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Rural–Urban Migration and Conservation Drive the Ecosystem Services Improvement in China Karst: A Case Study of Huanjiang County, Guangxi

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Abstract: Under the transformation from over-cultivation to ecological protection in China karst, the way human activities affect ecosystem services needs to be explored. This study incorporated satellite imagery and ecosystem models (Carnegie-Ames-Stanford Approach (CASA), Revised Universal Soil Loss Equation (RUSLE) and Integrated Valuation of Ecosystem Services and Trade-offs (InVEST)) to evaluate the main ecosystem services (net ecosystem productivity (NEP), soil conservation and water yield) in a typical karst region (Huanjiang County). The relationships between human activities and ecosystem services were also examined. NEP increased from 441.7 g C/m²/yr in 2005 to 582.19 g C/m²/yr in 2015. Soil conservation also increased from 4.7 ton/ha to 5.5 ton/ha. Vegetation recovery and the conversion of farmland to forestland, brought about largely by restoration programs, contributed to this change. A positive relationship between increases in NEP and soil conservation and rural-urban migration ($r = 0.62$ and 0.53 , $p < 0.01$, respectively) indicated the decrease in human dependence on land reclamation and naturally regenerated vegetation. However, declining water yield from 784.3 mm to 724.5 mm shows that the trade-off between carbon sequestration and water yield in ecosystems needs to be considered seriously for further ecosystem services improvement. Our study suggests that conservation is critical to vegetation recovery in the region. Furthermore, the relieved human pressure on land also plays an important role.

Keywords: remote sensing; ecosystem services; human activities; ecological restoration programs; rural–urban migration; China karst

1. Introduction

Ecosystem services, the benefits that humans receive from ecosystems, are of great significance to humans in product supply, system regulation and service support [1]. About 60% of ecosystem services worldwide are degraded because of anthropogenic activities, such as excessive population growth and irrational economic development [2]. The ecosystem services of carbon sequestration, soil conservation and water regulation in the degraded karst area are particularly important for regional sustainable development [3,4]. Unlike other karst regions in the world where the population is relatively sparse, high population density (about 195 people/km²) and limited arable land resources in the karst region of southwest China caused the sharp contradiction between human and land [5].

Hundreds of years of traditional farming practices made people heavily dependent on cultivated land [6]. Excessive farming activities destroyed the surface vegetation and accelerated soil erosion during the 1950s to 1980s, causing ecosystem degradation such as low vegetation coverage and landscapes of bedrock outcrops [7,8]. The fragile ecosystems (e.g., shallow soils and intense anthropogenic disturbances) in karst regions in China prevented a quick natural recovery and ecosystem services were destroyed.

Human activities mainly affect ecosystem service function by changing land-use patterns [3,4,9,10]. Major anthropogenic activities in the karst region of southwest China include farming, logging and urban expansion [11]. Since 1998, the Chinese governments implemented a series of large-scale ecological restoration projects to recover degraded land (including the karst regions). Monitoring results using satellite images showed that China was turning green [12,13], especially in the karst region of southwest China. However, these results from large-scale research are tendentious and general due to the coarse-resolution satellite images. Meanwhile, many previous studies focused on vegetation changes [14,15]. It is yet to be determined if vegetation growth improves ecosystem services and the impacts of anthropogenic activities on ecosystem services on a regional scale.

Satellite imagery is an important data source for ecosystem services assessment [14,16,17]. Images have been applied to monitor land cover changes, vegetation carbon sequestration, biodiversity and soil and water-related ecosystem services. Furthermore, surrogate information extracted from satellite imagery (e.g., plant and soil characteristics) are used to measure spatially explicit parameters of an ecosystem process that are related to ecosystem services [3,5]. Along with other data sources, results of satellite image classification feed ecosystem models for ecosystem services are studied [6,16].

The methods of ecosystem service value and physical assessment have been widely used in current studies [18,19]. More studies have been conducted evaluating ecosystem services by assessing ecosystem services using comprehensive models where the formation mechanism of ecosystem services are considered [13,20,21]. Net ecosystem productivity (NEP) is a direct reflection of the carbon accumulation capability of an ecosystem [22]. The value of NEP, the remaining part of the net primary productivity (NPP), deducts autotrophic respiration. NPP is commonly calculated using Carnegie–Ames–Stanford Approach (CASA) model [23], which is widely used in vegetation productivity assessment. Meanwhile, the geological background of carbonate rocks determines the dual structure (surface runoff and vertical water loss) in the hydrologic process in the karst area. This affects the process of soil erosion and its assessment [24]. A modified Revised Universal Soil Loss Equation (RUSLE) was used to evaluate soil conservation and had been proven to be suitable for the karst area [25,26]. Meanwhile, the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model includes a module for evaluating the water yield and has been applied in many studies [27].

Compared with the ecosystem services evaluation, exploring ecosystem health and its potential for ecosystem services and ecosystem recovery in the karst region also requires more attention. The fragility of the karst ecosystem and shallow soil have caused slow vegetation recovery [28,29]. Although the implementation of the ecological restoration projects improved vegetation growth, the karst ecosystem still lacks stability [30,31]. Therefore, understanding the current state of the ecosystem and its development potential might contribute to further improving ecosystem services through reasonable human activities.

This research applied CASA, modified RUSLE and InVEST models to simulate and evaluate ecosystem NEP, soil conservation and water yield in a typical karst region (Huanjiang, Guangxi, China). The study further analyzed the spatial–temporal changes of these three types of ecosystem services and explored the relationships between human activities and ecosystem services. Results from this study may be considered to guide the further ecosystem services improvement.

2. Study Area

The study area, Huanjiang County, ($107^{\circ}51'–108^{\circ}43'E$, $24^{\circ}44'–25^{\circ}33'N$) is located in the karst region, Guangxi Province, southwest China (Figure 1). The county has an area of 4572 km^2 , and elevation ranges from 128 to 1696 m. About half of the study area is dominated by carbonate rock, where typical landforms are depressions and tower karsts, with about 60% of this area having slope angles steeper than 25° . Another half of the Huanjiang County is a clastic region, where the typical landforms are relatively gentle hills. The climate is warm–moist subtropical, with a mean annual temperature of 19.9°C and a mean annual precipitation of 1389 mm. Subtropical evergreen forest is the climatic vegetation community climax in this area. Historically, severe human disturbances on slopes have led to serious vegetation degradation. Relatively high population density (about 81 people per km^2) and excessive farming on the slopes have caused the disappearance of the climax communities in this region. By the 1990s, large areas were dominated by grass and shrub. Destruction of vegetation had caused serious ecological degradation like water and soil erosion and exposed bedrock outcrop. A series of ecosystem restoration programs were implemented from the late 1990s, and the aims are to rebuild the damaged ecological environment. Carbonate regions are dominated by shrubs, where the implementation of the Green for Grain program is to convert the sloping farmland to forest land to reduce soil erosion. In the clastic region, some grasslands are used for plantation and farming due to their relatively good soil condition.

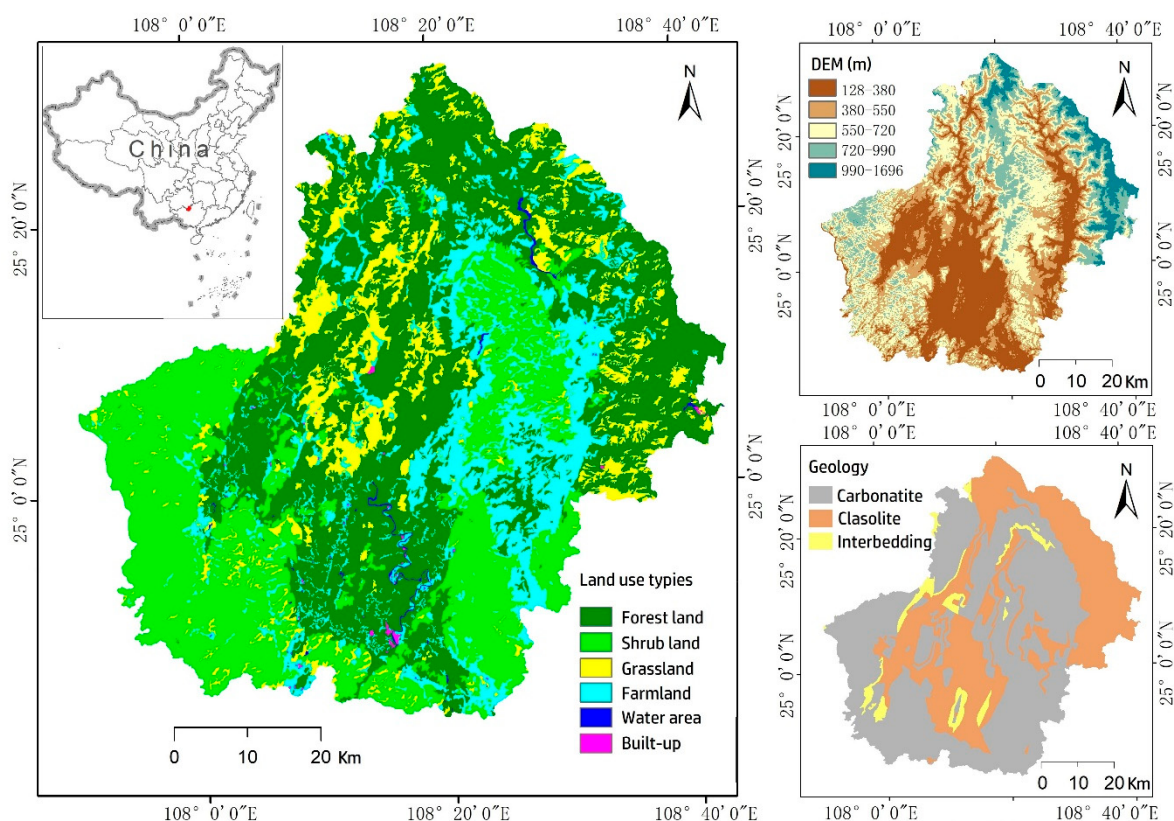


Figure 1. Location of the study area (Huanjiang County) and its land use and land cover in 2015, elevation and geology background.

3. Materials and Methods

3.1. Research Data

Meteorological station data from 2005 to 2015 for 64 meteorological stations in and around the study area were obtained from China Meteorological Data Network (<http://data.cma.cn/> (accessed on 23 January 2021)). Weather parameters include rainfall,

temperature, humidity, wind speed, air pressure, radiation, and others. ANUSPLIN interpolation was adopted for the interpolation of climate parameters to acquire regional maps. The maps were clipped using the boundary of the study area to obtain the meteorological data in this study. DEM data were acquired from the geospatial data cloud (<http://www.resdc.cn/> (accessed on 23 January 2021)) with a resolution of 30×30 m. Landsat 5 and Landsat 8 series images in 2005 and 2015 were downloaded from the Data-sharing Network of Earth System Science, China (<http://www.geodata.cn> (accessed on 23 January 2021)) to extract land use data for ecosystem service assessment. Many field data from these two years were used to facilitate the modeling, validation and assessment of ecosystem research. Land use data from Huanjiang County in 2005 and 2015 were extracted from Landsat series images using ERDAS IMAGINE 9.1 Software (Leica). Land use types include forest land, shrub land, grassland, farming land, water area and built-up (Table 1). A widely used maximum likelihood classifier was applied for land use and land cover classification. The training samples of forest land, shrub land, grassland and farming land were collected based on long-term positioning observation sample sites, which were built in the Huanjiang County from 2002 to 2004. The training samples of water area and built-up were determined based on historical landcover maps, and information from interviews with local residents was also used to confirm the land used types in 2005 and 2015. Spectral curves of training points were checked, and the separability (Jeffries-Matusita parameter) of training points of each land-use types was calculated to determine dependable training points. Finally, a total of 136 training samples (31, 40, 29, 13, 10 and 13 training points for forest land, shrub land, grassland, farming land, water area and built-up, respectively) in 2005 and 147 training samples (34, 40, 31, 14, 12 and 16 training points for forest land, shrub land, grassland, farming land, water area and built-up, respectively) in 2015 were determined for Landsat image classification. The combination of inverse Minimum Noise Fraction Rotation (MNF) image, Normalized Difference Moisture Index (NDMI) and Moisture Stress Index (MSI) was also used to reduce topographic effects and improve the classification accuracies [32]. Testing points for accuracy assessments were generated using a stratified random method. Class labels of 112 testing points (29, 36, 18, 13, 6 and 10 testing points for forest land, shrub land, grassland, farming land, water area and built-up, respectively) in 2005 were determined by visual interpretation of high spatial resolution IKONOS and Spot-5 images in 2004 and 2005, and historical land cover information collected from interviews with local people. A total of 132 testing points (39, 46, 21, 13, 5 and 8 testing points for forest land, shrub land, grassland, farming land, water area and built-up, respectively) in 2015 were determined using field survey in the whole Huanjiang County in 2015. Accuracy assessments were conducted using error matrices and kappa coefficient. The overall accuracy of the land cover classification was 86.6% and 87.9% in 2005 and 2015, respectively, with Kappa Coefficient of 0.83 and 0.84.

Table 1. Classification systems in the study area.

Primary Classes	Subclasses	Codes
Forest land	Natural forests, Artificial forest	Class1
Shrub land	Shrubs, Sparse forestland	Class2
Grassland	Grass, Brush grass, Meadow	Class3
Farmland	Dry farmland, Paddy field	Class4
Water area	Rivers, Reservoirs	Class5
Built-up	Residential area, Other construction land	Class6

3.2. NEP Calculation

NEP refers to the net primary productivity (NPP) minus the photosynthetic products consumed by heterotrophic respiration (RH):

$$NEP = NPP - RH \quad (1)$$

$$RH = 0.22 \cdot (\ln(0.3145R + 1) + \exp(0.0913T)) \cdot 30.465\% \quad (2)$$

where NPP can be calculated by referring to previous studies [14], RH is an empirical equation that is applicable to the land situation in China [33], R is the precipitation, T refers to the temperature.

3.3. Soil Conservation

The revised universal soil erosion model (RUSLE) is applied to simulate soil conservation [25]. It can be calculated by subtracting the potential of soil erosion (assuming it is the soil erosion on bare land, vegetation cover factor (C) and soil and water conservation factor (P) defined as 1) and the actual soil erosion (soil loss under vegetation cover) (unit: ton/ha):

$$A = R \cdot K \cdot LS \cdot C \cdot P \quad (3)$$

In the above equations, A is an average annual soil loss (ton/ha), R is the factor for annual rainfall erosivity ($\text{MJ} \cdot \text{mm} \cdot \text{ha}^{-1} \cdot \text{h}^{-1} \cdot \text{yr}^{-1}$) [34], R is the duration of each rainfall within a year, which can be fitted based on the observed long-term rainfall data. K is soil corrosion factors ($\text{t} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$), LS is a dimensionless factor for slope, C and P are the dimensionless factors related to land cover and soil conservation, which can be defined according to a previous study [35].

3.4. Water Yield Modeling

The evaluation of water yield was calculated using the water yield module in the InVEST model. The module is based on the water-thermal coupling equilibrium hypothesis of Budyko and the data of annual average precipitation [36]. The annual water yield $Y(x)$ of each grid unit x in the study area was determined as shown in Equation (1) (unit: mm):

$$Y(x) = \left(1 - \frac{E(x)}{P(x)}\right) \cdot P(x) \quad (4)$$

$$E_0 = \frac{\Delta}{\Delta + \gamma} \frac{R_n - G}{\lambda} + \frac{\gamma}{\Delta + \gamma} \frac{6.43(1 + 0.536U_2)(1 - Rh)e_s}{\lambda} \quad (5)$$

$$\omega = 0.69387 - 0.01042\text{lat} + 2.81063\text{NDVI} + 0.146186\text{CTI} \quad (6)$$

where $Y(x)$ is annual water quantity (mm) in grid x , $P(x)$ is the average annual precipitation (mm) of grid x , $E(x)$ is the potential evapotranspiration of grid x (mm), Δ is the slope of saturation vapor pressure and temperature ($\text{kPa} \cdot ^\circ\text{C}^{-1}$), γ is the dry-wet table constant ($\text{kPa} \cdot ^\circ\text{C}^{-1}$), R_n is net radiation, G is soil heat flux, λ is the latent heat of vaporization, U_2 is wind speed, Rh is relative humidity, E_s is saturation vapor pressure, ω is the nonphysical parameter of natural climate–soil property [24], lat is latitude, CTI is the terrain index.

3.5. Ecosystem Health Assessment

The ecosystem health assessment of Huanjiang County is based on the pressure–state–response (PSR) framework [30,37]. The PSR framework is formed from three parts (the pressure (P), the state (S) and the response (R)) [38]. The human pressure can be described using the indices like landscape fragmentation and population density. PSR assesses human pressure (e.g., fragmentation, population growth), which changes the environmental conditions (i.e., the state) of the ecosystem. The state of the karst ecosystem was represented using the indices of Normalized Difference Vegetation Index (NDVI), landscape diversity, average patch area, ecological service value and ecological resilience. Each index was weighted based on the analytic hierarchy process (AHP) [39], and then all indices were combined into what is referred to as the ecosystem health (ESH) index. We used the standardized indices as input to calculate ESH:

$$ESH = \sum_{i=1}^n W_i V_i \quad (7)$$

In the equation, n is the number of indices, W_i is the weight of index i , V_i is the value of index i after standardization.

3.6. Potential Vegetation Restoration Prediction

The protected area that is not disturbed by human was selected as vegetation reference to the bottom, and the regression equation between vegetation and meteorological factors is established when only the impact of climate change is considered. Then, the potential NDVI of the area is calculated using the above regression equation. Comparing with real NDVI calculated by satellite images, the difference value is the potential of vegetation restoration of the region.

Correlation analysis was conducted between monthly NDVI and climatic factors of the first N ($N = 0, 1, 2, 3, 4$) months; we found that monthly NDVI was most significantly correlated with rainfall and average temperature in the first 0–2 months (correlation coefficient > 0.65), and most significantly correlated with average temperature in the first 0–1 months (correlation coefficient > 0.7). Both rainfall and temperature have a hysteresis effect, with rainfall lagging by about 2 months and temperature lagging by about 1 month. Therefore, rainfall in the first 2 months and average temperature in the first 1 month of the year were used as input factors of the potential NDVI model in the simulation of potential vegetation growth. The regression equation between pixel-based NDVI and climatic factor combination (rainfall and temperature) is established:

$$Y_{ndvi} = a * P + b * T + c \quad (8)$$

where Y_{ndvi} is the monthly NDVI value, P is the rainfall and in the first months, T is the average temperature in the first 1 month and a , b and c are the fitting coefficients.

4. Results

4.1. Ecosystem Services Evaluation

4.1.1. NEP and Its Change

NEP increased from 2005 to 2015 (Figure 2). The mean accumulation rate of ecosystem carbon were 441.7 and 582.19 g C/m²/yr in 2005 and 2015, respectively, increasing by 12.77 g C/m²/yr during the study period. The spatial distribution of NEP was higher in the east of the study area in 2005, where patches of water conservation forest that had been protected by the government since the 1980s. On the contrary, NEP was lower in two areas near the southeast of the study region, where there was a relatively large area of cropland and forest plantation (Figure 1). The distribution of NEP changed in 2015, and that most of areas increased significantly, especially in the south of the study area.

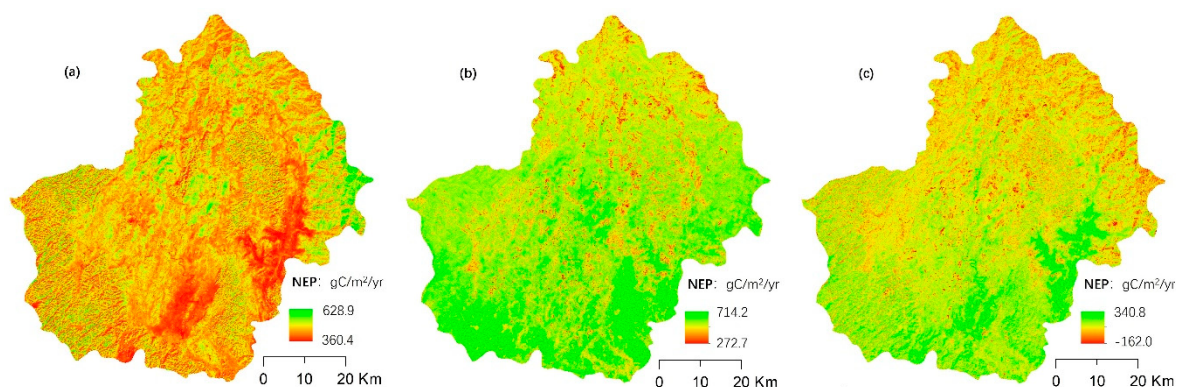


Figure 2. Spatial distribution of net ecosystem productivity (NEP) and its change in Huanjiang County. (a) The distribution of NEP in 2005; (b) the distribution of NEP in 2015; (c) the changes of NEP from 2005 to 2015.

From 2005 to 2015, NEP increased obviously in the southeast and southwest portions of the study region. Increasing land cover in the southeast, which had contributed to

NEP increase, may have been caused by a reduction in agricultural activities intensities or farming practice changes. In the southeast, large rocky mountains and shrub land are found, and vegetation may have recovered naturally in this period. NEP decreased to some extent in the north and central areas. However, the decreased area of NEP only accounted for 2.8% of the whole study area.

4.1.2. Soil Conservation and Its Change

The average annual soil conservation in Huanjiang County increased from 4.7 ton/ha in 2005 to 5.5 ton/ha in 2015, and the value of average annual soil conservation increased by 0.8 ton/ha from 2005 to 2015 (Figure 3). In terms of spatial distribution, the regions with higher soil conservation were mainly located in the center of the study area for two study periods. The probable reason is that the center of the study region has hills with gradual slopes and has thicker soil. In comparison, rugged rock mountains are in the southwest of Huanjiang County. Changes in soil conservation showed that areas with increased soil retention amount accounted for 81.92% of the study area, and only 18.08% of the study area remained unchanged or showed a small decline. Regions with improvement in soil conservation were mainly located in the central regions. Another improvement occurred in two parts in the southeast of the study region where about half of sugarcane and corn fields were converted into fruit and mulberry fields during the study period.

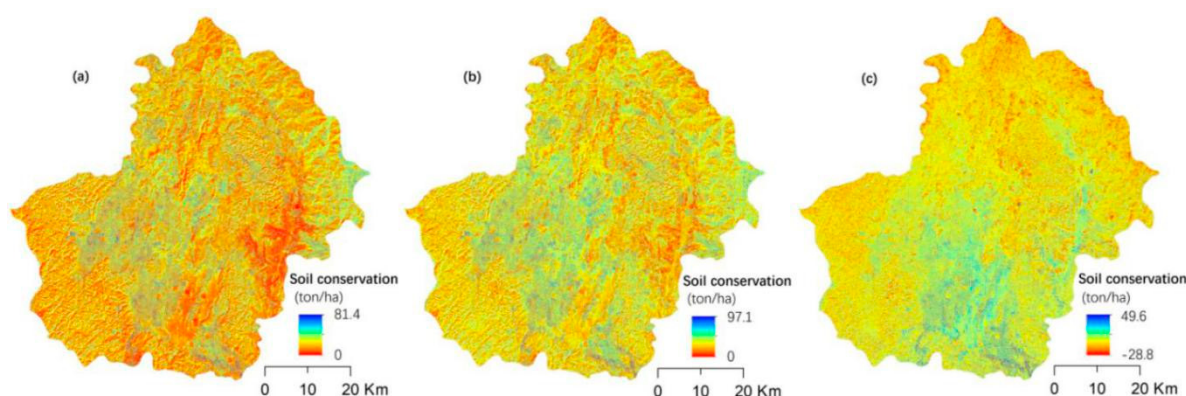


Figure 3. Spatial distribution of soil conservation and its change in Huanjiang County. (a) The distribution of soil conservation in 2005; (b) The distribution of soil conservation in 2015; (c) the changes of soil conservation from 2005 to 2015.

4.1.3. Water Yield and Its Change

There was a downward trend in water yield from 2005 to 2015 in the research area (Figure 4). The average annual water yield was 784.3 mm and 724.5 mm in 2005 and 2015, respectively. The spatial distributions of water yield in the study area are basically consistent between 2005 and 2015. The areas with higher water yield were mainly concentrated in the southeast and southwest of the study area, where rugged mountains are widespread: the large slope may be favorable for water yield. The regions of poor water yield are mainly the central and northwest of the research areas where the slopes are gentle and where most of the forest plantation, cropland and grassland were in 2005 and 2015. However, changes in water yield showed that the capacity of water yield enhanced in the central and north of the study regions from 2005 to 2015. On the contrary, water yield in the southeast and southwest of the study region decreased in this period.

4.2. Ecosystem Health in Huanjiang County

The areas with poor ESH are scattered and mainly distributed in the center of the study area (Figure 5a). The proportions of areas with high ESH (greater than 0.7) increased by 3% from 2005 to 2015 (from 71.06% to 74.32%) during the 11 year period. The area with low ESH (less than 0.2) decreased by about 4% (from 10.89% to 7.12%) (Figure 5b).

Overall, 66.72% of the pixels showed an increase in ESH, and 33.28% of the total area had a decreasing ESH.

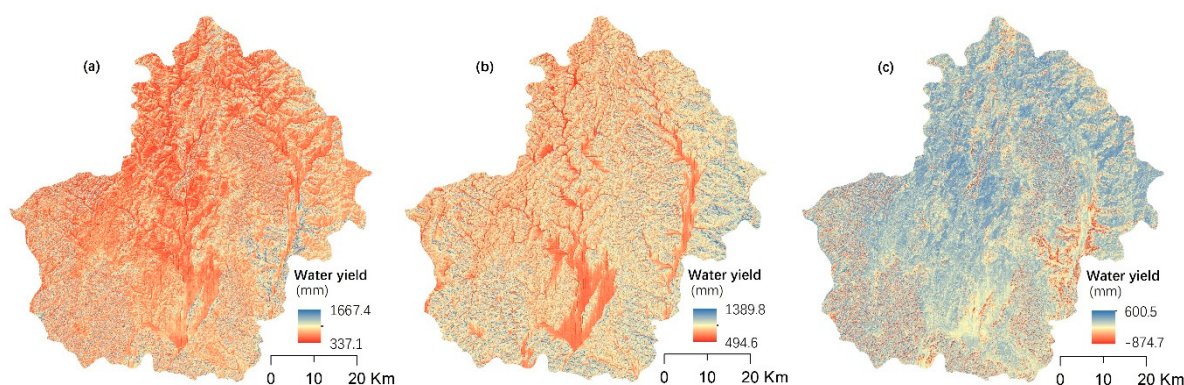


Figure 4. Spatial distribution of water yield and its change in Huanjiang County. (a) The distribution of water yield in 2005; (b) the distribution of water yield in 2015; (c) the changes of water yield from 2005 to 2015.

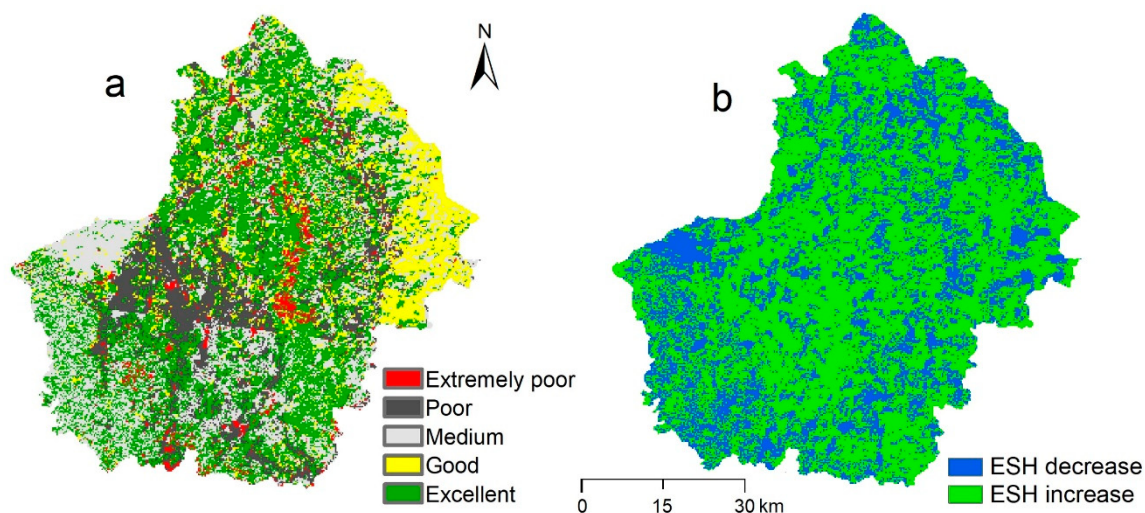


Figure 5. ESH assessment for the study area. (a) is the ESH index for 2005; (b) is the changes in ESH between 2005 and 2015.

4.3. Potential of Vegetation Recovery

Of the study area, 75.29% had vegetation deficit with varying degrees of variation ($NDVI_{\text{difference}} < 0$) (Figure 6d). Of the area with vegetation deficit, 0.27% had an extremely serious vegetation deficit ($NDVI_{\text{difference}} < -0.3$). These areas are mostly around towns and cities. Of the study area, 1.41% had a relatively serious vegetation deficit ($-0.3 < NDVI_{\text{difference}} < -0.1$) (Figure 6). Of the regions, 58.20% had a relatively small vegetation deficit ($-0.1 < NDVI_{\text{difference}} < 0$) (Figure 6d), which were mainly distributed in the south-center of the study area. Meanwhile, most of the vegetation deficit occurred in and around towns, indicating that human activities in high-density population areas still affected vegetation restoration significantly. On the contrary, the redundancy of vegetation was mainly located in the southwest of the study region, indicating that vegetation covered these regions well.

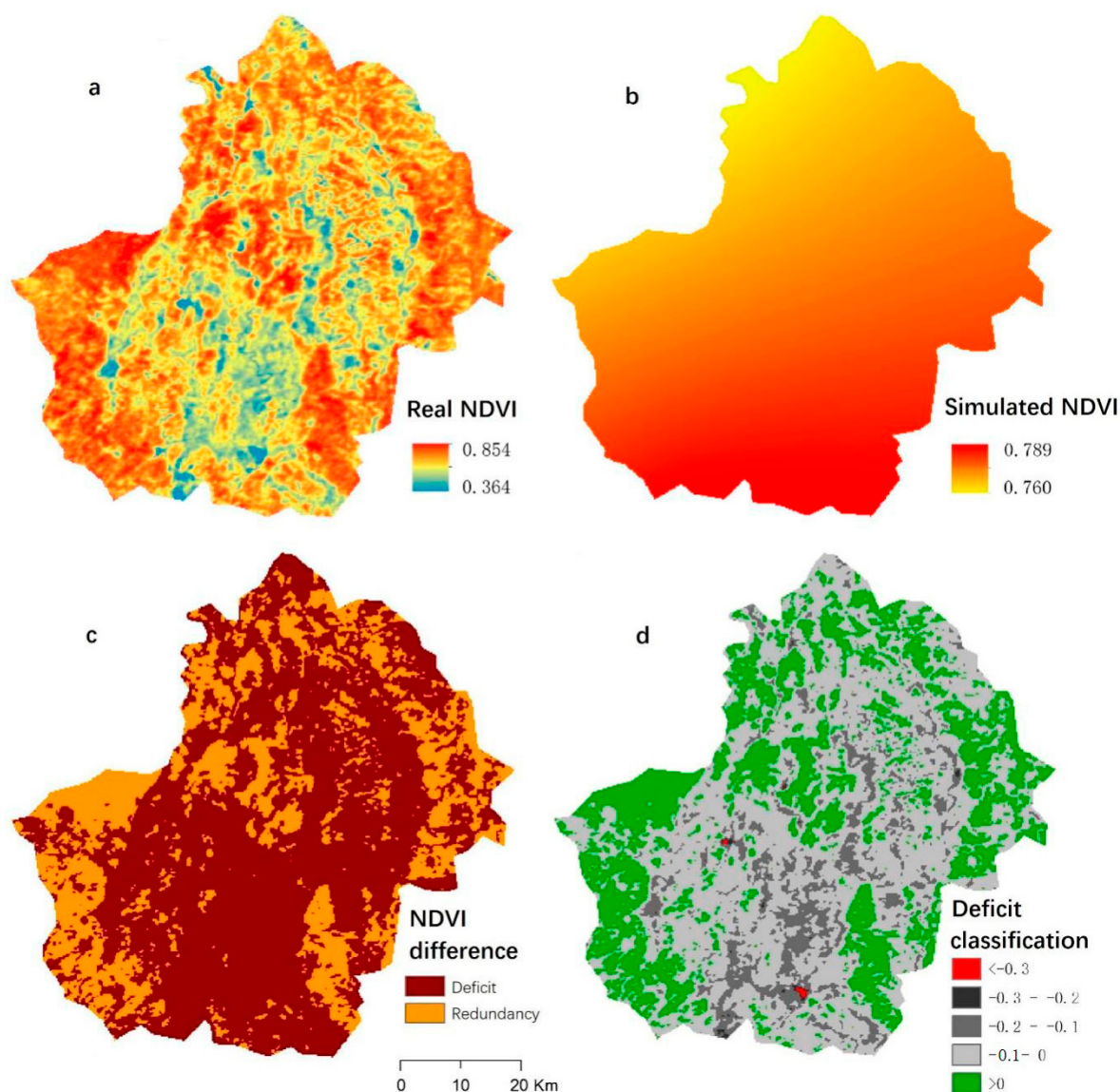


Figure 6. Spatial distribution of potential vegetation. (a) is the real vegetational NDVI in 2015; (b) is the simulated vegetational NDVI; (c) is the differences between (a) and (b); (d) is the classification of vegetation deficit.

5. Discussion

5.1. Increased Ecosystem Services via Ecological Restoration Programs

As a bridge between human and nature, ecosystem services and their changes are highly correlated with human activities (land-use changes) and natural conditions [11,40,41]. The improvement in NEP and soil conservation might be caused by vegetation recovery in the research area as land-use changes (Table 2). Shrub land was dominant, taking up about half (49.42%) of the study area in 2005. There had been a positive vegetational succession in the period from 2005 to 2015, and grassland and shrub land mainly evolved into shrub land and forest land, respectively. The grassland decreased by 202.3 km² (38.69%), and the forest land increased by 347.77 km² (33.55%). Forward succession of vegetation always raised vegetation biomass, soil carbon accumulation and abilities of water and soil retention [28,29]. Meanwhile, the area of farmland decreased by 165.72 km² (23.18%), such that most of them turned into planted forest land. All of these factors promoted vegetation restoration in the study region.

Table 2. Land-use changes in Huanjiang County from 2005 to 2015.

	2005		2015		2005–2015	
	Area (km ²)	Percentage (%)	Area (km ²)	Percentage (%)	Area (km ²)	Percentage (%)
Forest land	1036.52	22.94	1384.29	30.64	347.77	33.55
Shrub land	2227.6	49.30	2245.14	49.69	17.54	0.79
Grassland	522.83	11.57	320.53	7.09	−202.30	−38.69
Farmland	714.87	15.82	549.15	12.15	−165.72	−23.18
Water area	7.91	0.18	8.4	0.19	0.49	6.20
Built-up	8.28	0.18	10.5	0.23	2.22	26.78

The implementation of the ecological conservation program could be used to explain the significant vegetation recovery and therefore the ecosystem carbon sequestration and soil conservation in the typical karst area. Due to the fragility of the ecological environment and strong human activities, serious vegetation degradation occurred in the karst region of southwest China in the period from the 1950s to 1990s. Therefore, the program of mountain closure was enforced by the government, which imposed a ban to prohibit deforestation, forest burning and agricultural activities for vegetation recovery [42]. Local residents who violated the ban were fined. Despite initial resistance from villagers, they gradually began to comply with the ban along with the promotion of environmental protection awareness. In addition, the local government invested money to build biogas generation pits and improve the power system for residents to reduce the demand for fuel wood and to minimize the disturbance to vegetation [32]. The results of land-use changes indicated that about one third of vegetation experienced recovery from 2005 to 2015 in the study area.

The Grain to Green program has also been carried out in the karst region to convert cropland on steep slopes into forested land since 1999 [14,32]. The cultivation on slopes has caused serious vegetation destruction and soil erosion [3]. In order to prevent further environmental deterioration, local farmers were required to give up the sloping land by acquiring grain and financial subsidies from the government. The local government spent 0.8–1.3 million Yuan (6.6 Yuan equals 1 Dollar) per year as a subsidy to promote the implementation of the Grain to Green program [14]. Moreover, reforestation was implemented on the abandoned slopes to promote vegetation restoration. Our study showed that about a quarter of farmland converted into forested land could be explained by the implementation of the Grain to Green program.

Although NEP and soil conservation have improved in the study region, a decline of water yield occurred in this period as well. A study based on field sample data showed that the soil conservation and water yield in the karst region of southwest China gradually increased because of the vegetation growth [43]. However, studies focused on large-scale afforestation indicated that the increased coverage of forest plantation in southwest China significantly promoted evapotranspiration on the land surface, resulting in the decrease in regional soil moisture [44,45]. It was possible that the rapid growth of plantations (i.e., Eucalyptus and Masson's pine) in this karst region consumed and transpired more water [31]. The increase in NEP was highly correlated with vegetation recovery, soil carbon sequestration and soil conservation. A trade-off relationship exists between NEP, soil conservation and water yield. Therefore, the promotion of ecosystem services and its trade-off should be considered simultaneously.

Compared with the implementation of the ecological conservation programs, climatic conditions did not significantly favor vegetation growth in the study region. The Standardized Precipitation Evapotranspiration Index (SPEI) in the study area had a downward trend from 2005 to 2015, and most of its values were negative (Figure 7), indicating adverse climatic conditions in the study region. This result of climatic conditions is consistent with those of the previous studies [21,46]. It further proved that ecological engineering significantly promoted better vegetation recovery (NEP and soil conservation) under adverse climatic conditions in the karst areas of southwest China. However, whether the climatic

conditions in the karst region will limit the sustainable vegetation, recovery should be taken further into consideration in future research.

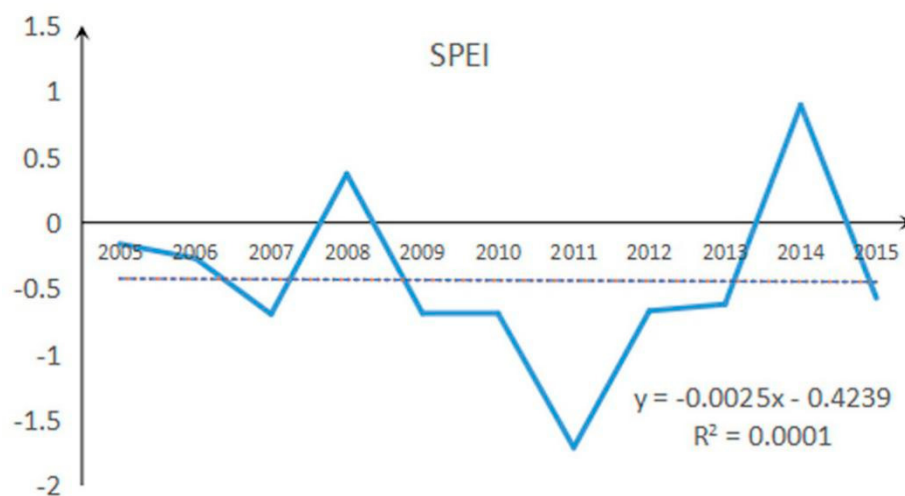


Figure 7. Standardized Precipitation Evapotranspiration Index (SPEI) and its changes during the study period.

One possible deficiency of our study is that the distribution and variation of hydrology in the karst region was not specifically considered. It was because of the highly fragile karst landscape and the dual hydrologic structure above- and belowground in the karst region that surface water may flow down underground pipes, magnifying errors or uncertainties of water yield estimation [47]. Hence, more long-term observations about water use efficiency of plants, underground vertical drainage and soil moisture should be conducted to better understand the water yield in the karst region.

5.2. Ongoing Outmigration Reduced Disturbance to the Ecosystem

The outmigration of residents moving to the city for work opportunities highly reduced the human pressure on nature and therefore impacted the changes in ecosystem services. In contrast with the implementation of ecological projects promoted by the government, outmigration for work reflected the voluntary willingness of residents more. The number of outmigrants increased from 2008 to 2015 (Figure 8b). The percentage of the migrant population out the total population, accounting for 13.1% in 2008, increased to 21.6% in 2015. As a matter of fact, the number of migrants is larger than the statistical data, because this statistic only shows the number of people who spent more than half of the year working outside the home. In fact, some people only go to city to work a few months each year.

In Huanjiang County, the percentage of outmigration out of the total population increased between 8.8% and 16.3% from 2005 to 2015 in eleven townships, except for in one town, where the county government is seated (−0.6%). There was a significant relationship showing that the NEP and soil conservation had a positive response of the rural–urban migration (Figure 8c,d). The correlation indices are 0.62 and 0.53 between the NEP and soil conservation and the rural–urban migration, respectively. This showed that townships with higher percentages of migrants reduced human pressures on nature more than towns with lower percentages. Those who moved to the city for work opportunities could earn more money and improve living conditions, which is generally better than purely depending on farming for a living [42]. Consequently, excessive reclamation on slopes in rural areas was reduced. Some former rural residents even gave up farming completely and worked in the city all year round. Meanwhile, some cultivated land was converted into forest plantation by farmers because plantations can effectively reduce crop rotation and let people spend more time to go out for work. This change can be supported by the decreasing area of cropland in the study area. Decreasing farming activities ultimately

reduced the disturbances on soil and facilitated soil carbon sequestration and water and soil conservation in the karst region [26,29]. For example, the regions in the southwest of the study area had a typical karst ecosystem environment (rugged terrain, shallow soil and fragile ecosystem) that is extremely sensitive to interference [48]. However, relatively high rural–urban migration in these regions contributed to lesser disturbances and improved the ecosystem services significantly (Figures 2, 3 and 8a). Therefore, rural–urban migration also improved these two ecosystem services in the study area.

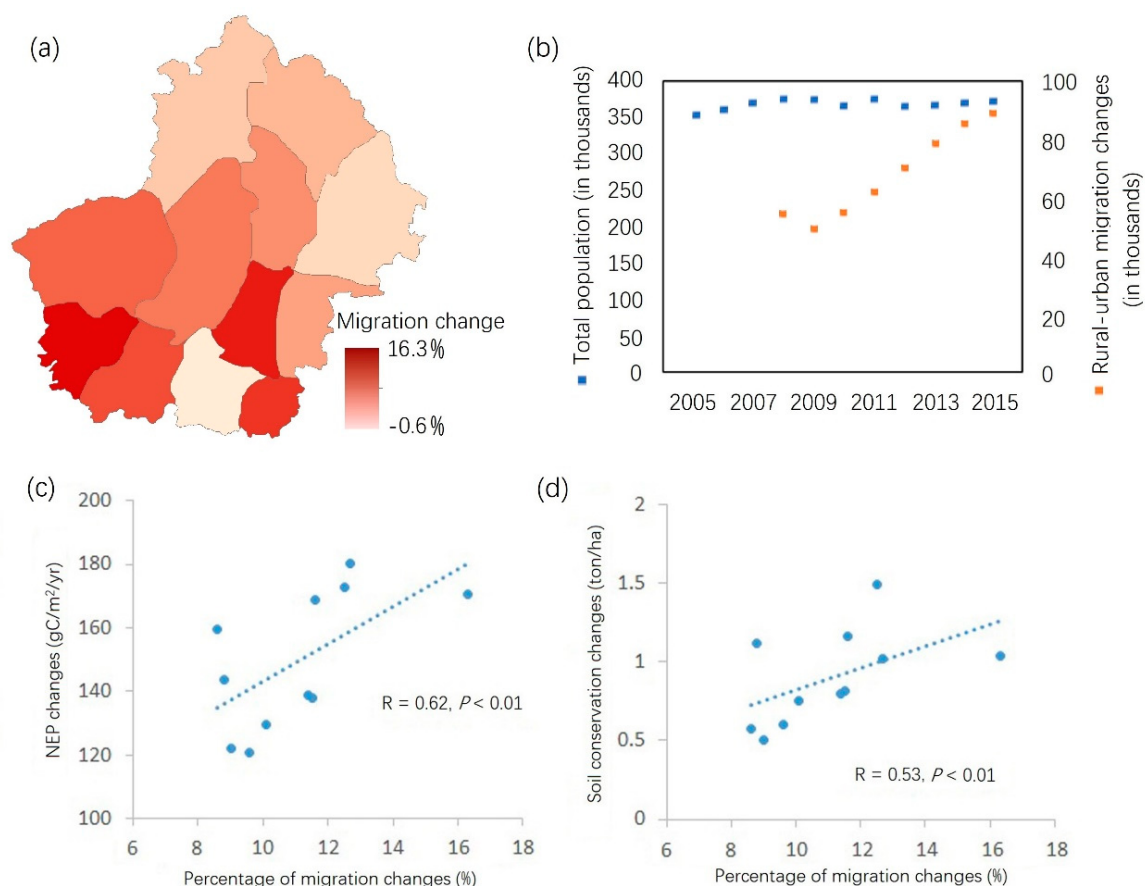


Figure 8. Changes in rural–urban migration from 2005 to 2015 and its correlations with ecosystem services in the Huanjiang County. (a) The distribution of the percentage of rural–urban migration changes from 2005 to 2015; (b) comparison of total population and rural–urban migration; (c,d) correlations between the percentage of rural–urban migration changes and ecosystem services.

5.3. Ecosystem Services Improvement via Vegetation Recovery

Vegetation recovery likely played a crucial role in the process of the improvement of NEP and water and soil conservation. Although the land-use changes reflected a positive vegetational succession (vegetation recovery) in the study area, 75.29% of the study areas appeared vegetation-deficit. The characteristics of shallow soils, rapid hydrological system and fragile ecosystems in the karst region of southwest China slowed down the vegetation recovery to some extent [6]. The fact that 33.28% of total areas had decreasing ESH corresponded to the ongoing ecosystem degradation; the majority of the local residents are still highly dependent on farming activities for a living. Hundreds of years of traditional farming practices cannot be overturned within 11 years [4]. However, our study may help to focus environmental managers' attention to the problematic areas with decreasing ESH. In karst regions, minimizing soil disturbances is critical for soil conservation, vegetation restoration and sustainable agricultural development [5,6]. Corn to forage grass, mulberry or natural vegetation, which reduces the disturbance frequency to the soil, are some of the

most effective methods for preventing water and soil erosion [29]. Meanwhile, the value generated from forage grass and mulberry could increase income to improve the supply services of the karst ecosystems.

6. Conclusions

The implementation of ecological restoration programs mainly by Chinese governments and the trend of outmigration effectively changed land use and land cover, leading to increased forest land and decreased farmland and grassland areas in the karst region of southwest China. This contributed to the improvement of carbon sequestration and soil conservation. Huanjiang County was a carbon sink from 2005 to 2015, and the average annual NEP increased from 441.7 g C/m²/yr in 2005 to 582.19 g C/m²/yr in 2015. Soil conservation also increased from 4.7 ton/ha to 5.5 ton/ha during the study period. However, water yield decreased from 784.3 mm to 724.5 mm in this period. The NEP and soil conservation are in a synergic relationship. The increase in NEP was highly correlated with vegetation recovery, soil carbon sequestration and soil conservation. A trade-off relationship exists between NEP, soil conservation and water yield. The quick growth of planted forest may consume lots of water sources, causing declining water yield in the karst region. An increment of NEP and soil conservation decreased the water yield amount.

Ecological health assessment showed that though vegetation recovered during the last 11 years, EHS of 33.28% of the total study region decreased, signifying the existence of overexploration in the karst region. Furthermore, the dominance of shrub land indicates the low stability of the karst ecosystem and a huge potential of vegetation recovery.

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