water

MDPI

Article

Habitat Quality Assessment and Driving Factor Analysis of Xiangyu in Feng River Basin Based on InVEST Model

Aidi Huo [1,2,3,4], Qi Liu [2,3,4,*], Zhixin Zhao [2,3], Ahmed Elbeltagi [5], Mohamed EL-Sayed Abuarab [6] and Hossein Ganjidoust [7]

[1] Key Laboratory of Mine Geological Hazards Mechanism and Control, Ministry of Natural Resources, Xi'an 710054, China; huoaidi@chd.edu.cn
[2] Key Laboratory of Subsurface Hydrology and Ecological Effects in Arid Region of the Ministry of Education, Chang'an University, Xi'an 710054, China; zhao1201xin@163.com
[3] School of Water and Environment, Chang'an University, Xi'an 710054, China
[4] Xi'an Monitoring, Modelling and Early Warning of Watershed Spatial Hydrology International Science and Technology Cooperation Base, Chang'an University, Xi'an 710054, China
[5] Agricultural Engineering Department, Faculty of Agriculture, Mansoura University, Mansoura 35516, Egypt; ahmedelbeltagy81@mans.edu.eg
[6] Faculty of Agriculture, Cairo University, Giza 12613, Egypt; mohamed_abuarab@cu.edu.eg
[7] Environmental Engineering Division Civil, Environmental Engineering Faculty, Tarbiat Modares University, Tehran 1411713116, Iran; ganjidoust264@gmail.com
* Correspondence: liuaqqi@chd.edu.cn; Tel.: +86-188-4645-0696

Abstract: Analyzing the evolution of regional habitat quality is an important means to assess the impact of engineering activities on ecosystems. Taking Xiangyu in the Feng River Basin as the study area, the land use change in 1985 and 2022 was analyzed, and the habitat quality and degradation degree were evaluated by using the Integrated Assessment and Tradeoff of Ecosystem Services (InVEST) model. The results showed that from 1985 to 2022, the transfer of land use types in Xiangyu mainly occurred on dry land, bare land, forest land, and industrial land. The area of dry land and bare land converted into industrial land is 10,825.15 m^2 and 249,123.09 m^2, respectively, and affected by the measures of returning farmland to forest and grassland in Shaanxi Province, the area transferred to forest land reached 371,471.87 m^2, mainly from dry land and bare land. The continuous expansion of industrial land led to a significant decline in habitat quality, and the areas with high habitat degradation were concentrated in forest land in a large range, which indicated that forest land was vulnerable to industrial land expansion. Land use change and human engineering activities are the main factors affecting the ecological environment, and limiting the expansion rate of industrial land is the key to protecting the ecological environment.

Keywords: habitat quality; habitat degradation; geological engineering; InVEST model; mine rehabilitation

Citation: Huo, A.; Liu, Q.; Zhao, Z.; Elbeltagi, A.; Abuarab, M.E.-S.; Ganjidoust, H. Habitat Quality Assessment and Driving Factor Analysis of Xiangyu in Feng River Basin Based on InVEST Model. *Water* **2023**, *15*, 4046. https://doi.org/10.3390/w15234046

Academic Editor: Jian Liu

Received: 24 October 2023
Revised: 16 November 2023
Accepted: 20 November 2023
Published: 22 November 2023

1. Introduction

Under the rapid development of the social economy and the continuous interference of human engineering activities, different types of land use have changed into each other, and the ecological environment has been seriously damaged [1]. Social development depends on the ecological environment, and maintaining the integrity of the ecosystem and biodiversity is of great significance for sustainable economic and social development. Habitat quality is the most commonly used health indicator to assess the functional integrity and diversity of ecosystems [2]. The evaluation of habitat quality is an important means to solve ecological problems, protect the ecological environment, and maintain regional security and development [3]. In terrestrial ecosystems, land use type change is a critical driving force leading to biodiversity reduction, habitat fragmentation, and landscape pattern change [4,5]. Therefore, exploring the impact of regional land use change on habitat quality is significant for analyzing regional ecological environment change, formulating corresponding ecological protection policies, and rationally planning land use resources [6,7].

At present, the main methods for assessing habitat quality include the habitat suitability index (HSI) [8], the Social Value for Ecosystem Services (SolVES) [9], and the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) [10]. Among these methods, InVEST has the most complete model function [11], and it can reflect spatial heterogeneity, temporal difference, and spatial visualization [12], which is widely used. Marta et al. modified the InVEST model to assess terrestrial habitat quality and extend it to freshwater habitats. The result can be useful to forecast the effects of management actions in river basins [13]. Lorenzo et al. applied the InVEST 3.13.0 software to evaluate the relationship between habitat quality and degradation as well as their hotspots in protected areas in Italy [14]. Yang et al. studied the impact of land use change on habitat quality in Northeast China based on the InVEST model and concluded that construction land expansion was the main factor causing habitat degradation [15]. Qi et al. used the habitat quality module of the InVEST model to evaluate the temporal and spatial variation characteristics of habitat quality along the Yellow River main stream, providing an important reference for regional ecological security management [16]. With the continuous improvement and development of the function of the InVEST model, it has been widely used in the evaluation of ecosystem service functions in different regions and scales [17–19]. The habitat quality assessment module in the InVEST model can effectively evaluate the evolution of regional habitat quality, analyze spatial and temporal distribution characteristics, and effectively detect changes in habitat quality and quantity over time. However, due to the different spatial and temporal scales of habitat quality analyses, previous studies mainly focused on areas with better ecological conditions [20,21]. Continuous mining in diggings leads to the weakening of the anti-interference ability of the ecosystem, a reduction in biodiversity, and the serious destruction of the ecological environment. At present, there are few studies on ecological quality assessments of small-scale watersheds with mining areas. Therefore, spatial distribution, development trend, and driving factors of ecological environment change in mining area need to be further studied.

Studies on the temporal and spatial evolution of habitat quality can assess the impact of human engineering activities on the biodiversity and complexity of ecosystems [22]. The Qinling mountain range holds a position of central hydrological significance and cultural emblematic importance within China's geographical and cultural landscape. This mountain range is also the boundary between north and south, which plays an essential ecological role in water resource protection, water conservation, carbon fixation, and oxygen release [23–25]. The ecological environment health status of the northern foot of the Qinling Mountains is strongly correlated with the effectiveness of biodiversity protection and ecological civilization construction, so it is particularly significant to monitor and evaluate its ecological restoration. To evaluate the temporal and spatial variation in habitat quality in small-scale areas, this paper analyzed land use changes in the study area from 1985 to 2022 and used the InVEST to generate spatial distribution maps of habitat quality and habitat degradation in the study area. In addition, the ecological quality changes of the Xiangyu iron mining area during this period were compared and analyzed. This can provide a scientific reference for monitoring and restoring the ecological environment in a small-scale watershed.

2. Study Area

The Feng River belongs to the Weihe River system of the Yellow River Basin, and it is the primary water source for the production and living of people in Chang'an District of Xi'an City, Shaanxi Province, China [26]. According to geographical conditions, the Feng River basin can be divided into upper, middle and lower reaches. Upstream is the water source of Feng River basin. The midstream reach is from the upstream reach to Qindu Town. The lower reaches are from Qindu Town to the estuary. The study area mainly refers to the Feng River's middle and upper reaches; the geographical range is 33°48′–34°7′ N, 108°33′–108°55′ E, and the total drainage area is 620.6 km^2, as shown in Figure 1. The Feng River basin belongs to the warm temperate continental monsoon climate, and it is prone to drought in spring and flood in autumn. The annual mean temperature is about 15.3 °C, the average evapotranspiration per year is about 960 mm, and the mean annual precipitation is about 676 mm, with seasonal differences and an uneven spatial distribution. There are three primary tributaries of the Feng River, namely Gaoguan Yu, Taiping Yu River, and Jue River, the study area includes Taipingyu, Gaoguanyu, and Xiangyu.

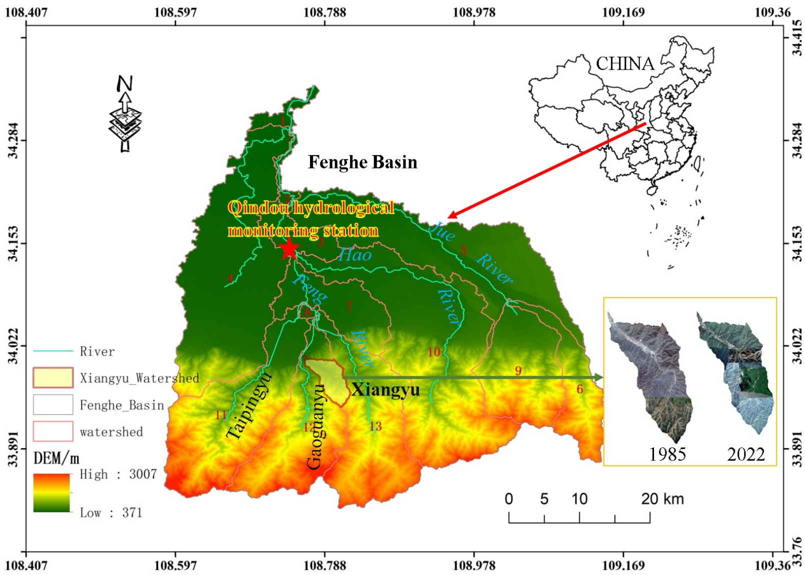

Figure 1. Location of study area.

3. Data and Methods

3.1. Data Sources

Basic remote images of 1985 and 2022 were obtained from the United States Geological Survey (USGS), with less than 10% cloud cover from June to September in the summer (Table 1). The digital elevation model (DEM) adopted ALOS data, and the spatial resolution is 12.5 m. After radiation correction and geometric correction using ENVI 5.6 [27,28], visual interpretation and supervised classification were used to generate land use type in the study area. It was verified that the visual interpretation accuracy reached 87%, and the Kappa coefficient reached 0.82 and 0.85.

Table 1. Data sources.

	Data	Sources
InVEST	Land use/land cover	Project of land use change, ecological effect and regulation in Qinling Mountains
	Basin and sub-basin boundaries	Generated by SWAT hydrologic analysis based on DEM data
	DEM (12.5 M)	ALOS (https://vertex.daac.asf.alaska.edu/ (accessed on 21 March 2023))
	Image from 1985 (30 m)	USGS (https://earthexplorer.usgs.gov/ (accessed on 21 March 2023)) Landsat-5TM
	Image from 2022 (0.5 m)	Quickbird

Dryland, bare land, and industrial land were extracted from land use using the two-classification method as input parameters of the InVEST model, which are shown in Figure 2. The 1 indicates the land use type, and 0 indicates other.

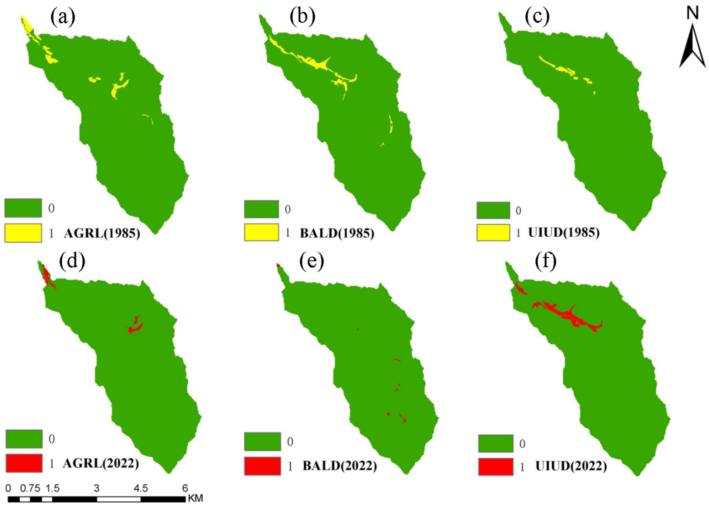

Figure 2. Stress factors of the InVEST model input parameters ((**a**) dryland in 1985; (**b**) bare land in 1985; (**c**) industrial land in 1985; (**d**) dry land in 2022; (**e**) bare land in 2022; (**f**) industrial land in 2022).

3.2. Methods

3.2.1. Land Use Change

According to the land use/cover situation and field investigation of the study area in 1985 and 2022, the land use was interpreted and classified. ArcGIS 10.7 software was used to superimpose the land use data of the two periods and obtain the land use type transfer matrix. It is a two-dimensional matrix, reflecting the status of land use transfer in the same area in different periods, which can better describe the spatial–temporal evolution process of land use. The expression of the transfer matrix [29] is shown in Formula (1),

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \dots & \dots & \dots & \dots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{bmatrix} \tag{1}$$

S is the total area; n is the number of land use types before and after the transfer; i (i = 1, 2, . . ., n) is the category before and after the conversion; and S_{ij} is the area of land utilization from type i transfer to type j.

3.2.2. Assessment of Habitat Quality Based on the InVEST Model

The use of the InVEST model to assess habitat quality is to establish a spatial correlation between land use data and threat sources and analyze the spatial distribution of habitat quality and habitat degradation under land use change according to the sensitivity of different environments to threat sources [30,31]. The model requires an input of land use data, the distance and weight of the habitat from the threat source, and the corresponding sensitivity. The calculation formula [13] of habitat quality is shown in (2),

$$Q_{xj} = H_j \left(1 - \frac{D_{xj}^z}{D_{xj}^z + K^z} \right) \tag{2}$$

Q_{xj} is the habitat quality index of land cover type j at grid x; H_j is the habitat suitability of j; k is a half-saturation constant, usually set to 0.5; z represents the normalization factor, generally set to 2.5; and D_{xj} is the degree of habitat degradation, which refers to the habitat degradation degree under the influence of stress factors, and its calculation formula is as follows [32]:

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{W_r}{\sum_{r=1}^{R} W_r} \right) r_y i_{rxy} \beta_x S_{jr} \tag{3}$$

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{rmax}}\right) (\text{Linear decay}) \quad (4)$$

$$i_{rxy} = \exp\left(-\left(\frac{2.99}{d_{rmax}}\right) d_{xy}\right) (\text{Exponential attenuation}) \quad (5)$$

D_{xj} is the habitat degradation of habitat type j in grid x; R is the quantity of stress factors; W_r is normalized threat weight of the threatening factor r; Y_r is the grid number of stress factors; r_Y is the stress intensity of grid y; i_{rxy} is the stress degree of stress factor r in grid y to grid x; $\beta_X \in [0, 1]$ is the anti-interference ability of the ecological environment (1 refers to complete accessibility); S_{jr} refers to the sensitivity of land type j to stress element r; d_{xy} is the linear distance between lattice x and y; and d_{rmax} is the maximum range of stress factor r.

Threat source refers to the factors that destroy the ecological environment or human intervention. With reference to existing studies and data, industrial land, dry land, and bare land were selected as threat factors, and the weight, impact distance, and attenuation type of each threat source were set, respectively, as well as the sensitivity of each land use type to a threat source (Tables 2 and 3). The relevant parameters were set based on the user guide to the InVEST Habitat Quality module, expert experience, and related literature [4,19,33,34] (details can be seen in [35]).

Table 2. Stress factors and stress intensities.

Stress Factors	Weight	Maximum Influence Distance/km	Dropoff Type
Industrial land	1	2	Linearity
Dry land	0.8	1	Linearity
Bare land	0.5	4	Exponent

Table 3. Sensitivity of land use types to habitat stress factors.

Land Use Types	Habitat Suitability	Industrial Land	Dry Land	Bare Land
Forest land	1	0.5	0.6	0.3
Dry land	0.8	0.9	0	0.3
Water area	1	0.8	0.4	0.2
Industrial land	0	0	0	0
Bare land	0.6	0.4	0.5	0
Grassland	1	0.3	0.5	0.4

4. Results and Analysis

4.1. Spatiotemporal Evolution Analysis of Land Use

In 1985, the main land use types in Xiangyu were forest land, dry land, and bare land. The land use types in 2022 were mainly composed of forest land and industrial land. From the perspective of the spatial distribution of land use types in Xiangyu, the transfer of land use types mainly occurred in dry land, bare land, forest land, and industrial land (Figures 3 and 4). The area of dry land, bare land, and industrial land transferred out is 265,880.68 m^2, 456,869.01 m^2, and 18,758.43 m^2, respectively, while the area transferred in is 17,325.37 m^2, 48,526.712 m^2, and 376,840.08 m^2. This shows that the dry land and bare land of Xiangyu have greatly decreased, while its industrial land has expanded on a large scale with the rapid development of cities and towns from 1985 to 2022. In addition, during this period, the area of forest land transferred out was 69,381.12 m^2, but a total area of 371,471.87 m^2 was transferred in. This illustrates that Shaanxi Province has implemented measures to return farmland to forest and grassland since 1999, and other ecological protection projects at the northern foot of the Qinling Mountains have achieved remarkable results. It can be seen from the statistical data and spatial distribution of land use that the biggest changes occur in the expansion of industrial land. Although relevant ecological protection policies have been adopted to improve the ecological status, the changes in regional habitat quality are still in need of further study due to the interference of engineering activities.

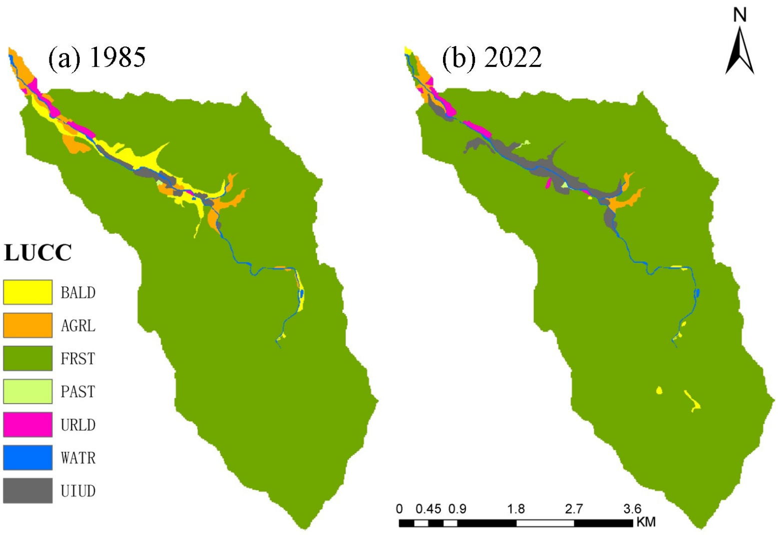

Figure 3. Spatial distribution of land use in Xiangyu ((**a**) 1985; (**b**) 2022). The land types can be divided into forest land (FRST), grassland (PAST), dry land (AGRL), industrial land (UIUD), water area (WATR), bare land (BALD), and residential land (URLD) (same as Figure 4).

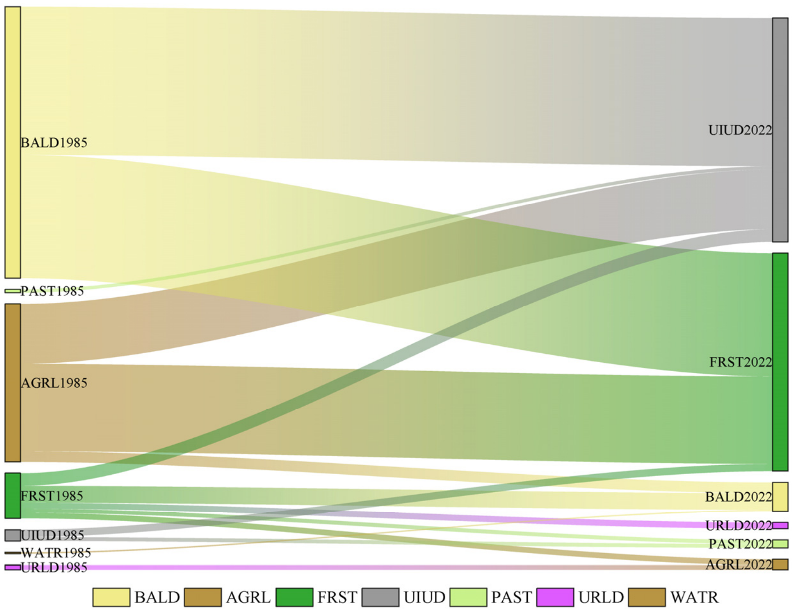

Figure 4. Land use type transfer from 1985 to 2022.

4.2. *Assessment of Habitat Quality and Habitat Degradation*

Based on the land use changes in Xiangyu in 1985 and 2022, the habitat quality assessment module in the InVEST model was used to evaluate the spatial and temporal evolution of habitat quality and habitat degradation in the study area over the past 37 years, as shown in Figure 5. The habitat quality index is between 0 and 1, the value close to 1 indicates good habitat quality in the region, while the value close to 0 indicates poor habitat quality in the region. It can be seen from Figure 5 that habitat quality has a spatial correlation with land use type. In 1985, the areas with low habitat quality were mainly distributed on bare land, dry land, and industrial land. However, in 2022, the expansion of industrial land to dry land and bare land was obvious, resulting in a large increase in low habitat quality. There was little change in the habitat quality of forest land, and the areas with increased habitat quality were concentrated in grassland area. Generally, compared with 1985, the average habitat quality index of the study area in 2022 showed a decreasing trend; the standard deviation increased from 0.0622 to 0.0916; and the area with low habitat quality increased from 0.02 to 0.43, showing obvious changes (Table 4).

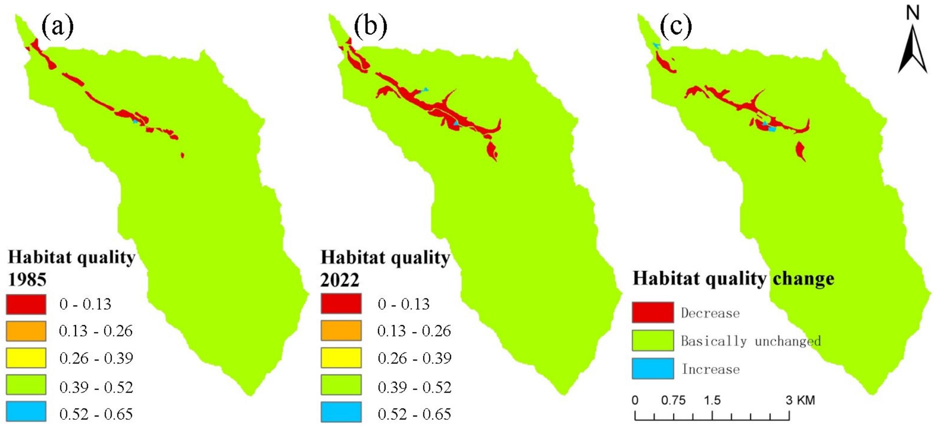

Figure 5. Habitat quality distribution from 1985 to 2022. (**a**) habitat quality of 1985; (**b**) habitat quality of 2022; (**c**) habitat quality change between 1985 and 2022.

Table 4. Statistics of the habitat quality.

Year	Average Habitat Quality Index	Standard Deviation	Habitat Quality Class/m^2				
			Low	Lower	Medium	Higher	High
1985	0.4994	0.0622	0	0.02	0.43	0.50	0.51
2022	0.4923	0.0916	0.01	0.43	0.44	0.50	0.51

The degree of habitat degradation indicates the degree to which land use types are stressed by stress factors, and its value is between 0 and 1. The higher the degree of habitat degradation, the higher the degree to which land use types are threatened, and it is easy to cause habitat degradation and a decline in habitat quality. The spatial distribution of habitat degradation in the study area is shown in Figure 6. It indicates that the spatial distribution pattern of habitat degradation and habitat quality was consistent. The forest land covered a large area of the study area and was the most stressed by the threatening factors. In 1985, the habitat degradation degree of bare land was significantly higher than that of the other land use types, while in 2022, a large area of bare land was converted into industrial land, and the habitat degradation degree showed a decreasing trend. Compared with 1985, the average degree of habitat degradation in the study area in 2022 decreased by 0.007, and the standard deviation changed from 0.0619 to 0.0988. The region with low habitat degradation has obviously increased, while the area with high habitat degradation did not change significantly (Table 5).

Table 5. Statistics of the habitat degradation.

Year	Average Habitat Degradation Degree	Standard Deviation	Habitat Degradation Degree/m^2				
			Low	Lower	Medium	Higher	High
1985	0.4799	0.0619	0.53	0.00	0.35	0.46	0.53
2022	0.4729	0.0988	0.01	0.35	0.45	0.49	0.53

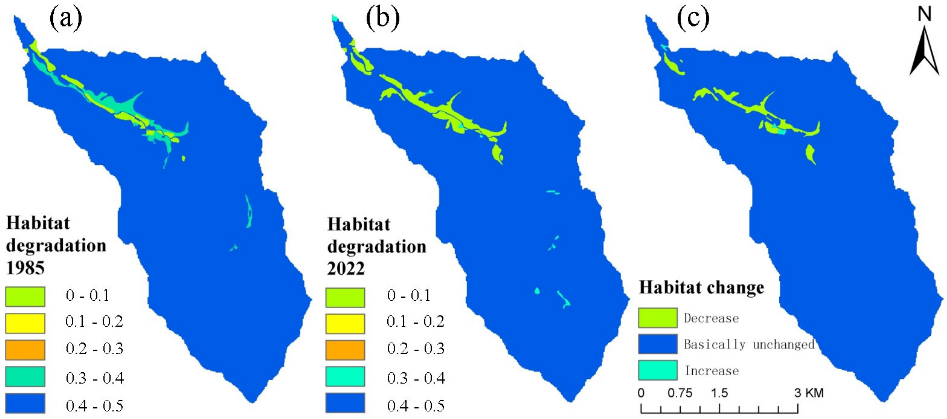

Figure 6. Habitat degradation distribution from 1985 to 2022. (**a**) habitat degradation of 1985; (**b**) habitat degradation of 2022; (**c**) habitat degradation change between 1985 and 2022.

4.3. Analysis of Ecological Environment Change in Xiangyu Iron Mining Area

The Xiangyu iron mining area is located on the west slope of Caolingzi in Xiangyu, Chang'an County, Xi'an City, Shaanxi Province. The mine was open for a total of two years. The spatial distribution of habitat quality changes and habitat degradation characteristics of the region from 1985 to 2022 is shown in Figure 7. After the mining stopped and natural restoration began, the uncultivated land in the mining area was converted into forest, and the quality of the habitat in the mining area and river showed an obvious upward trend. Due to the short mining time, there was no significant change in the degree of habitat degradation. The forest land and river basin had a high degree of degradation and were vulnerable to stress factors. Human engineering activities such as mining are important causes of ecological damage. In the future, the exploitation of mineral resources should repair the ecological environment as soon as possible, and effectively carry out ecological green restoration in mines.

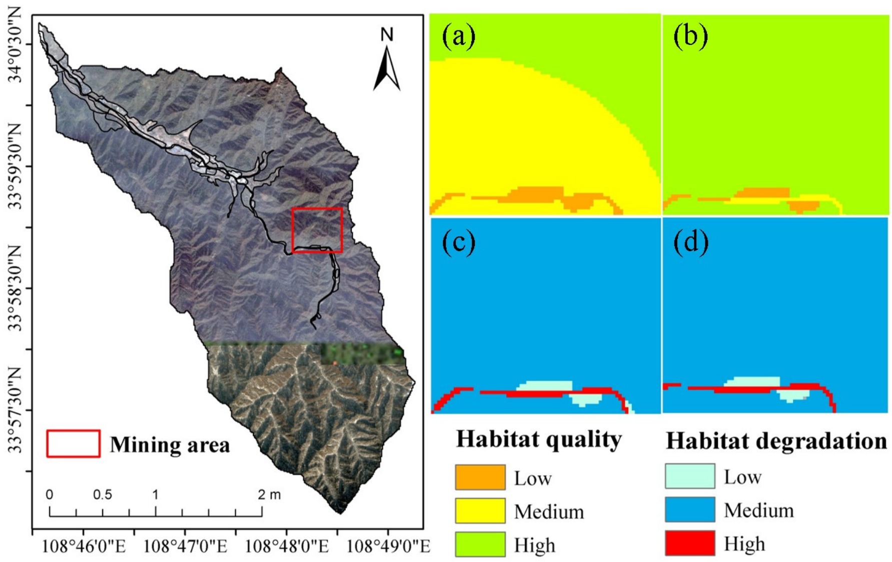

Figure 7. Location of Xiangyu mining area and ecological change. (**a**) habitat quality in 1985; (**b**) habitat quality in 2022; (**c**) habitat degradation in 1985; (**d**) habitat degradation in 2022.

5. Discussion

This study took Xiangyu as the study area, analyzed the land use change from 1985 to 2022, evaluated the spatial distribution characteristics of habitat quality change and habitat degradation degree in the study area based on the InVEST model, and provided a scientific reference for improving the ecological status and maintaining ecological security in the region.

The transfer of land use types in the study area mainly occurred between dry land, bare land, forest land, and industrial land. During the period of China's Great Leap Forward (1958–1960), to achieve industrial and agricultural production targets, a mass of human activities such as cutting down trees, digging coal, searching for mines, and resource exploitation caused serious damage to natural resources and the ecological environment. In the past 37 years, the area of dry land and bare land has decreased greatly, and the area of construction land has expanded significantly. The measures of returning farmland to forest and grassland since 1999 in Shaanxi Province and the implementation of ecological protection projects resulted in a large increase in the forest area of the study area. In recent years, to promote the construction of ecological civilization and maintain the safety of the ecological environment, remarkable results have been achieved in the protection and restoration of the ecological environment in mining areas in southern Shaanxi, especially at the northern foot of the Qinling Mountains. According to a survey, there are 112 mines in the Qinling region, of which 85 are artificially restored, 27 are naturally restored, and 83 are artificially controlled, so the ecological environment has gradually improved.

Xiangyu is located at the northern foot of the Qinling Mountains, with a forest coverage rate of more than 60%. With the continuous advancement in urban construction, land use types have changed greatly, so it is of great significance to study the impact of land use change on the ecological environment. The results of the habitat quality assessment in Xiangyu showed that the area of vulnerable habitat was significantly expanded due to the dual effects of land use change and human activities. Although a series of ecological protection projects have been undertaken in some areas of the northern foot of the Qinling Mountains, the continuous expansion of industrial land occupied t bare land and cultivated land, resulting in impaired habitat quality and threatening the habitat quality of the surrounding areas. The spatial distribution of habitat degradation in the study area indicated that from 1985 to 2022, a large area of bare land was transformed into industrial land, and the corresponding degree of habitat degradation showed a decreasing trend. However, large areas of forest land were vulnerable to stress factors, such as dry land, bare land, and industrial land. Therefore, limiting the expansion of industrial land and protecting the service function of the forest ecosystem are the important tasks of ecological environment protection in the Xiangyu region in the future.

The InVEST model has been widely used to assess ecosystem service functions, and studies on habitat quality assessments are emerging [30,35–37]. The spatial expression and dynamic study of regional habitat quality can be effectively realized by using the InVEST model. However, the model itself still needs to be further improved due to some issues, such as the fact that there is no uniform setting standard for the model parameters, the threat source parameters set by the relevant materials and references will cause subjective errors, and the influence range and degree of threat source will cause spatial differences in different time and regions. Therefore, in the assessment of habitat quality, parameter setting should focus on the degree of threat factors to the habitat and the cumulative influence range. Land use change and soil property evolution affect the ecological environment's quality and spatial patterns [38–40]. In future studies, the effects of engineering activities on habitat quality and habitat degradation will be further explored on other scales.

6. Conclusions

Based on the InVEST model, this study evaluated the changes in habitat quality and habitat degradation in Xiangyu from 1985 to 2022. Firstly, the land use type of the study area was interpreted by remote sensing images, then the habitat quality and habitat degradation were assessed by InVEST model, and finally the ecological environment evolution and its driving factors were analyzed and studied. The conclusions are as follows:

(1) Land use change can reflect the intensity of human activities and affect habitat quality. From 1985 to 2022, the land use type of Xiangyu mainly changed from dry land and

bare land to industrial land, and the characteristics of urban expansion were obvious. Under the influence of returning farmland to forest and grassland and ecological protection projects, the area of forest land in the region has increased significantly.

(2) There was a spatial correlation between habitat quality, habitat degradation degree, and the land use spatial pattern. From 1985 to 2022, the areas with low habitat quality in Xiangyu increased over a large area and were concentrated on industrial land. The areas with high habitat degradation were distributed over a wide range of forest land, indicating that forest land is vulnerable to the threat of industrial land expansion.

(3) After the natural restoration of the ecosystem, the habitat quality index of the Xiangyu mining area increased from 1985 to 2022, and the habitat degradation degree did not change significantly. In future mining processes, it is very important to make scientific and reasonable mining and ecological restoration plans for promoting environmental sustainability development.

(4) The ecological environment is prone to change under the influence of human engineering activities and land use policies. The habitat quality and habitat degradation of small watersheds with mining areas are strongly correlated with spatial distribution of land use types.

Author Contributions: Conceptualization, A.H.; data curation, A.H., Z.Z. and H.G.; formal analysis, Q.L., A.E. and M.E.-S.A.; funding acquisition, A.H.; investigation, A.H. and Z.Z.; methodology, Q.L.; project administration, A.H.; software, Z.Z.; supervision, A.H.; validation, A.E.; visualization, M.E.-S.A. and H.G.; writing—original draft, A.H. and Q.L.; writing—review and editing, A.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (Grant No. 42261144749, 42377158 and 41877232) and the Key Research and Development Program of Shaanxi Province, China (2023-ZDLSF63).

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors thank the anonymous reviewers and the editor for their constructive comments, which significantly improved the quality of this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Xue, X.Y.; Wang, X.Y.; Duan, H.M. Analysis on spatio-temporal evolution of habitat quality in Qilian Mountains based on land use change. *Bull. Soil Water Conserv.* **2020**, *40*, 278–284.
2. Xu, X.L.; Yang, X.C.; Wei, R.L.; Cheng, X.Q.; Ye, C.M.; Wang, L.X.; Sui, T.B. An assessment method of habitat quality in small watershed with mining area: A case study of Guobayan Mineral District in the Baoxing River Basin. *J. Geomech.* **2021**, *27*, 400–408.
3. Xia, Z.Q.; Xie, Y.L.; Wang, T. Land Use and Spatial and Temporal Change of Normalized Difference Vegetation Index (NDVI) in Shenfu Mining Area and Their Driving Factors Analysis. *Chin. Agric. Sci. Bull.* **2021**, *37*, 97–105.
4. Fan, D.Q.; Qiu, Y.; Sun, W.B.; Zhao, X.S.; Mai, X.M.; Hu, Y.W. Evaluating ecological environment based on remote sensing ecological index in Shenfu mining area. *Bull. Surv. Mapp.* **2021**, *7*, 23–28.
5. Lu, Y.Y.; Li, T.X.; Gong, J.Z. Attribution of habitat quality in different geomorphological types in Guangdong Province. *Ecol. Sci.* **2022**, *41*, 24–32.
6. Wang, B.X.; Cheng, W.M. Effects of Land Use/Cover on Regional Habitat Quality under Different Geomorphic Types Based on InVEST Model. *Remote Sens.* **2022**, *14*, 1279. [CrossRef]
7. Wang, P.; Qin, S.T.; Hu, H.R. Spatial-temporal evolution characteristics of land use change and habitat quality in the Lhasa River Basin over the past three decades. *Arid Zone Res.* **2023**, *40*, 492–503.
8. Meng, Q.L.; Li, M.Y.; Ren, C.Y.; Wang, Z.M.; Tian, Y.L. Dynamic assessment of habitat quality in eastern Jilin Province based on HSI model. *Remote Sens. Land Resour.* **2019**, *31*, 140–147.
9. Gao, Y.; Liu, K.; Ma, Q.; Li, Y.; Fan, Y.N.; Li, X.Q.; Gu, C. Assessment of social value of ecosystem services based on SolVES model and visitor's preference: A case study of Taibai Mountain National Forest Park. *Chin. J. Ecol.* **2017**, *36*, 3564–3573.
10. Shang, J.; Cai, H.S.; Long, Y.; Zeng, J.Q.; Chen, Y.; Zhang, X.L. Temporal-spatial distribution and transition of habitat quality in Poyang Lake region based on InVEST model. *Resour. Environ. Yangtze Basin* **2021**, *30*, 1901–1915.
11. Wei, W.F.; Bao, Y.; Wang, Z.T.; Chen, X.T.; Sun, Y.Z.; Zeng, M.L.; Mo, Y.G. Spatio-temporal responses of urban environment quality to land use change in mountainous cities of Karst area. *Acta Ecol. Sin.* **2023**, *43*, 3920–3935.

12. Wang, X.M.; Liu, X.C.; Long, Y.X. Spatial-Temporal Changes and Influencing Factors of Ecosystem Services in Shaoguan City Based on Improved InVEST. *Res. Soil Water Conserv.* **2020**, *27*, 381–388.
13. Terrado, M.; Sabater, S.; Chaplin-Kramer, B.; Mandle, L.; Ziv, G.; Acuña, V. Model development for the assessment of terrestrial and aquatic habitat quality in conservation planning. *Sci. Total Environ.* **2016**, *540*, 63–70. [CrossRef] [PubMed]
14. Sallustio, L.; De Toni, A.; Strollo, A.; Di Febbraro, M.; Gissi, E.; Casella, L.; Geneletti, D.; Munafò, M.; Vizzarri, M.; Marchetti, M. Assessing habitat quality in relation to the spatial distribution of protected areas in Italy. *J. Environ. Manag.* **2017**, *201*, 129–137. [CrossRef] [PubMed]
15. Yang, Z.P.; Xu, J.W.; Feng, X.H. Effects of land use change on habitat based on InVEST model in Northeast China. *Ecol. Sci.* **2018**, *37*, 139–147.
16. Qi, S.; Dong, C.; Wei, D.; Qiu, S.K. Temporal and spatial variation of habitat quality along the main stream of the Yellow River based on InVEST model. *Sci. Surv. Mapp.* **2022**, *47*, 114–122.
17. Berta Aneseyee, A.; Noszczyk, T.; Soromessa, T.; Elias, E. The InVEST Habitat Quality Model Associated with Land Use/Cover Changes: A Qualitative Case Study of the Winike Watershed in the Omo-Gibe Basin, Southwest Ethiopia. *Remote Sens.* **2020**, *12*, 1103. [CrossRef]
18. Zhang, W.J.; Sun, X.Y.; Shan, R.F. Effects of land use change on habitat quality based on InVEST model in Shandong Peninsula. *Environ. Ecol.* **2019**, *1*, 15–23.
19. Zhang, X.R.; Zhou, J.; Li, M.M. Analysis on spatial and temporal changes of regional habitat quality based on the spatial pattern reconstruction of land use. *Acta Geogr. Sin.* **2020**, *75*, 160–178.
20. Zhao, X.L.; Wang, J.; Su, J.D. Assessment of habitat quality and degradation degree based on InVEST model and Moran index in Gansu Province, China. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 301–308.
21. Zhou, T.; Chen, W.X.; Li, J.F.; Liang, J.L. Spatial relationship between human activities and habitat quality in Shennongjia Forest Region from 1995 to 2015. *Acta Ecol. Sin.* **2021**, *41*, 6134–6145.
22. Guan, L.S.; Chen, Y.; Wilson, J.A. Evaluating spatio-temporal variability in the habitat quality of Atlantic cod (Gadus morhua) in the Gulf of Maine. *Fish. Oceanogr.* **2016**, *26*, 83–96. [CrossRef]
23. Wu, W.Q.; Zhao, Y.; Tian, H.W.; Chen, Y.P. Spatio-temporal variation characteristics and driving mechanism of habitat quality of Qinling Mountains in recent 40 years. *J. Earth Environ.* **2023**, *14*, 488–504.
24. Zhao, Z.; Huo, A.; Cheng, Y.; Luo, P.; Peng, J.; Elbeltagi, A.; Mohamed, E.L.; Mokhtar, A. Experimental study on slope morphological characteristics and stability analysis of GCHP engineering in the loess plateau. *Adv. Space Res.* **2023**, *72*, 4324–4335. [CrossRef]
25. Huo, A.; Zhao, Z.; Luo, P.; Zheng, C.; Peng, J.; Abuarab, M.E. Assessment of Spatial Heterogeneity of Soil Moisture in the Critical Zone of Gully Consolidation and Highland Protection. *Water* **2022**, *14*, 3674. [CrossRef]
26. Feng, R.R.; Zhang, K.L.; Han, J.N.; Li, Y.H.; Liu, Q.Q.; Liu, K. Remote Sensing Evaluation and lnfluence Factor Analysis of Ecological Environment quality in the Fenghe River Watershed. *J. Ecol. Rural Environ.* **2022**, *38*, 860–871.
27. Qiu, T.Q.; Wang, X.R. Research on the temporal and spatial evolution of habitat quality in changes ha-Zhuzhou-Xiangtan Urban agglomeration based on InVEST model. *For. Resour. Manag.* **2022**, *5*, 99–106.
28. Wei, W.; Shi, S.; Zhang, X.; Zhou, L.; Xie, B.; Zhou, J.; Li, C. Regional-scale assessment of environmental vulnerability in an arid inland basin. *Ecol. Indic.* **2020**, *109*, 105792. [CrossRef]
29. Huang, L.; Chen, Q.J.; Feng, J.Z.; Liu, R.X. Spatial-temporal characteristics and driving mechanisms analysis of habitat quality in Shenfu mining area based on geodetector. *J. Xi'an Univ. Technol.* **2023**, 1–14. Available online: http://kns.cnki.net/kcms/detail/61.1294.N.20230424.1350.002.html (accessed on 21 March 2023).
30. Li, Y.; Feng, X.; Wu, L.H.; Luo, G.J.; Luo, H.F. Spatial-temporal Evolution and Quantitative Attribution of Habitat Quality in Typical Karst Counties of Guizhou Plateau. *Environ. Sci.* **2023**, 1–17. [CrossRef]
31. Zhang, X.; Liao, L.Y.; Xu, Z.D.; Zhang, J.Y.; Chi, M.W.; Lan, S.R.; Gan, Q.C. Interactive Effects on Habitat Quality Using InVEST and GeoDetector Models in Wenzhou, China. *Land* **2022**, *11*, 630. [CrossRef]
32. Zheng, Y.; Zhang, P.T.; Tang, F.; Zhao, L.; Zhao, X. The effects of land use change on habitat quality in Changli country based on InVEST model. *Chin. J. Agric. Resour. Reg. Plan.* **2018**, *39*, 121–128.
33. Yang, L.Y.; Pan, S.P.; Chen, W.X.; Zeng, J.; Xu, H.; Gu, T.C. Spatially non-stationary response of habitat quality to land use activities in World's protected areas over 20 years. *J. Clean. Prod.* **2023**, *419*, 138245. [CrossRef]
34. Zhong, L.; Wang, J. Evaluation on effect of land consolidation on habitat quality based on InVEST model. *Trans. Chin. Soc. Agric. Eng.* **2017**, *33*, 250–255.
35. Zhang, H.J. *A Comprehensive Asssssment for Watershed Ecosystem Services Based on Supply-Demand Perspective: A Case Study of Fenghe River Watershed in Xi'an*; Northwest University: Xi'an, China, 2021.
36. Liu, H.Y.; Lin, M.Z.; Zhou, R.B.; Zhong, L. Spatial and temporal evolution of habitat quality in Guangdong-Hong Kong Macao Greater Bay Area based on InVEST model. *Ecol. Sci.* **2021**, *40*, 82–91.
37. Yohannes, H.; Soromessa, T.; Argaw, M.; Dewan, A. Impact of landscape pattern changes on hydrological ecosystem services in the Beressa watershed of the Blue Nile Basin in Ethiopia. *Sci. Total Environ.* **2021**, *793*, 148559. [CrossRef] [PubMed]
38. Okolelova, A.A.; Glinushkin, A.P.; Sviridova, L.L.; Podkovyrov, I.Y.; Nefedieva, E.E.; Egorova, G.S.; Kalinitchenko, V.P.; Minkina, T.M.; Sushkova, S.N.; Mandzhieva, S.S.; et al. Biogeosystem Technique (BGT*) Methodology Will Provide Semiarid Landscape Sustainability (A Case of the South Russia Volgograd Region Soil Resources). *Agronomy* **2022**, *12*, 2765. [CrossRef]

39. Kalinitchenko, V.P.; Glinushkin, A.P.; Minkina, T.M.; Mandzhieva, S.S.; Sushkova, S.N.; Sukovatov, V.A.; Il'ina, L.P.; Makarenkov, D.A. Chemical soil-biological engineering theoretical foundations, technical means, and technology for safe intrasoil waste recycling and long-term higher soil productivity. *ACS Omega* **2020**, *5*, 17553–17564. [CrossRef]
40. Bunkin, N.F.; Glinushkin, A.P.; Shkirin, A.V.; Ignatenko, D.N.; Chirikov, S.N.; Savchenko, I.V.; Meshalkin, V.P.; Samarin, G.N.; Maleki, A.; Kalinitchenko, V.P. Identification of organic matter dispersions based on light scattering matrices focusing on soil organic matter management. *ACS Omega* **2020**, *5*, 33214–33224. [CrossRef]