

# Spatial Identification of Urban Ecological Function on the North Slope of Qinling Mountains Based on Ecological Sensitivity—A Case Study in Baoji, China

Pei Wang<sup>1</sup>, Langong Hou<sup>1\*</sup>, Xiaoqin He<sup>2</sup>

<sup>1</sup>School of Civil Engineering and Architecture, Southwest University of Science and Technology, Mianyang, China

<sup>2</sup>Huzhou Normal University, Huzhou, China

Email: Angelawpwy@163.com, \*soundskyhlg@163.com

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## Abstract

Since the 17th National Congress of the Communist Party of China, ecological civilization has been the key construction goal in China, which has a profound impact on the process of urbanization. In recent years, with the rapid development of urbanization and unreasonable land development and utilization, the ecological environment has deteriorated sharply, and the stability of ecological environment has always been a difficult problem in the process of regional development. The spatial division of urban ecological function can be divided into different types of spatial utilization according to the fragile state of ecological environment, which not only guarantees urban construction but also maintains the ecological environment health, and has great economic benefits and ecological value in formulating regional development strategies and ecological protection. In this paper, from four perspectives of “land, water, human and forest”, eight factors affecting ecological sensitivity were selected, and GIS spatial superposition method was used to conduct qualitative and quantitative analysis on the ecological sensitivity of Baoji City, and the evaluation results of single factor ecological sensitivity and comprehensive ecological sensitivity were obtained. The areas with different ecological sensitivity are divided into extremely sensitive areas, highly sensitive areas, moderately sensitive areas, slightly sensitive areas and non-sensitive areas. The research shows that the proportion of extreme, high, moderate, mild and insensitive areas in Baoji City is 7.32%, 10.57%, 22.25%, 42.91% and 16.95% respectively. Finally, the areas with different sensitivity grades are identified as three types of urban ecological function areas: ecological conservation area, ecological coordinated moderate utilization area and ecological suitable con-

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struction area, so as to provide scientific theoretical basis for urban construction and land use optimization in Baoji City.

### Keywords

Baoji City, Coefficient of Variation Method, Ecological Sensitivity, Urban Ecological Function Space

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## 1. Introduction

With the rapid development of urbanization and the continuous expansion of urban construction scale, the interference of human beings on the natural ecological environment has become more and more intense. Unreasonable development methods have led to the continuous deterioration of the ecological environment and seriously affected the harmonious coexistence between the ecological environment and the city, thus slowing down the urban development process. Ecological function zoning is to divide a region into regions with different ecological functions according to the pattern of regional ecosystem, the sensitivity of ecological environment and the spatial differentiation law of ecosystem service functions (Ouyang, 2007). Ecological functional areas have extremely high ecological service value in the process of urban development, such as soil and water conservation, water conservation, wind prevention and sand fixation, biodiversity protection, etc., and are of great significance in ensuring sustainable material needs of human beings, ecosystem integrity and regional ecological security (State Council, 2001). From the ecological point of view, ecological function zoning gives a scientific and reasonable theory and direction for the rational utilization of regional natural resources and the promotion of economic benefits of ecological functions. Therefore, ecological function zoning has become an important measure for the coexistence of regional development and ecological environment.

In 1935, British scholar Tansley (Li, 2014) introduced the concept of “system” on the basis of studying the dynamic evolution of forests. In his article, he explained the concept of ecosystem and the evolution of human activities, and integrated its analysis into a set of theories for people to study. After that, the spatial regionalization method of human living area was used to discuss the regional distribution law of crops growing on the ground, and the temperature change was positioned as the index of natural environment change. According to the influencing factors of ecosystem, the research on the division of human activity areas came into being. In the 20th century, due to the constraints of objective factors at that time and the limitations of people’s understanding of ecosystem and ecological environment, and only considering a single factor, there was no unified understanding of the principles, index systems and methods of ecological regionalization and a complete set of programs. Until 1976, American ecologist Bailey (Bailey, 1976) first proposed a real ecological function zoning scheme,

which used the relationship between spaces to divide the natural environment. With the continuous development of society, the theory of ecological function zoning matures, and ecological sensitivity is gradually applied to ecological function zoning. Influenced by Bailey's theory of ecological function zoning, the theory of ecological function zoning has been applied in many aspects, which also provides research ideas for other scholars. For example, Mamat (Mamat et al., 2017), based on the theoretical zoning of nature reserves, applied the ecological sensitivity research method and analyzed the ecological environment and spatial variation, and made functional zoning of the remains in Turpan.

Compared with foreign countries, China's research on ecological function zoning started in the early 1980s, and the initial ecological function zoning was basically in the agricultural field (Xiong, 1980; Xiong et al., 1981; Fu, 1985a, 1985b; Hou, 1988). With the continuous exploration of Chinese scholars, the spatial differentiation law of the importance of ecological service function and the sensitivity of ecological environment has been gradually applied to ecological function zoning for geographical spatial zoning. With the deepening of research in the field, the research method of ecological sensitivity has developed from the early single factor evaluation method (Kang & Zhang, 2012; Wang et al., 2014) to the present multi-factor comprehensive research (Liu et al., 2015; Xiao et al., 2020; Yang, 2011; Wang et al., 2016; Li et al., 2020; Ding et al., 2019), and the research scale has gradually tended to be microscopic, and the research field has gradually matured. For example, Jian Qing (Jian et al., 2011) took Qinglong Manchu Autonomous County as the study area, selected three ecological sensitivity factors, namely desertification sensitivity, soil erosion sensitivity and habitat sensitivity, and used GIS tools and "barrel principle" to divide their ecological functions. Fu Shilei (Fu et al., 2013) explores the heterogeneity of urban spatial landscape, selects the main ecological sensitivity factors according to the actual situation of Fuxin's natural environment, and constructs an ecological sensitivity evaluation system, thus dividing Fuxin into two regional types: water-eroded desert area and wind-eroded desertification area, and then dividing the urban security pattern to adapt to different ecological sensitive areas by zoning evaluation. Liu Zhihui (Liu et al., 2018) divided the key ecological functions of Libo County with rocky desertification and soil erosion as the index system. Zhang Guangchuang (Zhang et al., 2020), etc., selected elevation, slope, aspect, precipitation and other ecological environmental impact factors, constructed an ecological sensitivity evaluation system, and divided the ecological functions of the middle reaches of the Xi'er River. In China, most of the research areas on ecological sensitivity focus on river basins, plateaus, parks, mountains and industrial parks, covering a wide range, while the research on regions with provinces, cities, counties and villages as administrative units is less. The results are mostly applied to ecological function pattern (Zhang et al., 2012), ecological restoration (Zhang & Gu, 2019), ecological protection red line (He et al., 2018), land use pattern (Ma & Li, 2018), ecological tourism land division (Hu et al., 2013), ecological space control zoning (Chen et al., 2010), landscape pattern optimization

(Dong et al., 2010), construction land suitability evaluation (Zhang et al., 2015) and other fields. In recent years, ecological function zoning has also become a hot research field. By consulting the related literatures of ecological function zoning, it is found that most of the studies at home and abroad consider natural factors, and lack of systematic analysis of the impact mechanism of human activities in the ecological environment (Qu et al., 2018). In fact, human activities and the natural environment have evolved into a close and complex coupling development relationship. Loess is accumulated in the northern slope of Qinling Mountains, with heavy wind and sand, scarce precipitation, soil erosion, desertification and other natural disasters. With the high-intensity development of cities and frequent human activities, the ecological environment is deteriorating day by day. Baoji City, located on the northern slope of Qinling Mountains, is an important heavy industry city in northwest China. The “three wastes” pollution and unreasonable urban land use pattern make the ecological environment of Baoji City more severe, but it has not been improved and treated. In order to better integrate natural resources, improve ecological environment and promote the healthy development of economic environment in Baoji City, the ecological sensitivity of Baoji City was analyzed and evaluated to provide scientific theoretical basis for the division of urban ecological land in Baoji City. Considering the complexity of ecological environment, human factors should be taken into account when selecting factors to enhance the integrity of indicators. In this paper, eight ecological sensitivity factors are selected according to the ecological environment of Baoji City, and the weights are obtained by using AHP and coefficient of variation method. By using single factor analysis and multi-factor superposition analysis method, the sensitivity of each region in Baoji City is evaluated, so that the ecological space of Baoji City is scientifically and appropriately divided into functions, providing a theoretical framework for future urban planning and ecosystem management of Baoji City.

## 2. Research Area and Research Methods

### 2.1. Overview of the Study Area

The Qinling Mountains stretch from east to west, spanning several provinces in China. It is the boundary ridge of climate zone, crop type and water system between the north and south of China. Due to the influence of ecological factors such as accumulated temperature and precipitation, slope direction, slope, vegetation coverage and light, the climate on the north and south slopes of the Qinling Mountains is quite different. The south slope belongs to subtropical monsoon climate. Because of abundant illumination, humid climate, many branches of water system and large river flow, the greenbelt often presents subtropical evergreen broad-leaved forest, while the north slope with slightly weak illumination, little precipitation and small river runoff has warm temperate monsoon climate, and the vegetation is mostly xerophytic, mainly temperate deciduous broad-leaved forest.

Baoji is located on the northern slope of Qinling Mountains, a sub-central city of Guanzhong Plain urban agglomeration, with geographical coordinates of 106°18' - 108°03' east longitude and 33°35' - 35°06' north latitude, with an area of 18,100 km<sup>2</sup> and a total population of 3.761 million. It has jurisdiction over 4 districts and 8 counties: Weibin District, Chencang District, Jintai District, Fengxiang District, Taibai County, Fengxian County, Fufeng County, Linyou County, Longxian County, Meixian County, Qishan County and Qianyang County. Baoji City belongs to continental monsoon climate geographically and is located in a semi-humid climate zone with warm temperate zone at mid latitude. The forest coverage rate of the whole city is 53.78%. There are 643,000 hectares of forest land in mountainous areas. The regional overview of Baoji City is shown in **Figure 1**.

Baoji City is a heavy industry city in Northwest China. The extensive development mode of industrial economy makes the ecological environment of Baoji City deteriorate day by day and brings serious ecological problems. Ecological environment problems such as land desertification, soil erosion and serious deterioration of water resources have become increasingly prominent, which makes the ecological sensitivity stronger, but the deterioration of ecological environment has not been improved reasonably, which seriously slows down the urban development process of Baoji City. It is very urgent to plan the ecological environment of Baoji City at present. Therefore, this paper makes a sensitivity analysis on the ecological environment of Baoji City, so as to work out a scientific and reasonable urban functional zoning, and provide an important guarantee for the harmonious development of ecological environment and economy in Baoji City.

## 2.2. Data Sources and Preprocessing

The research data include Landsat—8OLI remote sensing images of Baoji City in 2019, DEM data of Baoji City, topographic map of Baoji City and related planning texts downloaded from geospatial data cloud. Then, using the spatial analysis and statistical functions of GIS, the ecological sensitivity of Baoji City is evaluated by single factor and analyzed by comprehensive ecological sensitivity. The data type, name, and source are shown in **Table 1** below.

## 2.3. Research Methods

### 2.3.1. Analytic Hierarchy Process

Analytic hierarchy process (AHP) is a multi-factor evaluation method, which was put forward by American logistics scientist T.L. Saaty in the mid-1970s. It is a quantitative and systematic analysis method. The ecological sensitivity evaluation index system is composed of several influencing factors, and the weight of each influencing factor is also different. Therefore, AHP is used to calculate the weight of each single factor. The calculation steps are as follows:

- 1) Decompose and combine various influencing factors to establish a hierarchical structure model.

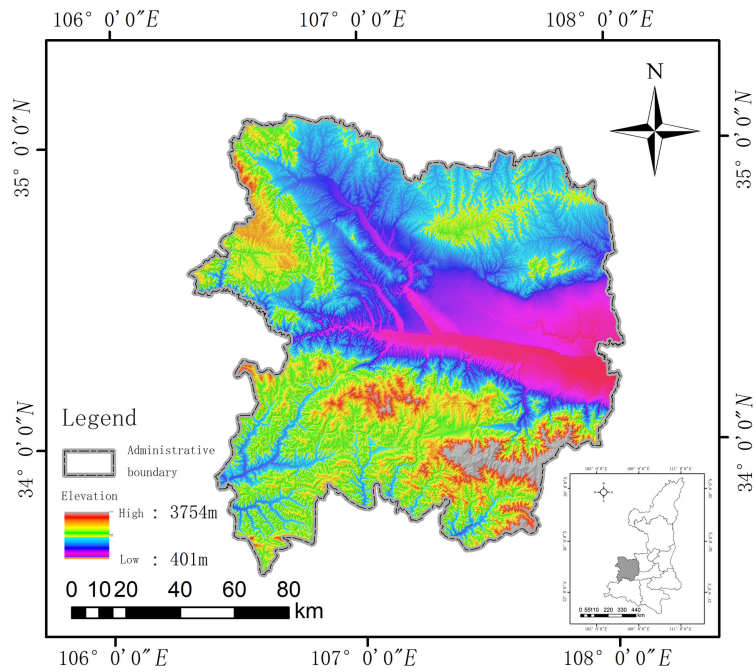


Figure 1. Regional overview of Baoji City.

Table 1. Data type, name and source.

data type	Data name	data source
Basic geographic data	1:50,000 topographic map and soil type map of Baoji City	Baoji natural resources planning bureau
remote sensing data	DEM digital elevation, Landsat8-OLI image	Geospatial data cloud
Planning text	Master Plan of Baoji City (2020-2035)	Baoji natural resources planning bureau

2) Constructing a pair comparison matrix by the range method;

$f(r_i, r_j) = C_{ij} = Cb^{(r_i - r_j)/R}$  Get the matrix  $C = (C_{i,j})_{m \times n}$  is the consistency judgment matrix. Where is a constant, which is the relative importance degree of the range element pair given in advance according to a certain standard  $R_{max} - R_{min}$  is extremely poor, where:

$$R_{max} = \max \{r_1, r_2, \dots, r_n\}, R_{min} = \min \{r_1, r_2, \dots, r_n\}$$

3) Consistency test:  $C = (C_{ij})_{m \times n} = C \cdot W^T$ .

### 2.3.2. Coefficient of Variation Method

The coefficient of variation method is an objective weighting method, which determines the index weight by statistically analyzing the variation degree of observed data among all statistical data. If the degree of variation of the analyzed data is large, the weight is also large; On the contrary, the weight given is smaller. The steps of determining the weight by coefficient of variation method are as follows:

1) find the average value of each index:  $\bar{u}_j = \frac{1}{M} \sum_{i=1}^M u_{ij}$  ( $i = 1, 2, 3, 4, 5, 6, 7, 8$ ;

$j = 1, 2, 3, \dots, M$ )

2) Find the standard deviation of each index:  $\sigma_j = \sqrt{\frac{1}{M} \sum_{i=1}^M (u_{ij} - \bar{u}_j)^2}$

3) Get the coefficient of variation of different indexes:  $K_j = \frac{\sigma_j}{\bar{u}_j}$

4) Normalized index weight:  $\omega_j = \frac{K_j}{\sum_{j=1}^M K_j}$

In the formula,  $i$  is the evaluation index category,  $j$  is the evaluation index factor, and  $\bar{u}_j$  it is the average value of indexes at all levels.  $\sigma_j$  Is standard deviation,  $\omega_j$  Is the normalized weight value.

### 2.3.3. Spatial Superposition Analysis

By using the superposition analysis function of arcGIS10.6 software in spatial analysis, the single factor sensitivity results were superimposed and analyzed, and the comprehensive analysis results of ecological sensitivity in Baoji City were obtained. See formula (1) for the mathematical model

$$S_i = \sum_{k=1}^n [W_k \times C_i(k)] \quad (1)$$

where  $i$  is the number of evaluation unit,  $K$  is the number of evaluation factors,  $n$  is the total number of evaluation factors,  $s_i$  is the comprehensive value of the  $i$ th evaluation unit,  $w_k$  is the weight of the  $w$  evaluation factor,  $C_i(k)$  is the sensitivity evaluation value of the  $k$ th evaluation factor of the  $i$ th evaluation unit.

## 2.4. Construction of Evaluation Index System and Classification of Each Factor

### 2.4.1. Construction of Evaluation Index System

Ecological sensitivity is a complex organic system composed of multiple factors, which is often the result of the interaction of complex and multi factors. When selecting the sensitive factors, we should collect the relevant suggestions of experts and refer to the research of domestic and foreign scholars. Based on the principles of comprehensive, scientific, feasible, standardized and representative, and combined with the current land use status of Baoji City, the elevation, aspect, slope, undulation, road buffer, water area factor, vegetation coverage (NDVI) and soil type are selected as the main influencing factors of ecological sensitivity in Baoji City, so as to construct the ecological sensitivity evaluation index system of Baoji City, According to the ecological sensitivity level, it can be divided into five levels: extremely sensitive, highly sensitive, moderately sensitive, mildly sensitive and non sensitive, with the values of 9, 7, 5, 3 and 1 respectively, and the specific grading standards are shown in **Table 2**.

### 2.4.2. Grade Division and Weight Assignment of Each Factor

After calculating and analyzing the weights by AHP and delphi, combined with the coefficient of variation obtained by the coefficient of variation method, the comprehensive weight of each single factor is obtained. After using AHP method

to calculate the weight of each single factor, it must go through consistency test  $C = (C_{ij})_{m \times n} = C \cdot W^T$ . The value of  $(C, T)$  is 0.04, ranging from 0 to 0.1, which indicates that it is feasible to judge the weight of ecological factors.

Using the coefficient of variation method, the coefficient of variation corresponding to each index is calculated by taking the area of each sensitivity single factor with different sensitivity levels as a unit, and the results are shown in **Table 3**.

Comprehensive weight of ecological sensitivity in Baoji city is obtained by AHP and coefficient of variation method, as shown in **Table 4**.

**Table 2.** Hierarchy of ecological sensitivity factors.

Ecological evaluation index	Impact factors	Insensitivity	Mild sensitivity	Moderate sensitivity	High sensitivity	Extreme sensitivity	AHP weight
land	Elevation/m	<902	902 - 1289	1289 - 1684	1684 - 2249	>2249	0.07321
	Slope/°	<15	15 - 25	25 - 35	35 - 45	>45	0.03301
	Aspect	due south	Southeast and southwest	East, west	Northeast, northwest	due north	0.04118
water	Fluctuation/degree	0 - 20	21 - 50	51 - 100	101 - 150	>150	0.06069
	Water buffer zone/m	>2000	1500 - 2000	1000 - 1500	500 - 1000	0 - 500	0.22403
human	soil types	rice soil	Newly accumulated soil, mountainous meadow soil	Brown soil, yellow cinnamon soil and calcareous soil	Yellow soil, yellow brown soil, calcium red soil, acid coarse bone soil	River, river	0.11143
forest	Road accessibility/m	<1000	1000 - 1500	1500 - 2000	2000 - 2500	>2500	0.30288
	Vegetation coverage (NDVI)	<0.25	0.25 - 0.45	0.45 - 0.65	0.65 - 0.85	>0.85	0.15357

**Table 3.** Weight of coefficient of variation.

	elevation	slope	Aspect	Fluctuation degree	way	waters	soil	Vegetation coverage (NDVI)
1	3705.44	5649.56	2142.727	5114.375	7130.468	14,776.48	59.27375	317.4735
3	4945.674	2807.201	4546.902	5759.33	1376.995	3226.556	679.8521	1318.487
5	5024.906	5304.65	4721.335	4328.976	3243.081	1471.234	8801.108	2503.272
7	3594.721	4179.554	4521.849	2349.874	2552.078	3938.825	8527.788	3710.757
9	831.2067	135.3074	2143.38	583.7187	12211.55	3096.416	27.98202	10,244.63
average value	3620.38954	3615.25448	3615.2386	3627.25474	2442.31	5301.9022	3619.200774	3618.9239
variance	2,303,295.751	4,014,774.445	1,449,609.301	3,628,899.498	15,658,411.13	23,094,170.81	17,031,218.85	12,268,935.7
standard deviation	1517.661277	2003.690207	1203.997218	1904.96706	3957.071029	4805.639479	4126.88973	3502.704055
variable coefficient	0.4192	0.55423	0.33303	0.52518	0.74622	0.9064	1.14028	0.96789

**Table 4.** Comprehensive weight.

Criterion layer	Index layer	Weight of AHP method	variable coefficient	Comprehensive weight	Normalized weight
Terrain factor	elevation	0.07321	0.4192	0.03069	0.03839
	slope	0.03301	0.55423	0.0183	0.02289
	Aspect	0.04118	0.33303	0.01371	0.01715
	Fluctuation degree	0.06069	0.52518	0.03187	0.03987
Water system factor	Water buffer zone	0.22403	0.9064	0.20306	0.25403
Vegetation factor	Vegetation coverage (NDVI)	0.15357	0.96789	0.14864	0.18595
	soil types	0.11143	1.14028	0.12706	0.15896
Human activity factor	Road buffer zone	0.30288	0.74622	0.22602	0.28276

### 3. Results and Analysis

#### 3.1. Single Factor Ecological Sensitivity Analysis

##### 3.1.1. Elevation Ecological Sensitivity Analysis

The elevation single factor diagram is shown in **Figure 2**. Baoji City is located on the northern slope of Qinling Mountains, with complex and diverse landforms, including low mountains, basins, plains and other types of landforms. Baoji city is mostly plain, with few basins, and the mountainous areas are mainly located in the south and southwest. It can be seen from **Figure 2** that the highly sensitive areas in Baoji city are concentrated in the Taibai Mountain area with extremely high altitude, and the general trend of sensitivity is that the low-sensitive areas in Guanzhong Plain gradually increase to the high-sensitive areas in the peripheral Taibai Mountain vein. Among them, the proportion of non-sensitive areas is small, mainly distributed near Guanzhong Plain where Meixian County is located, with an area of 3705.44 km<sup>2</sup>, accounting for 20.47%; The area of mild sensitive area is about 4945.674 km<sup>2</sup>, accounting for 27.32%, mainly distributed in parts of Longxian County, Qianyang County, Fengxiang County and Linyou. Moderately sensitive areas are scattered in the southwest border of Fengxian County and most areas of Linyou, with an area of about 5024.906 km<sup>2</sup>, accounting for 27.759%. Highly sensitive areas are mainly distributed in Jintai District and Weibin District, southwest of Longxian County, northeast of Fengxian County, northwest and southwest of Taibai, with an area of 3594.721 km<sup>2</sup>, accounting for 19.858%. Extremely sensitive areas are mainly distributed around Taibai County, covering an area of about 831.2067 km<sup>2</sup>, accounting for 4.59%. The area occupied by extremely sensitive and highly sensitive areas in Baoji City is 24.45%. This area has high elevation and high ecological sensitivity, which is prone to soil erosion and natural disasters. It should be strictly controlled and a red line area should be set up to prohibit development.

##### 3.1.2. Slope Ecological Sensitivity Analysis

The single factor diagram of slope is shown in **Figure 3**. Slope is one of the key factors affecting urban development and construction. The ecological sensitivity

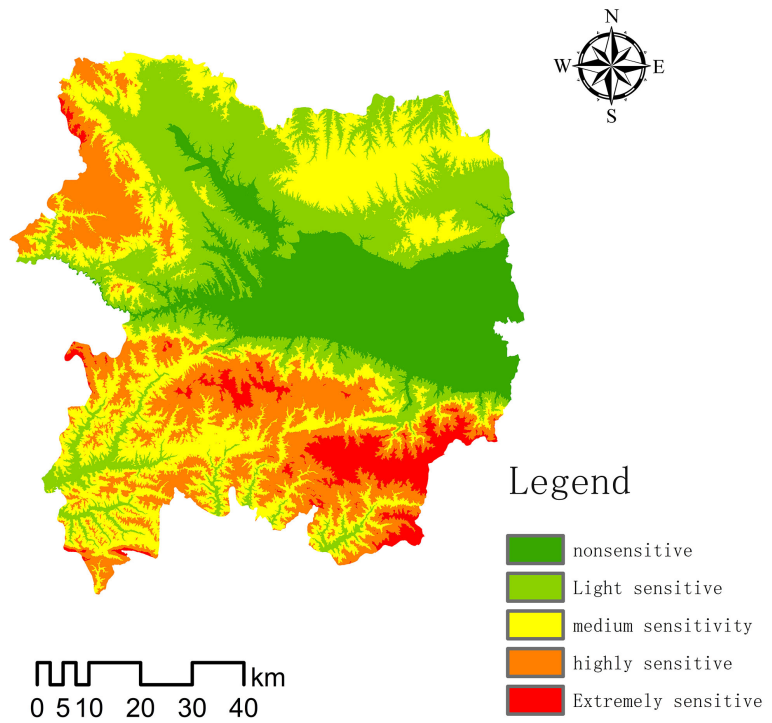


Figure 2. Elevation single factor diagram.

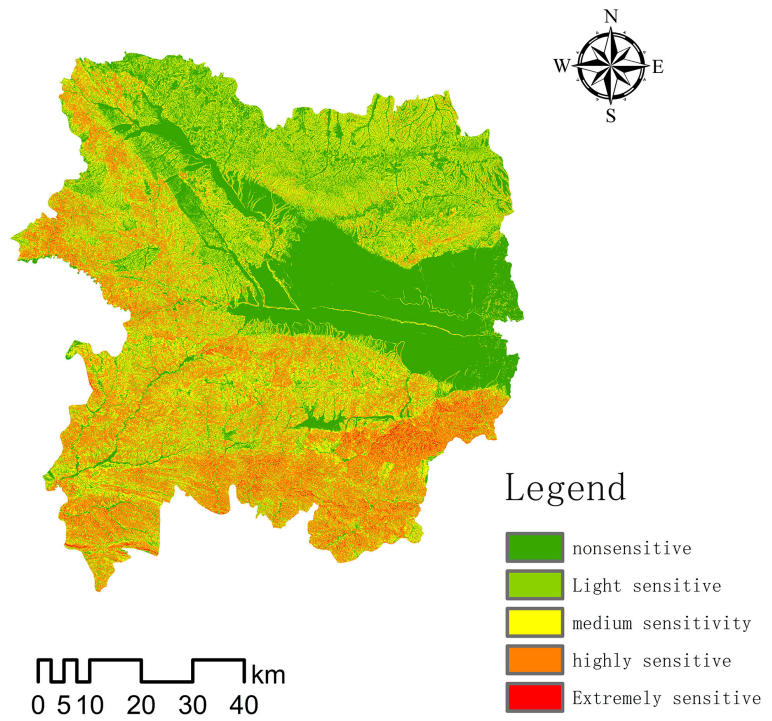


Figure 3. Slope factor.

of areas with high slope is very fragile, which easily leads to soil erosion. The greater the slope, the more serious the soil erosion is, which is a high-risk area in the future development and construction of cities. The overall sensitivity of slope

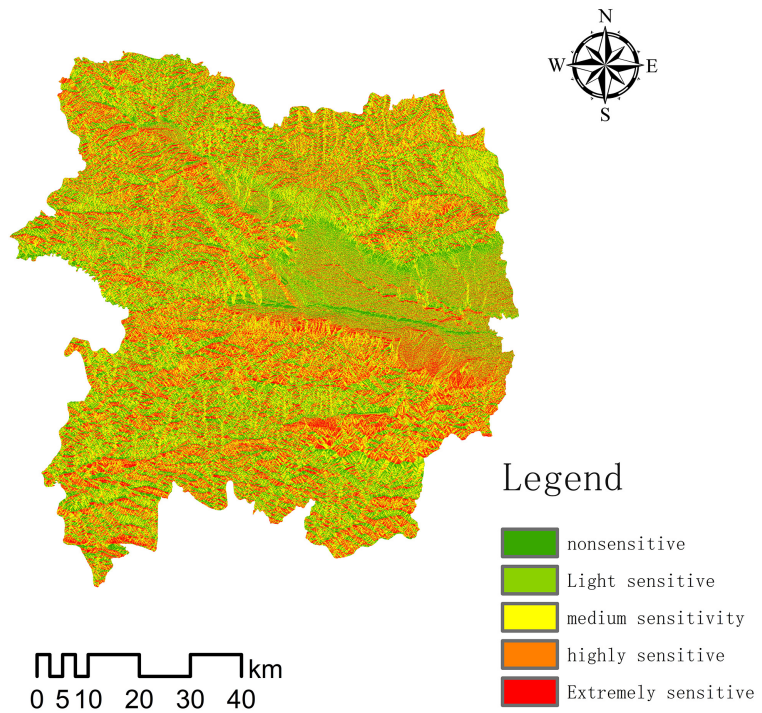
factors in Baoji city is not high, and the weight ratio is 0.02289. The extremely sensitive area with a slope greater than  $45^\circ$  is  $135.307 \text{ km}^2$ , accounting for 0.749% of the total area, mainly distributed in the surrounding areas of Taibai County, Longxian County, Fengxian County and Chencang district; Highly sensitive areas with slopes of  $35^\circ - 45^\circ$  are mainly scattered in Taibai County, Fengxian County, Chencang district County and Longxian County, with an area of about  $4179.55 \text{ km}^2$ , accounting for 23.121%. Moderately sensitive areas are scattered in Weibin District, Chencang district, Qianyang, Linyou and Fengxiang, with an area of  $5304.65 \text{ km}^2$ , accounting for 29.346%. Mildly sensitive areas are distributed in Longxian County, Qianyang County, Linyou county County and Fengxiang County, with an area of  $2807.201 \text{ km}^2$ , accounting for 15.53%; The insensitive area is  $5649.56 \text{ km}^2$ , accounting for 31.25%, which is mainly located in Guanzhong Plain.

### 3.1.3. Analysis of Ecological Sensitivity in Slope Direction

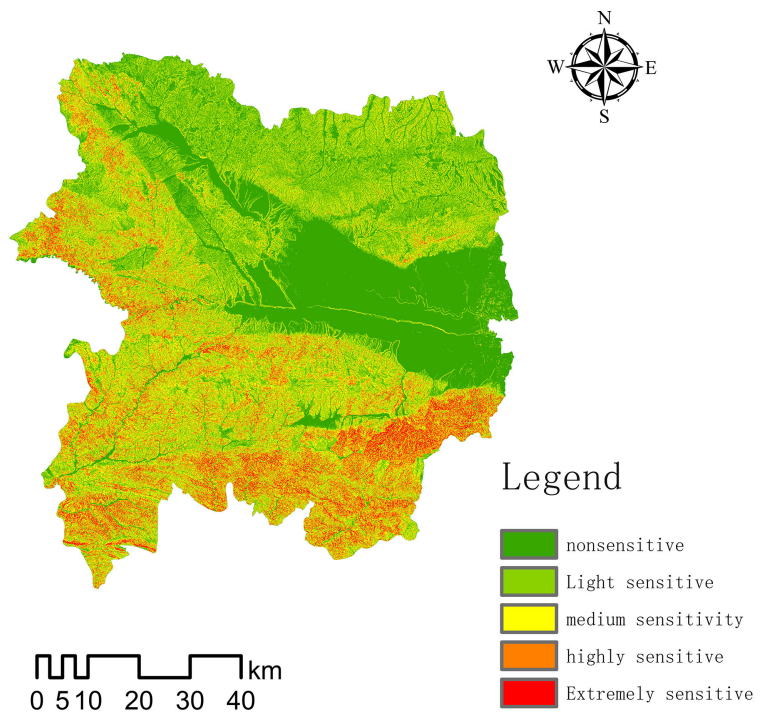
The slope single factor diagram is shown in **Figure 4**. Slope aspect has an important influence on vegetation coverage area, species richness of animals and plants, light intensity, lighting surface of buildings and energy utilization efficiency. Different slope directions have different intensity of solar radiation and illumination time, which have significant influence on temperature and soil moisture in different areas. Most of the extremely sensitive areas north of slope direction are distributed in Fengxian County and Taibai County, and scattered in the northern part of Baoji City, with an area of  $2143.38 \text{ km}^2$ , accounting for 11.86%. The highly sensitive areas facing northeast and northwest are mainly distributed in the northeast and middle of Baoji City, with an area of  $4521.849 \text{ km}^2$ , accounting for 25.015%; Non-sensitive areas with south slope direction are distributed in Fufeng, Qishan and Fengxiang, with an area of  $2142.727 \text{ km}^2$ , accounting for 11.85%. Moderately sensitive areas are mainly distributed in Qishan, Fufeng, northern Fengxiang and southwest Fengxiang. The area is  $4721.335 \text{ km}^2$ , accounting for 26.119%. Mildly sensitive areas are located in the north of Linyou, the middle of Fengxiang, the north of Qianyang, and most of Fengxian and Taibai counties, with a statistical area of  $4546.902 \text{ km}^2$ , accounting for 25.15%. Slope direction has a great influence on regional ecology, and the degree of illumination varies with the degree of ecological richness. Compared with the shade slopes of northeast and north slopes, the sunshine intensity of the sunny slopes in southeast and south slopes is stronger, and the ecological environment is better.

### 3.1.4. Ecological Sensitivity Analysis of Fluctuation Degree

The single factor diagram of fluctuation is shown in **Figure 5**. The ups and downs of the earth's surface affect the processes of erosion, transportation and accumulation of the earth's surface materials, and to a great extent determine the prone degree of geological disasters such as landslides, collapses and mudslides. It can be seen from **Figure 5** that the extremely sensitive area with fluctuation degree greater than 150 is  $583.719 \text{ km}^2$ , accounting for 3.22%, which is located in



**Figure 4.** Aspect factor.



**Figure 5.** Fluctuation factor.

the north of Meixian County and most areas of Taibai County; The highly sensitive area is distributed in the southwest of Baoji City, with an area of 2349.874 km<sup>2</sup>, accounting for 12.96%. Most of the moderately sensitive areas are located in the northeast and southwest parts of Baoji City and the northwest border,

with an area of 4328.98 km<sup>2</sup>, accounting for 23.869%; Mildly sensitive areas are mainly distributed in Longxian, Qianyang and linyou county, with an area of 5759.33 km<sup>2</sup>, accounting for 31.756%; The area of non-sensitive area is 5114.375 km<sup>2</sup>, which is mainly distributed in the low altitude area of Guanzhong Plain. The general trend of spatial distribution is “high in the west and low in the east, high in the south and low in the north”. The area with the highest surface undulation is located in Taibai Mountain with high altitude, and the undulation gradually decreases to the west along this high undulation belt. The areas with low fluctuation degree are all located in Guanzhong Plain, where the risk of natural disasters such as soil erosion, debris flow and collapse is small.

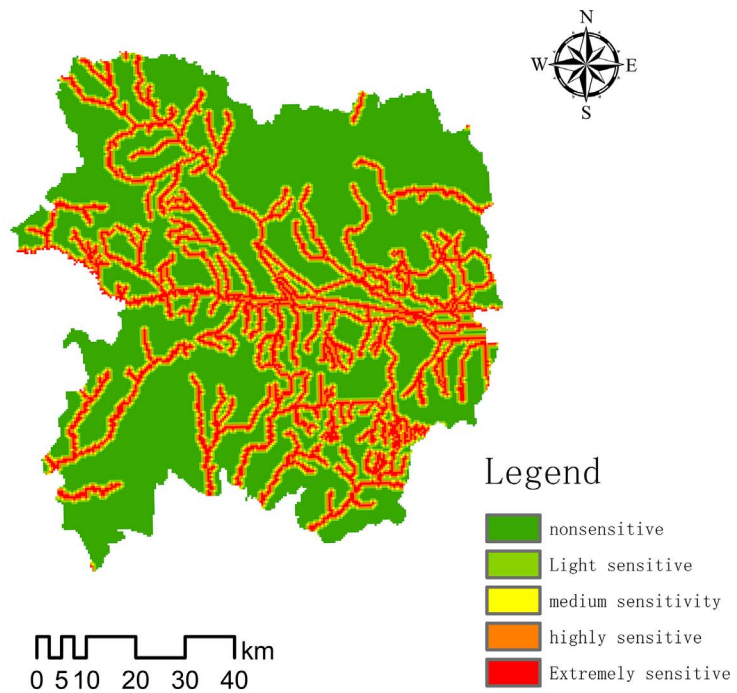
### 3.1.5. Ecological Sensitivity Analysis of Water Resources

In this study, the water area was divided into different buffer zones to show the sensitivity of different areas. As shown in **Figure 6**, the study area is rich in water resources, with many rivers and reservoirs. The sensitive areas are mainly along the Weihe River and its tributaries, and most of them are distributed along Wangjiaya Reservoir, Fengjiashan Reservoir and Dongfeng Reservoir. The extremely sensitive area is composed of buffer areas within 500 m of large and medium-sized water bodies, which are rich in species, fragile in ecological environment and easily disturbed by human activities, with an area of 3096.416 km<sup>2</sup>, accounting for 11.68%. The area of highly sensitive area is 3938.825 km<sup>2</sup>, accounting for 14.86%. The area of moderately sensitive area is 1471.234 km<sup>2</sup>, accounting for 5.55%. The lightly sensitive area covers an area of 3226.556 km<sup>2</sup>, accounting for 12.17%. The insensitive area covers an area of 14,776.48 km<sup>2</sup>, accounting for 55.74%, which is mainly located in residential areas, farmland and areas with high vegetation coverage beyond 2000 m. The closer to the water area, the higher the ecological sensitivity. With the increase of the distance, the ecological sensitivity decreases in turn. The construction land within 2000 m from the water source can be developed and utilized more. The ecological sensitivity of water area is high, and it is easy to be polluted. The discharge of substandard industrial wastewater is the main factor leading to the deterioration of water quality. It is suggested to protect the water source from the source and establish a water source protection base. The single factor diagram of the water buffer is shown in **Figure 6**.

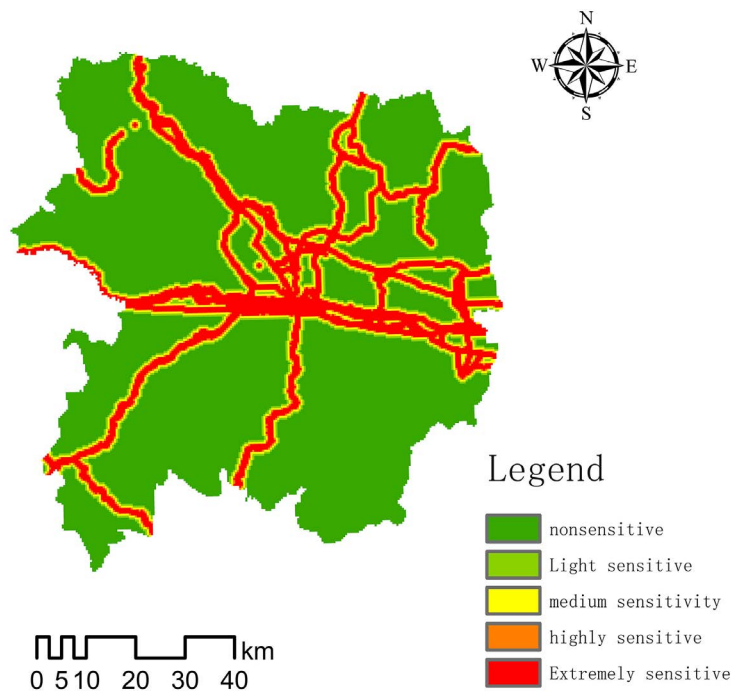
### 3.1.6. Analysis of Ecological Sensitivity of Human Activities

The road buffer single factor diagram is shown in **Figure 7**. The study area has convenient transportation and good road accessibility. Roads are mainly distributed along residential areas. The extremely sensitive area covers an area of 12,211.55 km<sup>2</sup>, accounting for 46.06%. The area of highly sensitive area is 2552.078 km<sup>2</sup>, accounting for 9.625%. The moderately sensitive area covers an area of 3543.081 km<sup>2</sup>, accounting for 12.23%. The lightly sensitive area covers an area of 1376.995 km<sup>2</sup>, accounting for 5.19%. The area of insensitive area is 7130.468 km<sup>2</sup>, accounting for 26.89%. With the increase of road distance, the sensitivity of road buffer areas becomes more and more intense, and most of

them are distributed in areas that are not artificially developed. Restricted by topographic factors, the main roads, residential areas and water areas in the study area are mostly distributed along the river valley. The closer the distance from main roads and residential areas, the lower the ecological sensitivity. The closer the distance to the water area, the higher the ecological sensitivity.



**Figure 6.** Water area factor.



**Figure 7.** Road factor.

### 3.1.7. Analysis of Ecological Sensitivity of Soil Types

It can be seen from **Figure 8** that most of Baoji City is located in sensitive areas, and the extremely sensitive area is mainly Weihe River area with an area of 27.98 km<sup>2</sup>, accounting for 0.15%; The soil types in Baoji City are mainly brown soil, yellow cinnamon soil and calcareous soil, and most of them are located in areas with high altitude and rich vegetation coverage, with strong fluctuation and steep slope, with an area of 8527.788 km<sup>2</sup>, accounting for 47.12%; Moderately sensitive areas are widely present in the north-central region, with an area of 8801.108 km<sup>2</sup>, accounting for 48.64%. The lightly sensitive area covers an area of 679.85 km<sup>2</sup>, accounting for 3.76%. Insensitive areas are scattered in northwest, central Guanzhong Plain and south Fengxian County, with an area of 59.27 km<sup>2</sup>, accounting for 0.328%. In recent years, with the development of urbanization in Baoji City, the increase of construction land makes land use types change, and the change of soil quality is closely related to people's construction activities. The soils in Baoji City are mainly sensitive soils such as brown soil and yellow cinnamon soil, which are mostly distributed in the northern region. When developing land, the southern region should be taken as the main development area to maintain the richness of soil types and species diversity. The single factor plot of soil types is shown in **Figure 8**.

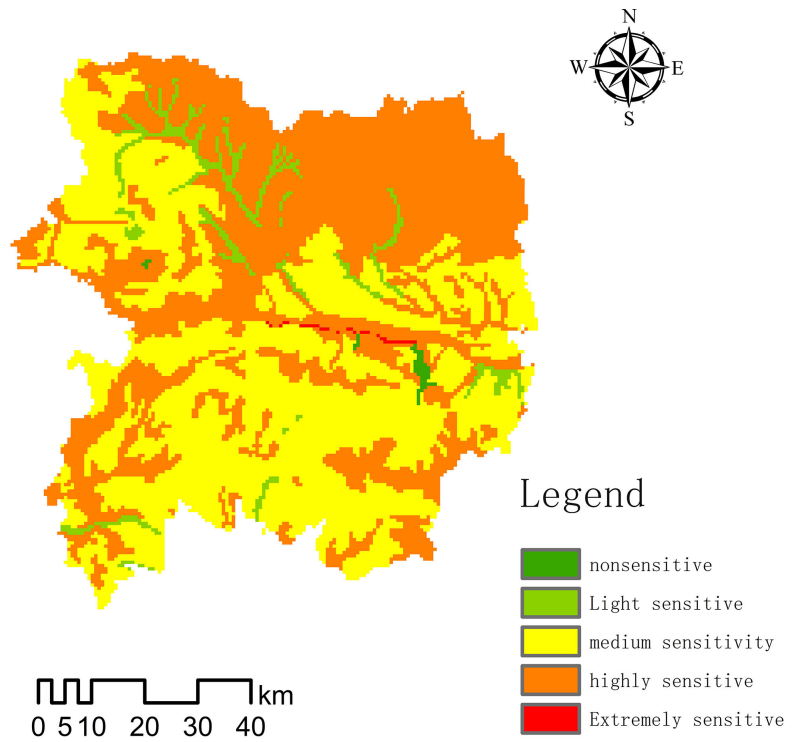
### 3.1.8. Ecological Sensitivity Analysis of Vegetation Coverage

Baoji City, located in Qinling Mountains, has a wide forest area, rich species, fragile ecological environment and high ecological sensitivity. The weight of vegetation coverage factor is 0.18595, and there is a positive correlation between vegetation coverage and ecosystem stability. Taibai Mountain is rich in biodiversity, with very high vegetation coverage density. Most of the extremely sensitive areas surround nearby, with an area of 10,244.63 km<sup>2</sup>, accounting for 56.62%. Most of the highly sensitive areas are around the northeast of Baoji City and in Qishan and Fengxiang, with an area of 3710.757 km<sup>2</sup>, accounting for 20.5%. Moderately sensitive areas are mainly distributed around Guanzhong Plain, scattered in the northern part of Linyou county and the north-central part of Longxian County, with an area of 2503.272 km<sup>2</sup> and an area ratio of 13.83%. The lightly sensitive area covers an area of 1318.487 km<sup>2</sup>, accounting for 7.287%, scattered in the middle of Guanzhong Plain. The area of insensitive area is 317.4735 km<sup>2</sup>, accounting for 1.75%. The location layout of sensitive areas with extremely high vegetation coverage shows a trend of "high at both ends and low in the middle". The main ecologically sensitive areas are mainly located in mountainous forest areas of Taibai Mountain. It is suggested to close mountains for afforestation and return farmland to forests with extremely high vegetation coverage. The single factor diagram of vegetation coverage is shown in **Figure 9**.

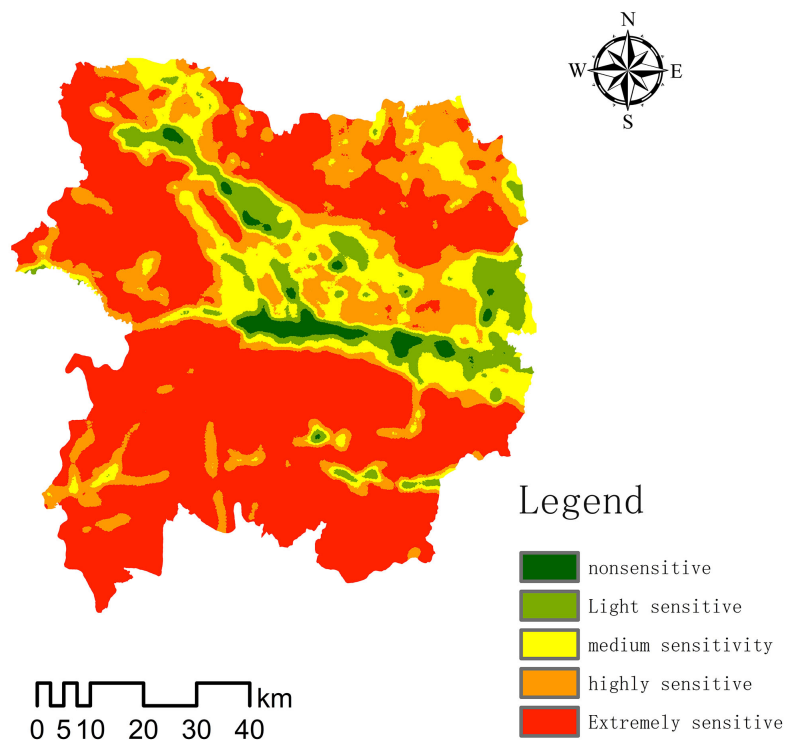
## 3.2. Comprehensive Ecological Sensitivity Analysis

In arcGIS, using the spatial analysis function of ArcGIS, eight single factor sensitivity evaluation results were analyzed by spatial superposition, and the spatial

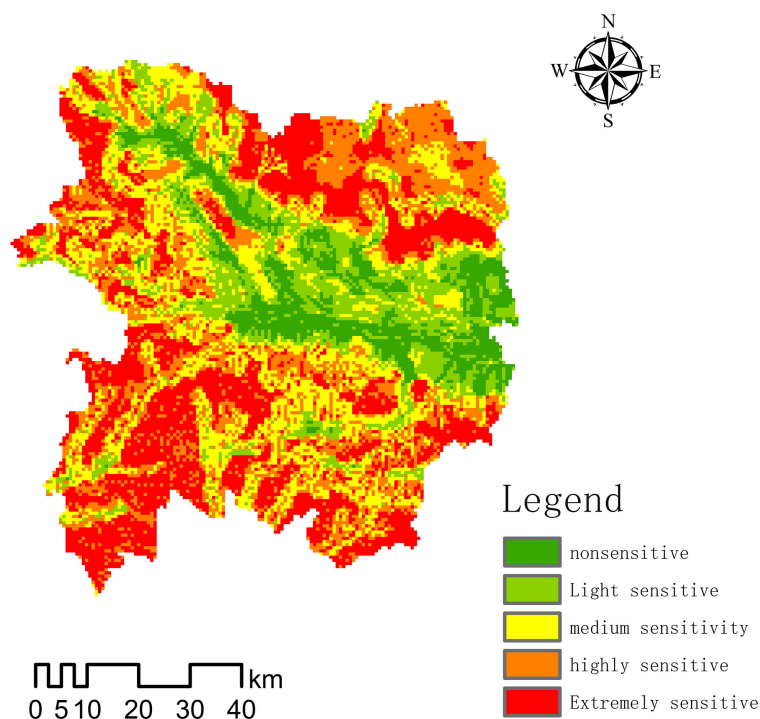
distribution map of comprehensive ecological sensitivity in Baoji City was obtained. Comprehensive ecological sensitivity is shown in **Figure 10**.



**Figure 8.** Soil type factors.



**Figure 9.** NDVI factor.



**Figure 10.** Comprehensive ecological sensitivity.

1) The insensitive areas are mainly distributed in chencang district, Weibin District, Qishan, Fufeng, Fengxiang, Meixian County, Longxian County and Qianyang County, with an area of 3003.18 km<sup>2</sup>, accounting for 16.95%. With the continuous acceleration of economic development and urbanization in this region, a series of urban problems have appeared, such as the increase of population density, the compactness of urban land and the contradiction between man and land. This area is mainly a grain production area in Baoji city, and it is also facing more demand for cultivated land, and the land carrying capacity will be weakened; The land sensitivity in this region is not very strong, and the high-intensity land use development has no serious impact on the ecological sensitivity in this region. In the process of urban development, attention should be paid to ecological environment protection and moderate development and utilization.

2) Mildly sensitive areas are mainly distributed in Linyou, Fengxiang, Qianyang, Longxian, Fengxian and Baoji, with an area of 7600.12 km<sup>2</sup>, accounting for 42.91%. The area is mainly fruit and wood planting base and barren land, which can bear less interference from human activities and cannot withstand large-scale development and utilization. If the intensity is severe, it will easily lead to ecological environmental pollution problems such as soil erosion and land desertification, and the ecological restoration in this area is slow. Therefore, in the process of development and utilization, we should speed up ecological restoration and reduce the damage to ecological environment, so as to maintain the safety of ecological environment.

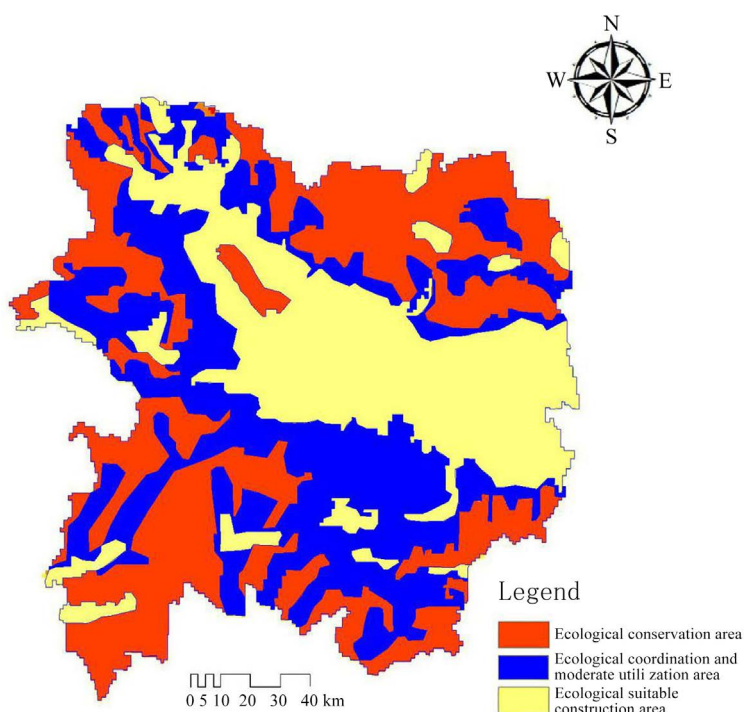
3) Moderately sensitive areas are mainly distributed in Taibai County, Fengxian County and Baoji, as well as the northern part of Fengxiang County, the western part of Longxian County and the southern part of Linyou, with an area of 3942.18 km<sup>2</sup>, accounting for 22.25%. The region is mainly based on forestry and fruit industry, which is an important forestry and fruit industry base in Baoji City. It is a place where many rivers gather, and its ecological environment carrying capacity is limited, which can be developed and utilized moderately under control. There is a certain degree of environmental pollution in the region, so reasonable and effective measures can be taken to improve the environment.

4) Extremely and highly sensitive areas are mainly distributed in Taibai National Nature Reserve County, Fengxian County and Longxian County with high vegetation coverage, high altitude, large slope and strong fluctuation, and parts of Baoji. The area of extremely and highly sensitive areas is 3169.44 km<sup>2</sup>, accounting for 17.89%. Qinling Mountains is one of the most important ecological nature reserves in China. The region is mainly alpine region with high altitude. The subalpine meadow and the remains of glaciers in the fourth season are the main characteristic landscapes in this region, and the vegetation vertical zone spectrum is the most complete, the vegetation coverage is high and the biodiversity is very rich. The ecological sensitivity of this region is very fragile, so it is not suitable for development and construction. Once it is destroyed by human activities, it will not only affect the damaged region, but also lead to the risk of collapse of the whole forest belt complex ecosystem. Therefore, we should enlarge and perfect the nature reserves to protect the extremely fragile ecological environment of Qinling Mountains.

#### 4. Ecological Function Regionalization of Baoji City

According to the different ecological sensitivities of the land, the strategies of ecological function land use in Baoji City will be different. Conclusion According to the requirements of ecological protection and development and land use scenarios, ecological function zones can be divided into three types of ecological function zones: ecological conservation zone, ecological coordinated utilization zone, and ecological suitable construction zone. The ecological function zoning of Baoji City is shown in **Figure 11**. The extremely sensitive and highly sensitive areas are composed of the ecological conservation area, the moderately sensitive areas are composed of the ecological coordination and proper utilization area, and the low sensitive and non-sensitive areas are composed of the ecological suitable construction area. According to the regional characteristics, the following conclusions can be drawn:

1) Ecological conservation area. The ecological environment of extremely sensitive and highly sensitive areas in Baoji city is very fragile, and most of them are landscape land, which is mainly divided into north and south parts, accounting for about one fifth of the total area. The distribution of ecological sensitivity in the south is located in Taibai Mountain of Qinling Mountains, which is a national nature reserve with rich biodiversity, high vegetation coverage, numerous



**Figure 11.** Ecological function zoning of Baoji city.

scenic spots in ecological conservation areas and tourist areas, and fragile ecological environment, which is prone to ecological environment problems. The northern region is characterized by high soil sensitivity, high forest coverage, year-round glacier landform and complex geological environment. Extremely sensitive and highly sensitive areas constitute the fragile ecological security system of Baoji City. The ecological environment of these areas is easily disturbed by human factors, and it is very difficult to restore the ecology after being destroyed. The development cost and restoration cost after development are very high. They should be regarded as key protected areas, not suitable for large-scale human activities. We should adhere to the principle of giving priority to protection, and establish a virtuous ecological cycle by establishing water conservation areas, forest parks and nature reserves to protect ecological security and environment. On the premise of protection, we can develop eco-tourism areas around Qinling Mountains.

2) Ecological coordination and moderate utilization area. Moderately sensitive areas occupy a wide area, the ecological environment is relatively fragile, and have certain anti-interference ability to the outside world. They are the most widely distributed among all sensitive areas, mainly distributed in the northwest and southeast of Baoji City. Qinling Mountain is a national forest reserve, and according to Article 18 of the Regulations on Ecological Environment Protection of Qinling Mountains in Shaanxi Province, the ecological functional area of water conservation and biodiversity of the mixed forest of coniferous and broad-leaved trees in Zhongshan Mountains at an altitude of 1500 - 2600 m is listed as a restricted development zone. Therefore, the Qinling Mountains in this area

should be protected by natural forests and build a landscape ecological corridor. For areas where soil erosion has occurred, closing mountains for afforestation and returning farmland to forests should be carried out, and the construction of eco-tourism areas should be developed on the premise of protection.

3) Ecological suitable construction area. The low sensitive areas are mainly plain and hilly topography, with an elevation of less than 902 m and a slope of 0 - 10. The soil types are mainly light sensitive soils of newly accumulated soil, mountain meadow soil and paddy soil, which are located at low altitude, with gentle slope and less vegetation coverage. Mainly distributed in the central part of Baoji City. The regional ecological sensitivity is weak and the foundation bearing capacity is good, which is the main area for urban development and construction. However, the development and construction should follow the principle of paying equal attention to ecological protection and rational development and utilization, reduce the contradiction between man and land, and pay attention to the coordinated development of man and natural environment.

## 5. Conclusion

According to single factor analysis of Baoji City, the highly sensitive and highly sensitive area is mainly located in Qinling Mountain Forest Belt in Taibai Mountain, which has high elevation and slope, strong fluctuation, rich vegetation coverage and quiet distance from water source, and the slope direction is mainly northeast slope and north slope. The altitude, slope and undulation of the areas with medium and low sensitivity are moderate, and the vegetation coverage is abundant. They are located in residential areas far away from water sources and built-up areas with high road accessibility. According to the comprehensive ecological sensitivity analysis, the area which is mainly insensitive and slightly sensitive covers an area of about 10,608.3 km<sup>2</sup>, and the ecological environment in this area is good, which is suitable for developing agriculture, forestry and animal husbandry. This area belongs to the urban construction area, so we should pay attention to the coordination between man and land, orderly control the development intensity and pay attention to the sustainable development of ecological environment. The extremely sensitive area covers an area of about 3169.44 km<sup>2</sup>. Most of the areas are ecologically fragile areas such as water areas, forests and steep mountainous areas, which are easily disturbed by human activities. If damaged, it is difficult to recover in a short time. Therefore, this area should be set up as an ecological protection area to establish a virtuous cycle of the ecosystem, so as to conserve water resources and protect the safety of the ecosystem, prohibit development and utilization, and take certain first-aid measures to deal with sudden natural occurrence. The eco-environmental sensitivity of Baoji City shows a trend of “high in the north and south, low in the middle”. Most of the areas with high ecological sensitivity are located in Taibai Mountain Nature Reserve, which has high vegetation coverage, rich biodiversity and great ecological benefits and economic value. Therefore, the construction of eco-environmental conservation areas should be vigorously advocated in this

area, and development and construction are prohibited in this area. Minimize the impact of human activities.

## 6. Discussion

The land area of Baoji City is mostly in the middle and high sensitive areas, and the overall ecological sensitivity is high. In the process of urban construction, different land development methods will have a direct impact on the ecological environment. It is of great significance to divide different urban ecological functional spaces reasonably and efficiently for regional development and land spatial planning. Extremely sensitive areas and highly sensitive areas are mostly located at high altitude, with low vegetation coverage, fragile ecological environment and low ecosystem stability. It is difficult to recover the ecological environment damage caused by human activities in this area, so we should avoid the interference of human activities and delineate ecological red lines to protect and maintain this area; Moderately ecologically sensitive areas have low altitude, steep slope and fragile ecological environment. The ecological environment in this area has certain anti-interference ability to human activities, and slight human activities will not have much impact on the ecological environment. This area can be scientifically and reasonably developed and utilized in urban development and construction, and can be used as an urban control development area; The low ecological sensitive area and non-ecological sensitive area in Baoji City have low slope and high vegetation coverage. The natural conditions and biological activities in this area have strong anti-interference ability to the outside world, which is located in the urban construction and development area, and can be developed and utilized with great intensity, so as to enhance ecological benefits and reduce the risk of damage to the ecological environment in scientific and rational planning and utilization.

Combining with the actual ecological situation of Baoji city, the sensitive factors are selected, and the factors affecting the ecological sensitivity of Baoji city are superimposed and analyzed by GIS technology, and then the thematic map of comprehensive ecological sensitivity results of Baoji city is obtained. The operation method is simple and the operation is efficient. It avoids the complexity of raster overlay operation and low operation efficiency, and can more intuitively and accurately reflect the overall sensitivity of each region in Baoji City. Compared with the traditional AHP method, the introduction of coefficient of variation method in weight determination is more objective, but just simply multiplies the AHP weight and the coefficient of variation, which needs to be studied. There are many factors affecting ecological sensitivity in Baoji City, and other factors are inevitably ignored when selecting indicators. It is expected that scholars will further improve the indicator system in the future.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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