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Assessment of Topographic Effect on Habitat Quality in Mountainous Area Using InVEST Model

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Abstract: The topographic differentiation patterns of changes in habitat quality are of great significance for the scientific formulation of environmental protection policies in mountainous areas. Here, the distribution, changing trends, and the effects of the topographic gradient on habitat quality were studied using the InVEST model, the topographic distribution index, and the Mann–Kendall test. The results showed that at $p < 0.05$ ($Z = 1.67$), the habitat quality from 2000 to 2020 showed three types of trends (significant decline, non-significant change, and significant increase), accounting for 22.2%, 41.8%, and 36% of the changes, respectively. Because of the livelihood structure of the local residents and geological disasters in high-elevation areas, this terrain was the predominant area showing a significant decline in habitat quality. Thanks to the consolidation of projects for the protection of natural forest resources, the return of farmland to forest, and the implementation of projects for protecting the natural forest, the low-lying topography was the predominant area showing a significant increase in habitat quality. The middle topographic position was the predominant area showing no significant changes in habitat quality. Based on the results of the analysis, ecological management and protection measures for high-, medium-, and low-elevation areas were suggested.

Keywords: habitat quality; InVEST model; topographic effect; Mann–Kendall; natural woodland protection project; ecological management policy

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Citation: Xiang, Q.; Kan, A.; Yu, X.; Liu, F.; Huang, H.; Li, W.; Gao, R. Assessment of Topographic Effect on Habitat Quality in Mountainous Area Using InVEST Model. *Land* **2023**, *12*, 186. https://doi.org/10.3390/land12010186

Academic Editor: Muhammad Shafique

Received: 29 November 2022
Revised: 26 December 2022
Accepted: 30 December 2022
Published: 6 January 2023

1. Introduction

Changes in habitat quality are an important part of environmental research [1,2]. These changes can deeply affect the material and energy flow between habitat patches, thus changing the functions of the regional habitat [3–7]. Habitat quality assessment can reveal the advantages and disadvantages of a regional ecosystem to a certain extent [8,9]. The ecological structure of mountainous areas is mostly affected by the topography. Compared with plain areas with a small topographic relief, the differentiation and structure of the environment in mountainous areas are more closely related to the topography, resulting in spatial heterogeneity and regional differences in habitat quality [10]. Therefore, strengthening the research on regional differences in the habitat quality in mountainous areas is crucial for biodiversity protection, ecosystem service function, ecological security pattern construction, regional ecological balance, system health, and land ecological security [11,12].

Land use has always been considered to be closely related to habitat quality [13,14]. Therefore, studying the relationship between changes in land use and changes in habitat quality can provide a basis for analyzing regional environmental shifts, formulating regional environmental protection policies, and realizing the sustainable use of land resources [15]. Most researchers use the InVEST model for multiscale quantitative assessment of habitat quality and express the analysis results in the form of a thematic map [16,17]. The InVEST model is widely used because of its low demand for data, strong spatial visualization, and high accuracy of the results obtained [18,19]. The model can reflect the habitat distribution under different landscape patterns. The habitat quality module of the InVEST model evaluates the habitat quality by analyzing land use/cover (LULC) maps and the threat of different forms of land use toward biodiversity [20,21]. The model evaluates the biodiversity status of the landscape and combines the LULC change and biodiversity threat data with expert knowledge to obtain consistent indicators of the response of biodiversity to threats [3,19].

Studies of habitat quality changes have generally focused on plain or urban agglomeration areas, while less attention has been paid to the quality of the mountain habitat. Because of the influence of the terrain gradient, the spatial heterogeneity of the habitat quality is characterized by the energy transfer and flow in the social ecosystem of the mountain [22]. Studying the changes in the habitat quality in mountain areas is conducive to understanding the flow characteristics of social ecosystems, revealing the mechanisms behind the changes in land use and elucidating the characteristics of human activities in these areas [23,24]. China's mountainous areas show a fragile ecology and a backward economy. As the social economy of the region has started to develop, the relationship between human activities and the environment has become increasingly closer, causing damage to the mountain ecosystem and increasingly serious environmental problems [25–27], which seriously threaten the ecological security of mountainous areas [28]. Thus, performing a comprehensive, multiscale, and long-term dynamic monitoring sequence of the quality of the environment in mountainous areas, and scientifically monitoring and evaluating the impact of human activities on the mountainous environment and its temporal and spatial changes is critical for protecting the ecology of these areas.

Therefore, the objectives of this study are (1) to analyze the temporal and spatial changes in the habitat quality from 2000 to 2020 and to evaluate the effectiveness of an ecological construction; (2) to analyze the topographic gradient effects of the temporal and spatial variation in the habitat quality in mountainous areas; and (3) to elucidate the mechanisms behind the changes in habitat quality in a mountainous terrain environment and to suggest measures for environmental protection.

2. Materials and Methods

2.1. Study Area

The upper reaches of the Minjiang River are located in the steep terrain zone between the Minshan Mountain, Longmen Mountain, and Sichuan Basin, and belong to the alpine canyon area on the eastern edge of the Qinghai-Tibet Plateau [29–31] (Figure 1). The average altitude of the basin is 3440 m, the total length of the main stream of the basin is 337 km, and the basin area is about 2.12 million km^2. The relative topographic elevation difference is greater than 3000 m, which is a typical representative of the alpine canyon landform on the eastern edge of the Qinghai-Tibet Plateau [32,33]. The upper reaches of the Minjiang River are also a hotspot of biodiversity in the world and a key area for biodiversity conservation in China, as well as an important part of the eastern woodland area of the Qinghai-Tibet Plateau. This is one of the three woodland areas in China and one of the five grassland areas in Northwest Sichuan [34,35]. Accurately determining the changes in the habitat quality in the upper reaches of the Minjiang River is of great significance to the ecological security of Western Sichuan and the Yangtze River Basin.

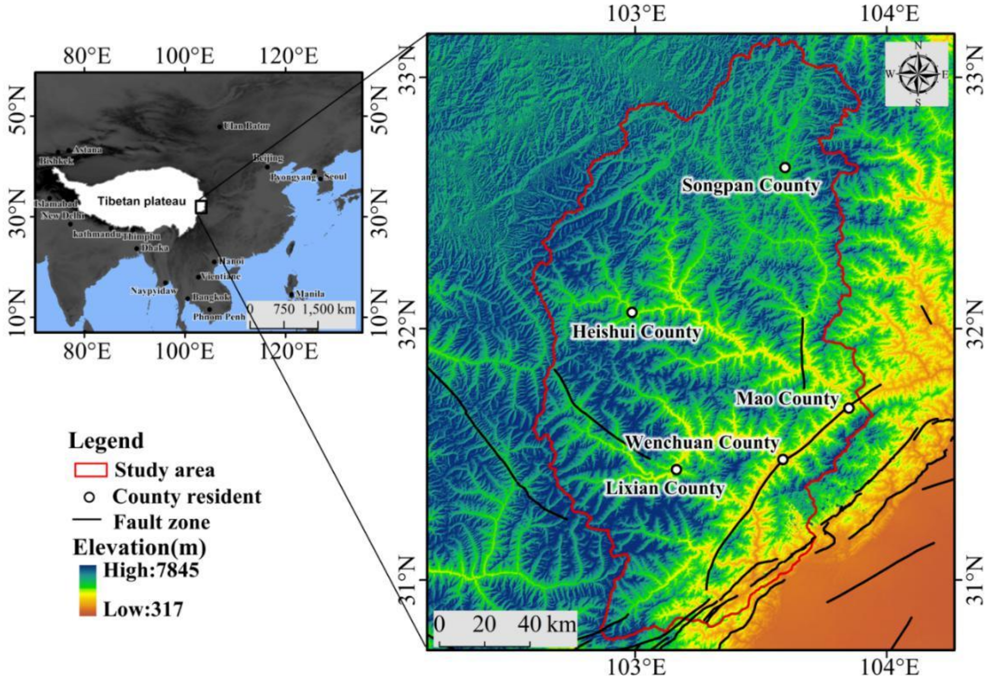

Figure 1. Spatial location of the investigated watershed.

2.2. Data Sources and Data Processing

The land use data in this study (2000, 2010, and 2020) was obtained from the Data Center of Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn, accessed on 15 October 2022) and showed a resolution of 1 × 1 km. The data included six first-class land types and 25 s-class land types. The 30 m spatial resolution digital elevation model (DEM) data used in this study was obtained from a mirror website of the Computer Network Information Center for Geospatial Data (http://www.GScloud.cn/, accessed on 15 October 2022). The boundary data of the study area and the Qinghai-Tibet Plateau were procured from the National Qinghai-Tibet Plateau Scientific Data Center (http://data.tpdc.ac.cn/, accessed on 15 October 2022). All data in this paper adopted the Krasovsky_1940_Albers projection.

The study area was divided into 2 × 2 km geographic grid units, with a total of 28,543 effective grids. Each index was dispersed into a unified standard grid unit for the calculation. ArcGIS software was used to load the land-use data, classify, and summarize the data in the attribute table, and to summarize the three-level land types into second-level land types establishing the second-level land-use classification system. The vector data of land use was further reclassified using ArcGIS software and the vector data of the cultivated land, urban land, rural residential land, and industrial and mining land were extracted as the threat sources affecting habitat quality in the InVEST model.

2.3. Methodology

Our research method includes four steps: (1) exploring the land use change in the upper reaches of Minjiang River in 2000, 2010, and 2020; (2) studying the changes of habitat quality in the upper reaches of Minjiang River in three stages; (3) by combining the results of the topographic index, the topographic gradient effect of habitat quality in the upper reaches of Minjiang River was studied; and (4) analyzing the formation mechanism of the terrain gradient of habitat quality. Figure 2 illustrates the schematic diagram of our research method.

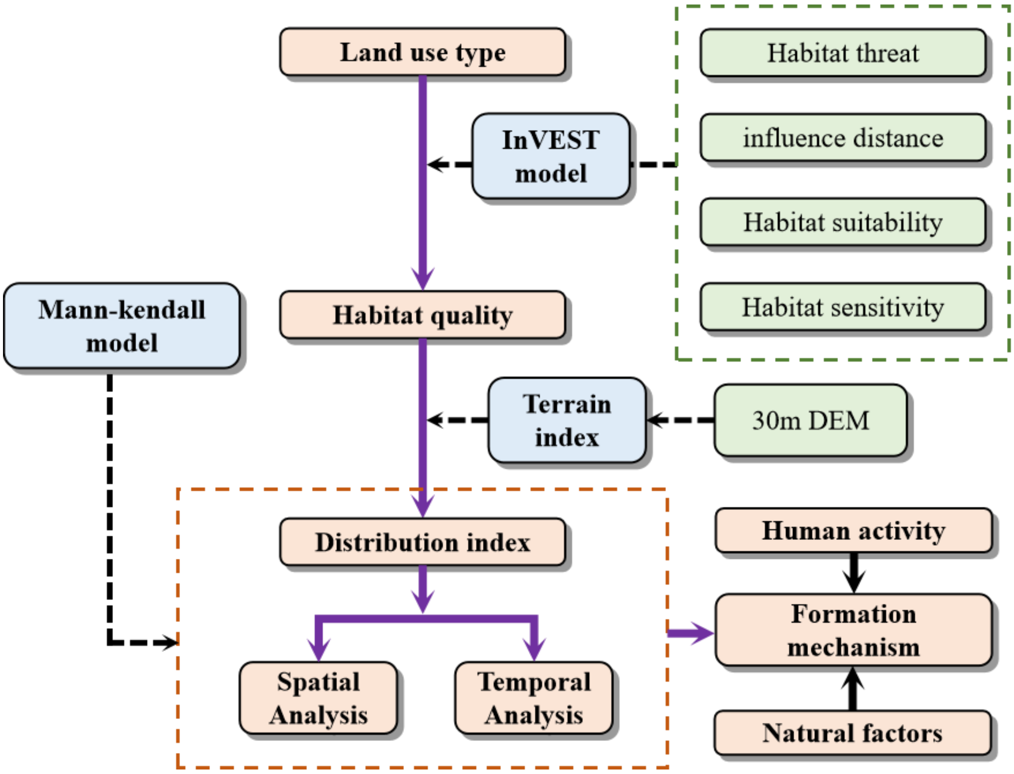

Figure 2. Technical process.

2.4. Measurement of Land Use Change

The change ratio was used as an index to analyze how land use tended to change. Equation (1) was used to calculate the change ratio. The spatial superposition function of ArcGIS software was used. The land-use types in the study area from 2000 to 2010 and from 2010 to 2020 were counted and superimposed. A transfer matrix was used to calculate the loss of all types of land:

$$C_n = \left[\frac{(U_b - U_a)}{U_a}\right] \times 100\% \tag{1}$$

In Equation (1), C_n represents the change ratio of a certain type of land use and U_a and U_b are the area corresponding to the land use at the beginning and end of the study (km), respectively.

2.5. InVEST Model

The InVEST (Integrated Valuation of Environmental Services and Tradeoffs) model was jointly developed by Stanford University, the World Wildlife Fund, and the Nature Conservancy to quantitatively assess habitat quality from the perspective of biodiversity [18,36]. The habitat quality in the InVEST model connects the land use/cover map with the threat source and evaluates the habitat distribution and degradation under different landscape patterns according to the response of different habitats to the threat source. The calculated habitat quality and scarcity can reflect the biodiversity of the region [37,38]. The formula of the InVEST model is as follows:

$$D_{xj} = \sum\nolimits_{r=1}^{R} \sum\nolimits_{y=1}^{Y_r} \left(\frac{\omega_r}{\sum_{r=1}^{R} \omega_r}\right) r_y i_{rxy} \beta_x S_{jr} \tag{2}$$

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{r\max}}\right) \text{ (Linear decay)} \tag{3}$$

$$i_{rxy} = \exp\left[-\left(\frac{2.99}{d_{r\max}}\right)d_{xy}\right] \text{ (Exponential decay)} \tag{4}$$

where ω_r is the weight of the different threat factors, r_y is the intensity of the threat factor, β_x is the anti-interference level of the habitat,S_{jr} is the relative degree of sensitivity of the different habitats to different threat factors, r is the habitat threat factor, y is the grid in the threat factor r, d_{xy} is the distance between grid x, grid y and $d_{r\max}$ is the influencing scope of the threat factor r. The habitat quality index was calculated as follows [18,36,37]:

$$Q_{xj} = H_j\left[1 - \left(\frac{D_{xj}^2}{D_{xj}^2 + k^2}\right)\right] \tag{5}$$

where Q_{xj} is the habitat quality index of the x grid according to land use/cover type j, H_j is the habitat suitability for the number of land uses/cover types j (for a value range of [0,1]), D_{xj} is the degree of habitat degradation of the x grid according to land use/cover type j, and k is the semi-saturation constant where D_{xj} is half the maximum [39].

Different threats have different impacts, which can be expressed according to the weight and maximum impact range. This study referred to the research of [10,13,14], and the selected cultivated land, urban land, rural residential land, industrial and mining land, and main roads as the threat sources in combination with the existing data and field conditions. Based on the values recommended by the model and considering the actual situation, the weight and maximum distance of the influence of these five threat sources were assigned (Table 1). In addition, the feasibility of each type of land use as a habitat is also related to its suitability and sensitivity to threats. The higher the suitability of a habitat, the higher its quality. The stronger the sensitivity of a habitat to threats, the lower its anti-interference ability and the lower the habitat quality. By referring to the recommended value of the model, based on the relevant literature [9,16–18] and expert opinions, the suitability of the habitats and their sensitivity to threats were determined (Table 2).

Table 1. Habitat threats and their attributes.

Threats	Maximum Distance of Influence	Weights	Types of Spatial Decay
Cultivated land	3	0.3	Linear
Urban land	10	0.8	Exponential
Rural residential area	6	0.6	Exponential
Industrial land	7	0.6	Exponential
Main roads	7	0.5	Linear

Table 2. Habitat suitability and sensitivity of different types of land use.

Primary Land Type	Secondary Land Type	Habitat Suitability	Sensitivity				
			Cultivated Land	Rural Residential Area	Urban Land	Industrial Land	Main Roads
Cultivated land	Paddy field	0.4	0.3	0.4	0.5	0.2	0.1
	Dryland	0.6	0.3	0.4	0.5	0.2	0.1
Woodland	Woodland	1.0	0.8	0.85	0.9	0.8	0.6
	Shrubland	1.0	0.4	0.5	0.6	0.4	0.2
	Open woodland	1.0	0.9	0.9	1.0	0.8	0.7
	Other woodlands	1.0	0.9	0.9	1.0	0.9	0.7
Grassland	High-cover grassland	0.8	0.4	0.5	0.6	0.4	0.2
	Medium-cover grassland	0.7	0.5	0.5	0.7	0.5	0.3
	Low-cover grassland	0.6	0.5	0.5	0.6	0.4	0.4
Water area	Canal	1.0	0.7	0.8	0.9	0.6	0.5
	Lake	1.0	0.7	0.8	0.9	0.6	0.5
	Reservoir pit	1.0	0.7	0.8	0.9	0.7	0.6
	Beach	0.6	0.7	0.8	0.8	0.7	0.6
	Beach land	0.6	0.7	0.7	0	0.7	0.6
Constructed land	Urban land	0	0	0	0	0	0
	Rural residential area	0	0	0	0	0	0
	Other constructed land	0	0	0	0	0	0
Unused land	Glaciers and permanent snow	0.1	0.1	0.2	0.3	0.2	0.2

2.6. Topographic Distribution Index

The distribution index (DI) of the habitat quality is estimated in two steps.

Step 1: The topographic potential index is calculated. This is an index for the composite analysis of elevation and slope attribute information of any point in space [40,41]:

$$T = \ln\left[\left(\frac{E}{\overline{E}} + 1\right) \times \left(\frac{S}{\overline{S}} + 1\right)\right] \tag{6}$$

In Equation (6), T is the topographic position, E and $\overline{E}$ are the elevation of a point and the average elevation of the area where the point is located, respectively, and S and $\overline{S}$ are the slope of a point and the average slope of the area, respectively. The higher the elevation and the greater the slope, the greater the topographic potential index and vice-versa.

Step 2: The topographic distribution index is calculated. This index reveals the topographic gradient effects on habitat quality by calculating the distribution index of different habitat quality levels on different topographic gradients [42]. Equation (7) was used for the calculation:

$$DI = \frac{A_{ij}}{A_i} \Big/ \frac{A_j}{TA} \tag{7}$$

where DI is the distribution index, A_i is the total area corresponding to class i ecological quality, A_j is the area of level j topography,A_{ij} is the area corresponding to class i ecological quality for class j topography, and TA is the total area of the study.

We used the distribution proportion to describe the distribution of changes in habitat quality for different terrains. Equation (8) was used for the calculation:

$$D_n = \frac{A_{ni}}{A_i} \times 100\% \tag{8}$$

where n represents the terrain level, i represents the change in habitat quality, A_{ni} represents the area that experienced the change in habitat quality i for terrain level n, A_i represents the total area of change in habitat quality i, and D_n represents the distribution proportion.

2.7. Mann–Kendall Test

The Mann–Kendall test is used for climate diagnosis and prediction and can be used to judge whether a mutation in the climate series has occurred and if so, the time of the mutation. The Mann–Kendall test is also often used to detect the trend of the precipitation and drought frequency under the influence of climate change. In this study, the Mann–Kendall test was used to determine the changing trend of habitat quality. The significance of the Z-value statistics of the Mann–Kendall monotonic trend was calculated using the habitat quality time series of each grid [43–45]:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & , \quad S > 0 \\ 0 & , \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & , \quad S < 0 \end{cases} \tag{9}$$

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} \operatorname{sgn}(Q_j - Q_i) \tag{10}$$

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \tag{11}$$

$$\operatorname{sgn}(Q_j - Q_i) = \begin{cases} 1, Q_j - Q_i > 0 \\ 0, Q_j - Q_i = 0 \\ -1, Q_j - Q_i < 0 \end{cases} \tag{12}$$

According to the normal distribution table when $|z| \geq 2.33$ and $|z| \geq 1.64$, the time series changes significantly at $p < 0.01$ and $p < 0.05$. According to the calculated value, the changing trend in habitat quality can be divided into three types:

(1) $Z \geq 2.33$, extremely significant increase;
(2) $1.64 \leq Z < 2.33$, significant increase;
(3) $-1.64 < Z < 1.64$, no significant change.

3. Results

3.1. Habitat Quality Distribution and Its Changes

(1) Land-use change

Changes in the type of land use were obtained based on the land-use maps of 2000, 2010, and 2020 (Figure 3). The main land-use types in the upper reaches of the Minjiang River were woodland and grassland, representing more than 95% of the total area. The rest were cultivated land, water areas, unused land, and constructed land of various sizes. From 2000 to 2020, the upper reaches of the Minjiang River exhibited an increase in constructed land, water areas, and unused land, a fluctuation in cultivated land, and a decrease in woodland. From 2000 to 2010, woodland experienced the greatest decrease, with a reduction of 252.9 km^2, representing a loss of −1.02%. The constructed land exhibited the greatest increase (13.9 km^2), representing a gain of 84.54%. From 2000 to 2010, all the areas except for woodland, experienced an increase, with cultivated land, grassland, water areas, constructed land, and unused land showing gains of 9.60%, 2.40%, 57.03%, 84.54%, and 0.18%, respectively, (Figure 4). From 2010 to 2020, the cultivated land and woodland area decreased, with losses of −4.76% and −0.16%. The area of grassland, water areas, constructed land, and unused land increased, exhibiting gains of 2.40%, 57.03%, 84.54%, and 0.18%, respectively, (Figure 5).

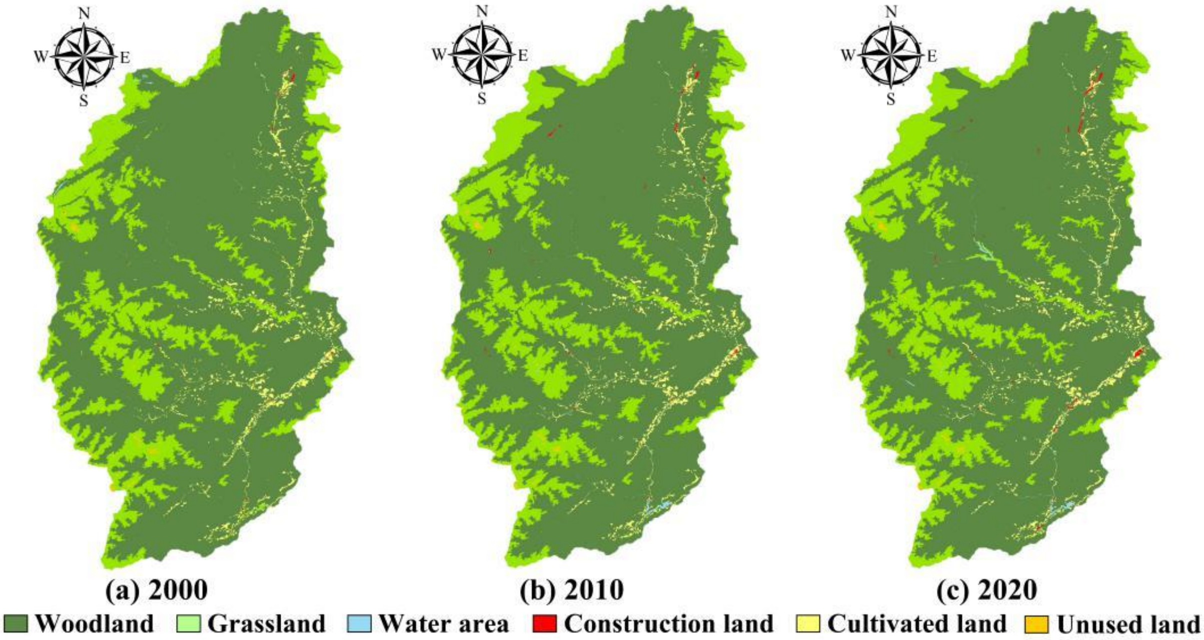

Figure 3. Land-use change from 2000 to 2020: (**a**) 2000, (**b**) 2010, (**c**) 2020.

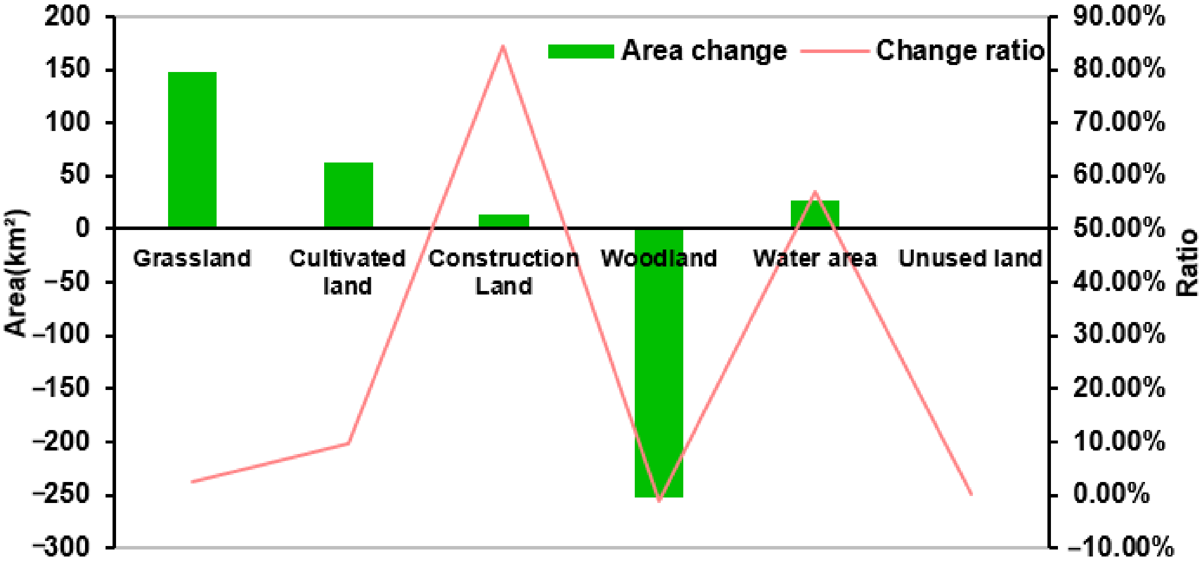

Figure 4. Changes in the area and ratio of various land-use types from 2000 to 2010.

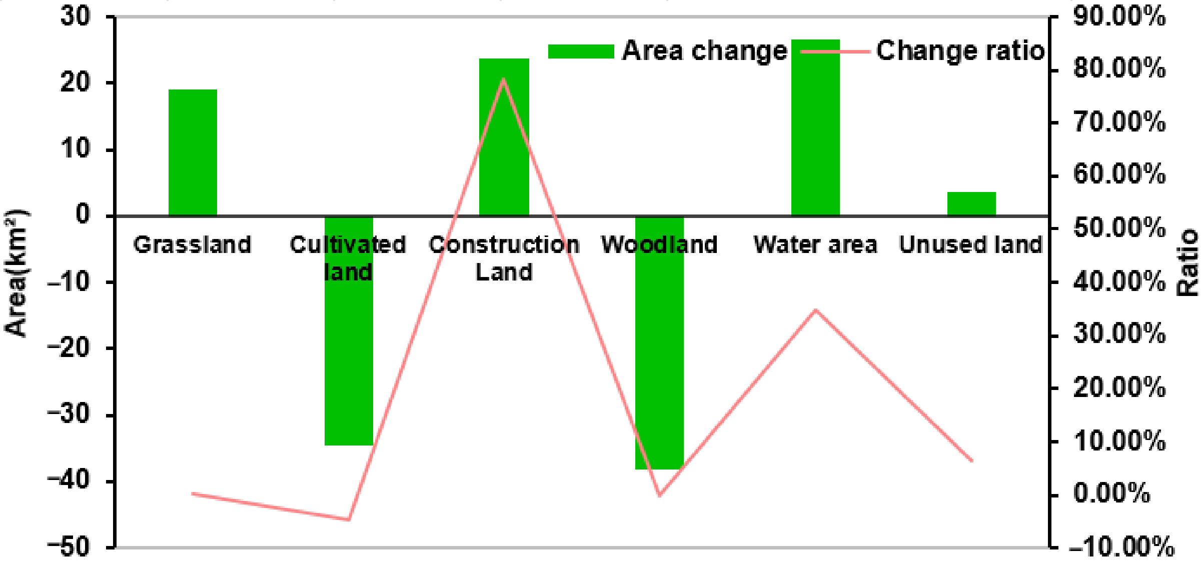

Figure 5. Changes in the area and ratio of various land-use types from 2010 to 2020.

(2) Changes in habitat quality

In the InVEST model, the habitat quality changes continuously from 0 to 1. The closer the value is to 1, the higher the habitat quality, the weaker the intensity of land development and utilization, and the greater the ecological benefits of the land. The habitat quality maps for 2000, 2010, and 2020 were obtained by applying the InVEST model (Figure 6). ArcGIS was used to reclassify the habitat quality to facilitate its temporal and spatial comparison. Because no corresponding area was observed in the range of 0.2–0.4 for the habitat quality of the three phases, the habitat quality was divided into four levels (I, II, III, and IV) with ranges of 0–0.2, 0.4–0.6, 0.6–0.8, and 0.8–1.0, respectively. Then, the spatial distribution map of the habitat quality in the upper reaches of the Minjiang River was generated. From the perspective of a spatial pattern, habitat quality generally presents the distribution characteristics of high-value agglomeration and low-value linear dispersion in the north and south. The habitat quality of the basin was generally high and accounted for an average of 75.7% of the total area for the three years evaluated. The high-quality habitat was mainly distributed in the north of the study area, which belongs to the plateau grassland, with few roads and residential areas and low-intensity human activities. The south is under the control of the Wolong Nature Reserve, a national nature reserve, and the intensity of human activities is relatively low. The area with habitat quality of Level I in Phase III accounted for 0.285% of the total. This area was distributed in the high mountains of the west and also was linearly distributed in the river valley along the main stream of the river.

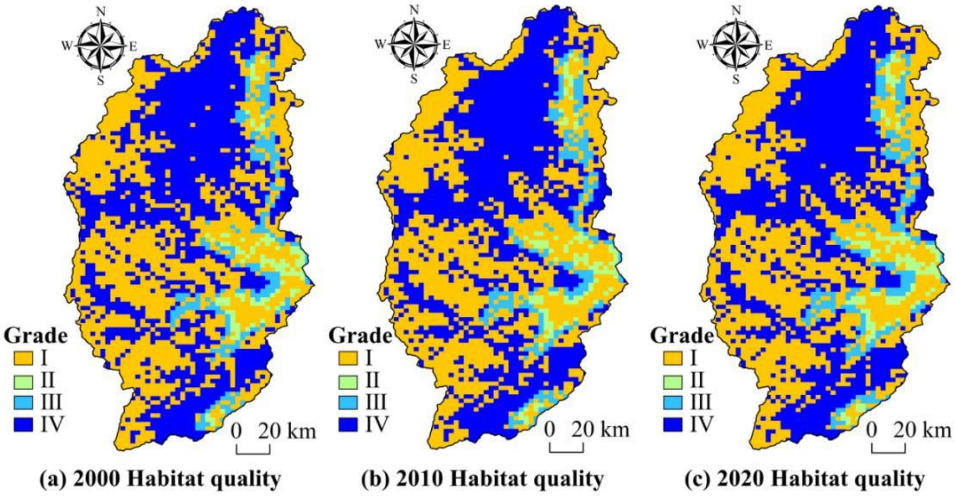

Figure 6. Distribution of habitat quality from 2000 to 2020: (**a**) 2000 (**b**) 2010 (**c**) 2020.

From the perspective of temporal and spatial changes, the area of watershed Level IV decreased by 2% from 2000 to 2010, mainly changing from Level IV to Level III. The areas of habitat quality of Level II and Level I increased by 12.15% and 19.52%, respectively. From 2010 to 2020, the ecological quality area of Level IV decreased by 0.02%, Level III increased by 0.79%, and Level II decreased by 3.8%. The ecological quality area of Level I increased by 31.8%. Level II, Level III, and Level IV exhibited increases of 50.76%, 29.27%, and 20.92%, respectively. Overall, the habitat quality decreased from 2000 to 2020, which was reflected in the decrease in the area of Level IV habitat quality and the increase in the area of Level I habitat quality. By comparing the three years, we observed that the habitat quality of Level IV significantly decreased but the area of habitat quality of Level I continues to increase (Figure 7), and the environmental pressures are still considerable.

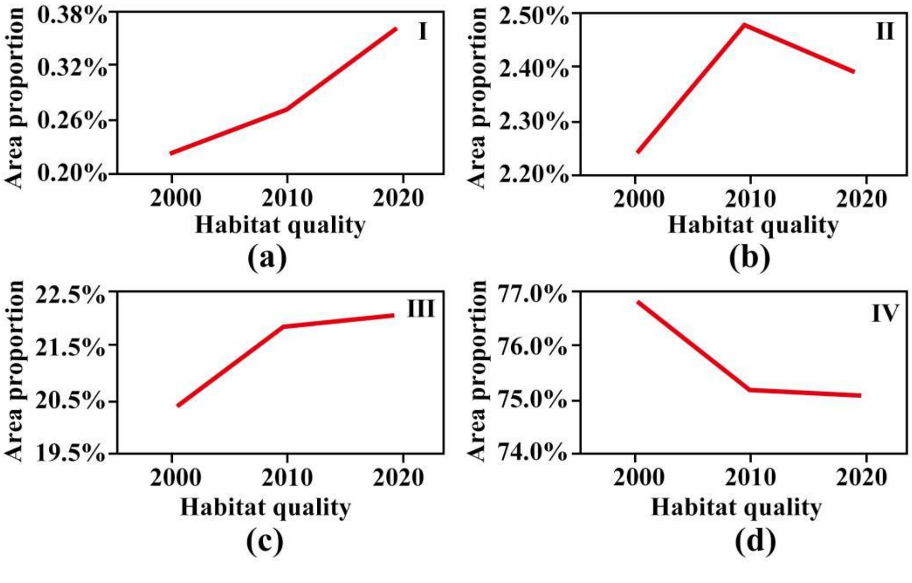

Figure 7. Changes in the different levels of habitat quality: (**a**) Level I (**b**) Level II (**c**) Level III (**d**) Level IV.

3.2. Distribution of Habitat Quality on Different Levels of Terrain

(1) Terrain position calculation

Using the equal interval classification method ArcGIS, the altitude, slope, and topographic potential index of the upper reaches of the Minjiang River were reclassified. The interval values were 1000, 12, and 0.34, respectively, which were divided into six grades from small to large. The altitude was concentrated in Grade 3 (2000–3000 m), Grade 4 (3000–4000 m), and Grade 5 (4000–5000 m), accounting for 95.9% of the total area. The slope was concentrated in Grade 2 (12°–24°), Grade 3 (24°–36°), and Grade 4 (36°–48°), accounting for 89.1% of the total area. The topographic potential index was mainly concentrated in Grade 3 (1–1.34) and Grade 4 (1.34–1.68), accounting for 94.1% of the total area (Figure 8). Some differences were observed between the topographic potential index and the changes in the height and slope of the area. This suggests that the distribution of the topographic potential index is affected by topographic combinations with high elevation/small slope and low elevation/large slope.

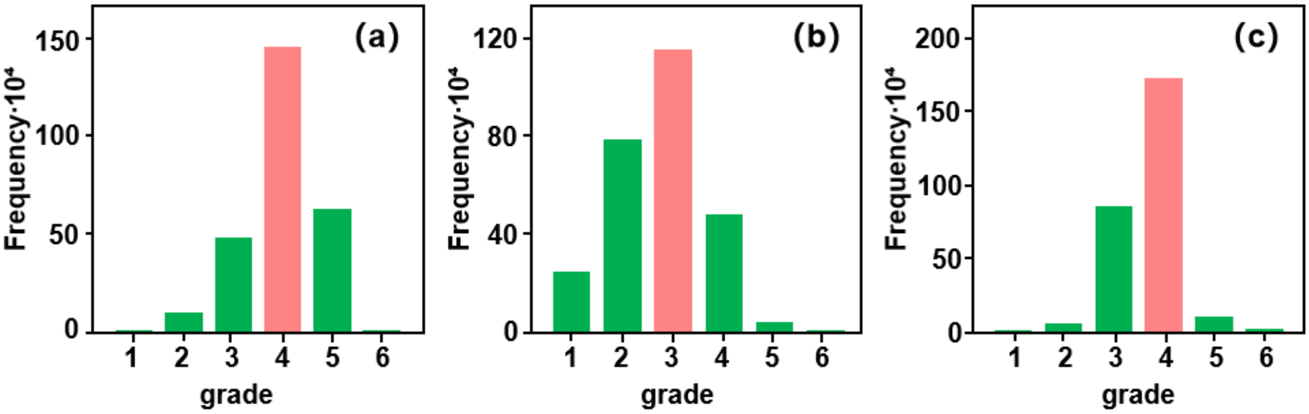

Figure 8. Terrain location calculation results: (**a**) Elevation, (**b**) Slope, (**c**) Topographic potential index.

(2) Topographic gradient effects of habitat quality distribution

The topographic distribution indexes of the different habitat qualities in 2000, 2010, and 2020 were statistically analyzed to reveal the topographic gradient effects of the temporal and spatial distribution of the habitat. As shown in Figure 9, the distribution index of the habitat quality of Grade 6 was significantly higher than those in Grades 1–5. Moreover, the distribution index in 2020 became lower for the terrain in Grades 1–4 and higher for the terrain of Grade 6 compared with 2010 and 2000. The distribution index of medium-quality habitat on the terrain of Grades 5 and 6 was significantly higher than that of Grades 1–4. In contrast with the concentrated distribution of medium- and low-quality habitat in the highlands, the higher-quality habitat was mostly distributed in the middle and low terrain of Grades 1–3 (Figure 10). The distribution in the highlands of Grades 4–6 in 2010 and 2020 was significantly lower than in 2000. The topographic gradient effects of high-quality habitat presented a symmetrical distribution pattern of high in the middle and low on both sides. The distribution index was higher for Grade 4 terrain and lower for Grades 1–3 and 5–6.

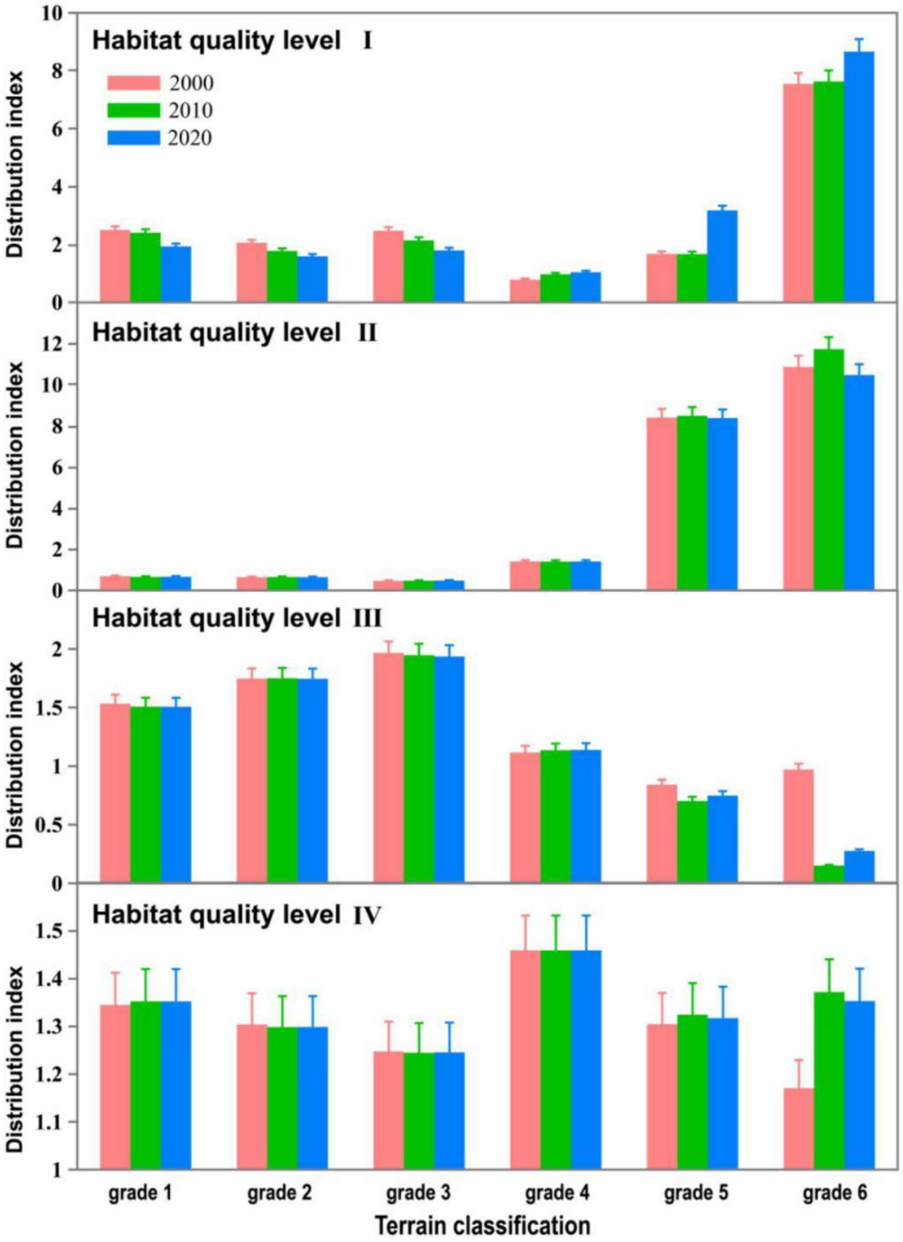

Figure 9. Topographic distribution index of different levels of habitat quality.

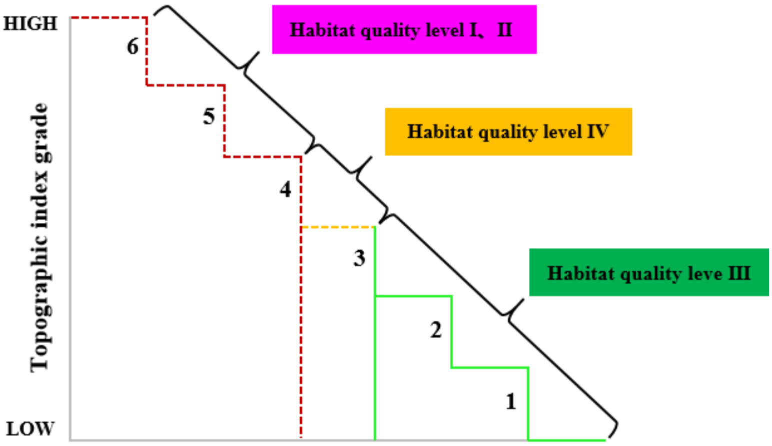

Figure 10. Main distribution differences of habitat quality in various topographic positions.

4. Discussion

4.1. Topographic Differentiation of Habitat Quality

To analyze the consistency of the changing trend of habitat quality we calculated the trend proportion of the annual average habitat-quality value from 2000 to 2020. At $p < 0.05$ (z = 1.67), the proportions of the three types of trends (significant decline, no significant change, and significant increase) were 22.2%, 41.8%, and 36%, respectively. As shown in Figures 11 and 12, we determined the distribution proportions of the changes in habitat quality for different topographies. As a result, the grids with significant increases and decreases were mainly distributed in the highlands (Grades 5 and 6). For example, habitat quality Levels IV and III changed into habitat quality Level I. The grids with significant increases were mainly distributed in the lowlands (Grades 1–3). For example, habitat quality Level I changed into habitat quality Level III. The grids that did not change significantly were mainly distributed in the middle terrain (Grade 4). Therefore, the results show that the highlands were the predominant area of the grid with a significant decrease in habitat quality, whereas the lowlands were the predominant area of the grid with a significant increase in habitat quality. The middle topographic position was the predominant area of the grid with no significant changes in habitat quality (Figure 13). This result is consistent with that reported by Wang and Cheng (2022) for the geomorphic differentiation of habitat quality.

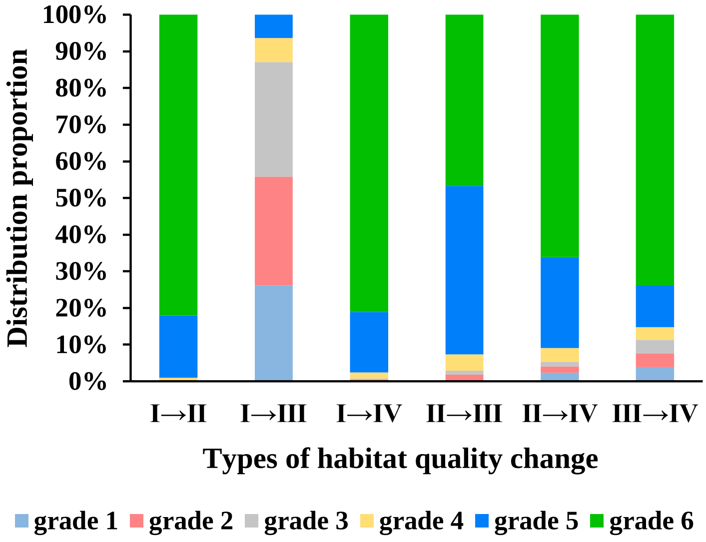

Figure 11. Proportion of habitat quality increases for different topographic positions.

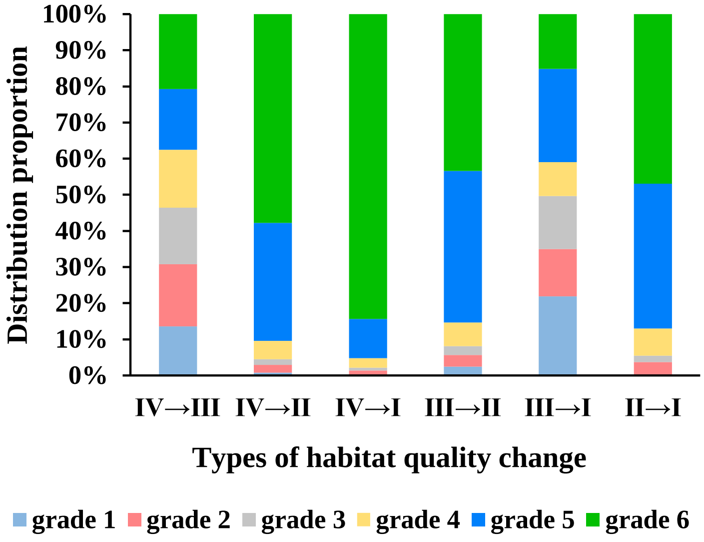

Figure 12. Proportion of habitat quality decreases for different topographic positions.

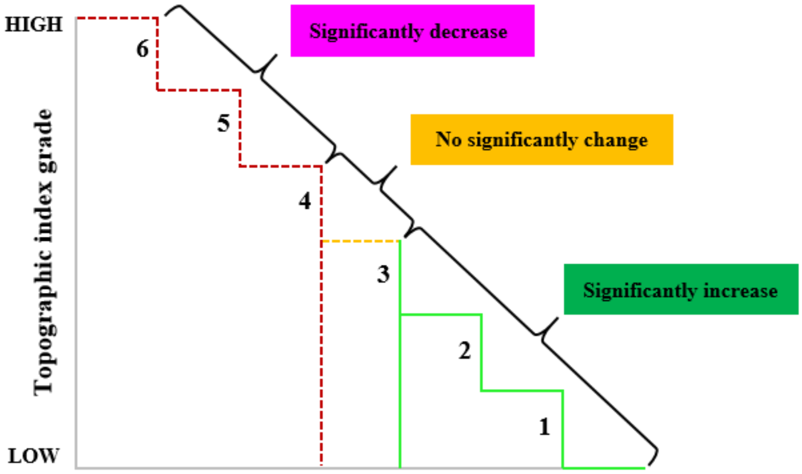

Figure 13. Predominant changes in habitat quality for different topographic positions.

4.2. Impact of Human Activities on Habitat Quality

Human disturbances in habitat quality are mainly caused by construction, development, reclamation, and logging. Construction, development, and reclamation change the land-use type from woodland or shrub woodland to constructed land or cultivated land, resulting in changes to the ecosystem structure. A mutation point is observed before and after the disturbance [46].

The economic development of the highlands in the upper reaches of the Minjiang River (terrain of Grades 5 and 6) is relatively backward, and the structures of agriculture, animal husbandry, and people's livelihood are relatively simple. The livelihoods of some of the poorer people are excessively dependent on woodlands and grasslands, which show a high development intensity that exceeds their carrying capacity, causing great damage to the natural resources and environment [35]. In high-terrain areas, poor farmers lack livelihood assets, resulting in their inability to develop alternative resources, so they can only rely on free energy sources (e.g., turf and trees), which aggravates soil erosion and forest destruction. The energy consumption behavior, which is mainly based on energy needed for living, has become the most basic factor behind the environmental degradation in ecologically fragile areas [47].

From 2000 to 2020, the proportion of ecological restoration with a significant increase in habitat quality for terrain Grade 4 reached 80.7%. According to the spatial distribution of land use in the area of the study, the middle terrain was not only the predominant area covered by woodland, shrub woodland, and grassland, but also the main implementation area of desertification control, returning farmland to woodland and grassland, and preventing the access to mountains for wood harvesting [12]. The implementation of these projects can rapidly improve habitat quality. The comparison of the periods of 2000–2010 and 2010–2020 revealed that the woodland area decreased gradually. Although the land type still changed from woodland to grassland in the last decade, the scale of this change was significantly reduced when compared with 2000–2010. This result shows that the consolidation of projects to protect natural woodland resources, the conversion of farmland to woodland, and woodland protection projects implemented in the upper reaches of the Minjiang River during the 12th and 13th Five-Year Plans were effective for the protection and restoration of woodlands. The results of the Mann–Kendall test revealed that the distribution of the grids with a significantly increased and a significantly decreased habitat quality for the middle terrain was the same.

The low-lying areas are areas of dense human economic and social activities. Habitat quality showed notable improvements, but also declines, in these areas. For example, the distribution index of low- to high-habitat quality was significantly higher in low-lying areas than in medium- and high-elevation areas, indicating that these areas have benefitted from improvements in environmental protection policies and ecological awareness in recent years.

4.3. Effects of Natural Factors on Changes in the Habitat Quality of Highlands

Geological disasters, such as large barrier lakes, dam breaks, and river blockage caused by large earthquakes occur frequently in the upper reaches of the Minjiang River, inundating the cultivated land, woodland, and grassland on both sides of the river valley, thus reducing the quality of the ecological services of both the woodland and grassland [34]. Moreover, the numerous facilities built after earthquakes have greatly increased the growth rate of the constructed land. Hence, some of the cultivated land, woodland, and grassland were transformed into constructed land [35]. From the perspective of land-use change, in the highlands, the area of degraded woodland reached 77.3% in the period from 2000 to 2020, resulting in low-quality habitats. Therefore, woodland degradation caused by natural factors is an important reason for the highlands to become the predominant area with a significantly reduced habitat quality.

In addition, this study found that in the highlands, the unused land portion continued to grow. This may be due to the high incidence of geological disasters, such as debris flow and landslides that transformed part of the woodland and grassland cover into unused land, resulting in a lowered environmental quality. The habitat quality and the density of geological hazards in the highlands were significantly ($p < 0.01$) and negatively correlated (Pearson correlation coefficient = -0.68). This result shows that the change in habitat quality is closely related to natural disasters. Combined with the human activities in the highlands, this result reflects the characteristics of the livelihood structure of the local residents as well as the high incidence of geological disasters. In turn, this is the main factor behind the substantial downward trend in habitat quality in the highlands (Figure 14).

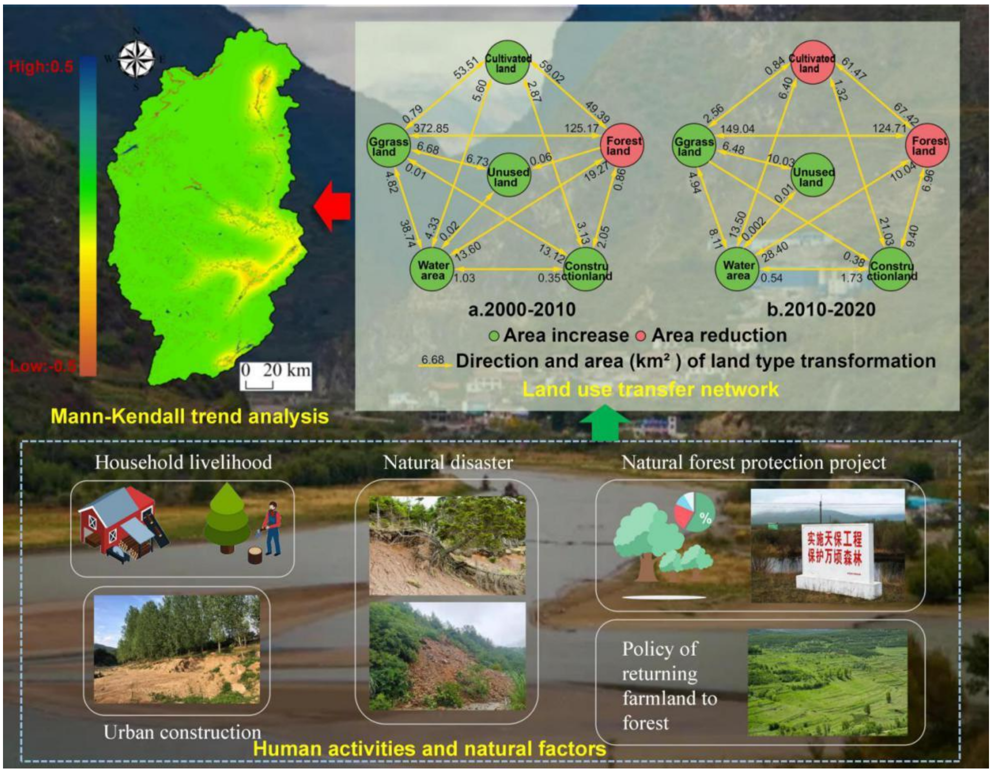

Figure 14. Mechanism behind the topographic gradient effects on habitat quality.

4.4. Policy Suggestions for improving the Quality of the Mountain Habitat

The topographic gradient differentiation patterns of the habitat quality distribution can reflect the direct factors behind the habitat quality change. Hence, different habitat protection measures should be taken for different topographic gradients: (1) for the highland areas with serious ecological quality degradation, woodland and grassland protection policies should be formulated, establishing and expanding ecosystem protection areas and strengthening woodland management and protection. Meanwhile, efforts should be made to promote ecological construction and poverty alleviation activities, develop eco-friendly industries, and improve the livelihoods of the local residents. Farmers and herdsmen living in areas with a fragile ecology, frequent geological disasters, and economic difficulties may be encouraged to migrate to conditional areas; (2) for the middle-elevation terrain, close attention should be paid to the effects of the implementation of environmental protection and restoration projects to prevent the emergence of the dual-track trend of governance and destruction; and (3) for the low-lying areas, we should further consolidate environmental protection projects, strictly control human interference with the environment, strengthen land-intensive construction, and encourage projects, such as sewage treatment plants, environmental sanitation, and urban greening.

5. Conclusions

The upper reaches of the Minjiang River are a global biodiversity hotspot and a key biodiversity conservation area in China. In the past two decades, the management department has adopted a series of environmental protection projects to improve the quality of the regional habitat. This study analyzed the habitat quality and revealed the influence of topography upon it. This study also evaluated the effects of environmental protection in the upper reaches of the Minjiang River for the past 20 years. The results show the following: (1) in the past 20 years, the areas of the constructed land, water, and the unused land have continued to expand, that cultivated land has fluctuated, that woodland has continued to decrease, and the phenomenon of mutual conversion between woodland and grassland is increasingly prominent; (2) the low-quality habitat is concentrated in the highlands, whereas the high-quality habitat is concentrated in the middle terrain, and the medium-quality habitat is distributed in the lowland. The high-quality habitat decreased, whereas the low-quality habitat increased; and (3) the livelihood structure of residents and geological disasters are the main reasons behind the decline in habitat quality in the highlands. Thanks to the environmental protection policies and ecological awareness, the habitat quality in medium- and low-elevation terrain is relatively balanced.

In this paper, the topographic gradient effect on habitat quality was analyzed from the perspective of land use, and some beneficial insights for ecological management in mountainous areas were obtained. However, because obtaining a direct observation index of habitat quality is difficult, the results of the InVEST model were not validated and the model parameters were selected by referring to the relevant literature. In addition, habitat quality includes many aspects, such as water conservation, soil conservation, and carbon storage. Therefore, future studies should perform an evaluation and verification of the InVEST model based on the measured data and build a comprehensive evaluation model of habitat quality under multiple ecological conditions.

Author Contributions: Conceptualization, Q.X. and A.K.; methodology, Q.X.; software, Q.X.; validation, Q.X., A.K. and H.H.; formal analysis, Q.X.; investigation, R.G.; resources, X.Y. and F.L.; data curation, Q.X.; writing—original draft preparation, Q.X. and A.K.; writing—review and editing, Q.X. and A.K.; visualization, Q.X.; supervision, W.L.; project administration, A.K.; funding acquisition, A.K. All authors have read and agreed to the published version of the manuscript.

Funding: Funding was provided by the 2022 Chengdu University of Technology "Double First Class" Key Construction Project of Philosophy and Social Sciences (ZDJS202219), the Key R&D Project of Sichuan Science and Technology Plan (2022YFS0563), and the Chengdu University of Technology Postgraduate Innovative Cultivation Program (CDUT2022BJCX001).

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Acknowledgments: We thank student Xu and He from the United States for proofreading the manuscript.

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

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