:

1) Overall, the ecological sensitivity of the Han River basin is on a decreasing trend. Spatially, mild sensitivity and moderate sensitivity account for a large proportion, and mild sensitivity is mainly concentrated in the southeast, and a larger proportion of moderate sensitive areas become mild sensitive areas in 2015-2020, and ecological sensitivity decreases significantly. In time, the rate of change of insensitive, highly sensitive and extremely sensitive areas is large but the proportion is less than 2%, and the insensitive and mildly sensitive areas increase significantly, while the moderately sensitive, highly sensitive and extremely sensitive areas show a decreasing trend, indicating that the ecological and environmental quality of the Han River basin in general continues to develop for the better over time.

2) Based on the geodetector analysis of the changes in the degree of ecological sensitivity driving by each indicator in the Han River basin in different years, the results show that soil erosion and geohazard q values are larger in each year and are the main driving factors, while the response degree of landscape fragmentation and NDVI are not obvious, indicating that the ecological sensitivity driving factors in the Han River basin do not differ much from each other in different spatial and temporal areas that play a leading driving role. . The non-linearity is enhanced in the interaction detection, which indicates that the degree of ecological sensitivity in the Han River basin is significantly influenced by multiple factors. The degree of ecological protection sensitivity is less influenced by the indicator layer, and the erosion sensitivity is more significant.

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