Chapter

Spatio-Temporal Variation of Ecosystem Services and Its Trade-off Relationships in Southwest Guangxi

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Abstract

Identifying the mutual relationship between ecosystem services in southwest Guangxi can jointly optimize a variety of services to avoid damaging others while improving one service, which is of great significance for promoting the sustainable management of regional ecosystem, guiding the rational development of natural resources and improving human well-being. Based on remote sensing data, land use data, meteorological data and DEM data, with the support of Carnegie-Ames-Stanford Approach (CASA) model, Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model and Revised Universal Soil Loss Equation (RUSLE) model, this paper studies the changing characteristics of typical ecosystem services in southwest Guangxi and explores the mutual relationship between different ecosystem services. The results showed that the mean change trend of the whole vegetation net primary productivity (NPP) has been increasing in the study area over the past 19 years. In the past 19 years, water conservation in southwest Guangxi has shown a fluctuating upward trend, with the growth rate of water conservation quality 255.88 $mm/hm^{-2}\cdot a^{-1}$. During the study period, the range of soil retention variation to the total of 65.38–96.88 $t/hm^{-2}\cdot a^{-1}$ increased 22.73 $t/hm^{-2}\cdot a^{-1}$, with a mean of 79.19 $t/hm^{-2}\cdot a^{-1}$. Vegetation NPP in the study area is synergistic with soil conservation and water conservation, and soil conservation with water conservation as well.

Keywords: ecosystem services, net primary productivity, water conservation, soil conservation, trade-off relationships

1. Introduction

Ecosystem services refer to the benefits that human beings can directly or indirectly obtain from ecosystems according to their own development needs, which mainly transfer energy and materials to social and economic systems, accept and transform waste in social and economic systems, as well as the direct services that ecosystems provide food, biomass, clean air, water and other resources [1]. Ecosystem as the basic unit of the biosphere, including maintaining human survival and development of food, freshwater, production and living raw materials supply services, also contains maintaining the dynamic balance of ecosystem and environment primary productivity, soil formation, climate regulation support services and regulation services, as well as pleasant human spiritual and cultural level of aesthetic, entertainment, tourism and other cultural services [2–4]. Trade-off refers to the situation that the supply of some ecosystem services is reduced by the increased consumption of other types of ecosystem services, showing a trend of one after another [5]. Ecosystem has a great impact on people's lives, and there are certain links between various ecosystem services [6]. Therefore, studying the trade-offs and synergy between ecosystem services can better guide production and life practice and bring great benefits to human life.

With the rapid development of social economy, the change of natural environment, the ability of human beings to transform nature and the intensity of obtaining natural resources, environmental damaging behavior of humans occurs frequently, bringing great damage to the ecosystem, and the ecosystem service benefits are also reduced. In this context, research on ecosystems has attracted the attention of many international scientists, and the analysis and evaluation of ecosystems have gradually become a research hotspot in ecology [7–11]. In 1997, *Nature's Services: Societal Dependence on Natural Ecosystems* was published, regarded as a landmark work in the field of ecosystem services, making more scholars have a keen interest in the field of ecosystem services and begin to focus on research on ecosystem services [1]. Subsequently, Costanza [9], Millennium Ecosystem Assessment Plan (MA) [5] has been comprehensively analyzed by ecosystem services from different perspectives of different disciplines, functions, processes and internal connections. In recent years, people have paid more attention to the economic benefits brought by ecosystem services but ignored the most basic and important ecological benefits, which made the imbalance between the supply of services, regulatory services, support services and cultural services in the ecosystem, and the trade-off relationship showed the trend of gradual deterioration [12, 13].

In recent years, many Chinese scholars have also joined the ranks of studying ecosystem services and using various research methods to explore the relationship between Chinese ecosystem services found out their drivers, provided theoretical knowledge and scientific basis for government decision-making, and made great contributions. Current research methods for ecosystem service trade-offs mainly explore the relationship between services using rose graph analysis, production possibility boundary methods [14], correlation functions in R language [15], correlation analysis, linear and power function regression [16]. Some scholars, based on remote sensing images, explore the number of regional land-use changes, spatial and temporal differences; estimate ecosystem service index; and explore the trade-offs between ecosystem services [15]. These methods for regional ecological system service trade-off theory research laid a solid foundation and also help the national government to make major decisions.

Guangxi's southwest region mainly includes Nanning, Baise, Chongzuo, Qinzhou, Beihai and Fangchenggang. The region is Guangxi karst and karst landform distribution. The region as the southwest of China ecological security barrier area and core area for poverty alleviation, which is the national key development of Beibu Gulf economic zone ecological hinterland, is also the 21st-century Maritime Silk Road, the Silk Road Economic Belt and the organic important connection point of new western land and sea access. However, this region is a contiguous poverty-stricken area in southwest Guangxi, and a concentrated area of most poverty-stricken counties at the state level. Regions, rocky desertification and ecosystem structure stability are poor. In view of this, this study in southwest Guangxi as the research area and its characteristics develops the karst region ecosystem service trade-off evaluation model, evaluates the ecosystem service balance. The research results can provide technical support for the quantitative assessment of national ecological engineering governance measures, in order to promote the optimization of karst regional ecosystem services and improve regional sustainable development.

2. Study area overview

In this paper, southwest Guangxi was selected as the study area, southwest of Guangxi Zhuang Autonomous Region, the north bank of the Beibu Gulf, geographically located between 104°28′–109°56′E and 20°26′–25°07′N (**Figure 1**). The study area includes six urban areas: Baise, Nanning, Chongzuo, Qinzhou, Fangchenggang and Beihai, with the total area of 95,661.65 km^2, accounting for about 40% of the total area of Guangxi. In the study area, karst landform development is relatively typical as a geological formation. The landform assemblage form is mainly peak cluster depressions, peaks forest valleys, with steep terrain and large mountain slopes. The overall trend is tilted northwest to southeast. The overall mountain elevation of the study area is between −18 and 2036 m.

The study area belongs to the subtropical monsoon climate zone, characterized by short winter and long summer, high precipitation and long sunshine time. Its average annual temperature is between 19.81 and 23.09°C. The annual rainfall in the study area is abundant, obviously affected by the monsoon climate. Annual rainfall is between 87.71

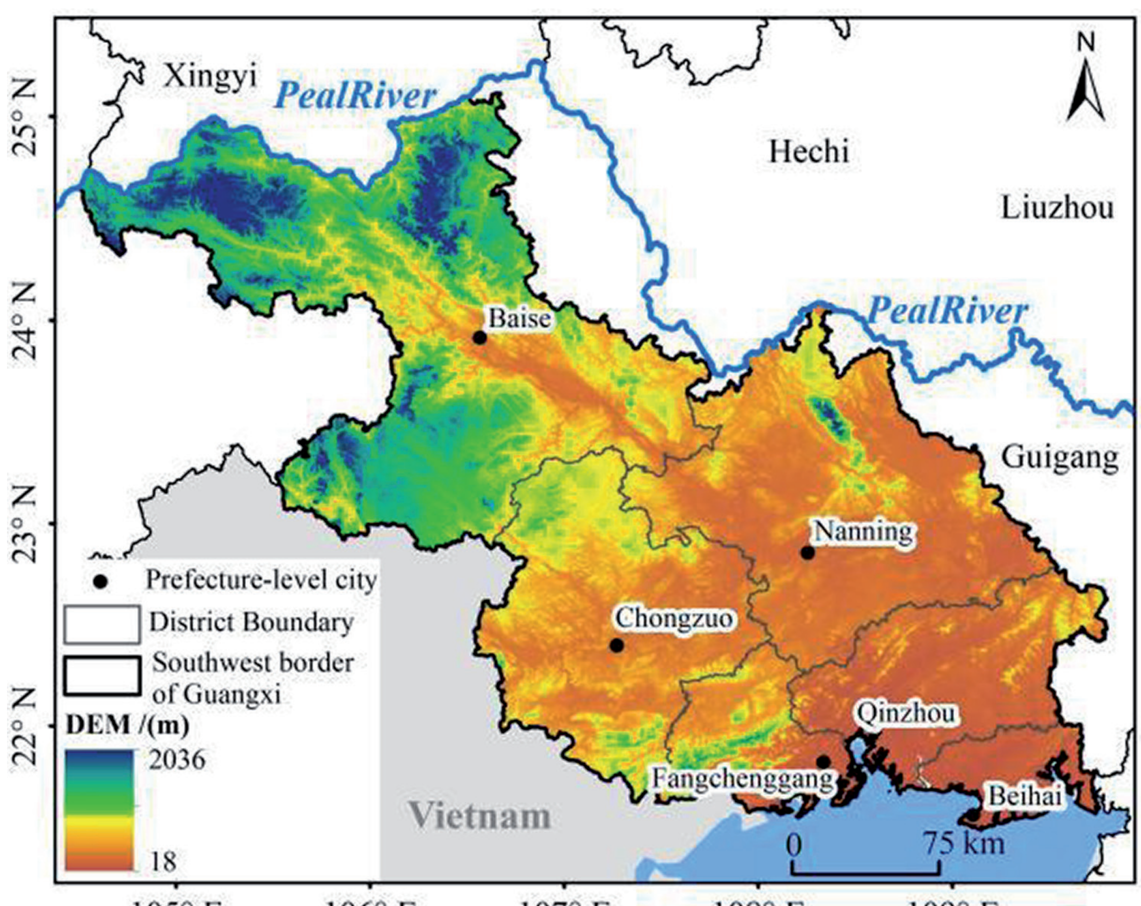

Figure 1.
Geographical location of southwest Guangxi.

and 214.01 mm, among which the rainfall is mainly concentrated in April–October. The area has strong sunshine, and the range of annual effective cumulative temperature is between 6803.32 and 8343 J/m^2·a, with relatively abundant heat, providing sufficient thermal energy conditions for plant growth. The landform of southwest Guangxi is complex. Under conditions of good subtropical climate, the region is rich in plants, with diverse vegetation types, such as evergreen broad-leaf forest, deciduous broad-leaf forest and shrub forest, and mangrove forests are also distributed in the southern coastal areas.

3. Materials and methods

3.1 Data collection and process

The main data used in this study are remote sensing data, meteorological data and land use type data.

1. Remote sensing data were obtained from NASA 2000 to 2018 (h27v06 and h28v06 MODIS13Q1) data products, a terrestrial level 3 standard data product with a temporal resolution of 16 days and a spatial resolution of 250 m × 250 m. Image correction, splicing, reprojection and clipping were preprocessed with MRT and ArcGIS software, and finally the maximum value synthesis method of the spatial analysis tool was used in ArcGIS to obtain the monthly Normalized Difference Vegetation Index (NDVI) data from January to December of each year.

2. Meteorological data were obtained from the China Meteorological Science Data Sharing Service Network (http://cdc.cma.gov.cn), containing day-to-day data on air temperature, rainfall, solar radiation, evapotranspiration. The time span is 2000–2018 from January to December, mainly including 25 meteorological stations in and around southwest Guangxi. ArcGIS interpolated daily temperature and sporadic daily meteorological data to obtain daily meteorological grid data. Rainfall data, by image rotation of the data in ENVI and ArcGIS, coordinate correction, change of data units, clipping, raster to point, interpolation analysis, format conversion and other treatments, obtained the monthly precipitation data in the study area.

3. Land use data and DEM data were derived from the Geospatial Data Cloud (http://www.gscloud.cn/), with a spatial resolution of 30 m × 30 m. Land use data were generated by manual visual interpretation using ENVI5.1. Land use data include six types of cultivaaq8ted land, woodland, grassland, waterbody, construction land and unused land. The final DEM data was obtained by mosaic raw data and clipping.

3.2 Research methods

3.2.1 Net primary productivity (NPP) estimation

NPP refers to the total amount of organic dry matter produced by green plants per unit time and per unit area, whose spatiotemporal changes are mainly dependent on the complex interactions between vegetation, soil and climate [17]. As an important component of the surface carbon cycle, NPP is a major factor in determining ecosystem carbon sinks [18]. NPP has now become an indispensable indicator in studies of the impact of global changes on ecosystems [19]. There are many models to estimate

NPP, which can be divided into ecosystem ecological process model, climate-related statistical model and optical energy utilization model. The model used in calculating NPP is the CASA model improved by Zhu Wenquan based on previous research, which is more consistent with the regional scale estimation of vegetation NPP [19].

3.2.2 Water conservation estimation

This study uses the water production module of InVEST model to study water conservation in the southwest region of Guangxi. The water production module is based on the principle of water balance. The precipitation of the unit raster minus the actual evaporation precipitation yields the water production of the unit raster [20, 21]. Combining the calculation of various parameters based on the raster is conducive to analyzing the influencing factors leading to spatial heterogeneity in the calculation results. The calculation formula is as follows:

$$Y_{xj} = \left(1 - \frac{AET_{xj}}{P_x}\right) \bullet P_x \tag{1}$$

The Y_{xj} in the formula is the water yield (mm) of unit grid x class j land use/coverage type in the study area, AET_{xj} is the actual annual evapotranspiration amount (mm) of unit grid x class j land use/coverage type in the study area, P_x is the annual precipitation (mm) in unit grid x in the study area.

3.2.3 Soil conservation service model

Soil conservation (SC) service was estimated using the RUSLE model and corrected based on experimental data from the study area to obtain a computational model meeting the study area [22], with the following formula:

$$SC(x) = SC(p) - SC(r) = R \times K \times LS \times (1 - C \times P) \tag{2}$$

In the formula, $SC(x)$ indicates the soil conservation ($t \cdot hm^{-2} \cdot a^{-1}$) in the study area, $SC(p)$ indicates the potential soil erosion amount ($t \cdot hm^{-2} \cdot a^{-1}$), $SC(r)$ indicates the actual soil erosion amount ($t \cdot hm^{-2} \cdot a^{-1}$), R indicates the precipitation erosion force factor MJ·mm/hm^2·h·a), K indicates soil erodibility factor (t·h/MJ·mm), LS indicates the slope length-slope factor, C indicates surface vegetation management and coverage factors, P indicates soil conservation measures factors, the dimensionless number between 0 and 1.

3.2.4 Production possibility frontier (PPF)

PPF represents a combination of maximum production of two products that can be achieved under the conditions of established economic resources and production technology. PPF is assuming that the number of two products acts as the positive half-axis of X and Y axes, respectively. In the case of certain resources, assuming that the full resources are used to produce A products, then the A products can produce 60, with B products 0, and so on. If 50 A products are produced, then 22 B products are produced, corresponding point (50, 22). If 40 A products are produced, then 33 B products are produced, corresponding point (40, 33). If 32 A products are produced, then 39 B products are produced, corresponding point (32, 39). If 20 A products are produced, then 45 B products are produced, corresponding point (20, 45). If the A products of 0 are produced, then 50 B products are produced, corresponding point (0, 50). Thus obtain the PPF between the products A and B (the coordinate data of the aforementioned points are designed according to the definition of the PPF) [23]. As shown in **Figure 2**, the product B in the figure shows a downward trend with the increase of product A, which shows the trade-off relationship between product A and product B.

From the economic point of view, the production possibility boundary has the following characteristics:

- Resource limitations play a main role in product configuration;
- Any point on the boundary of the production possibility represents the maximum output combination, points within the boundary indicate that the output of the combination does not reach the maximum value, and points outside the boundary indicate that the output cannot be achieved under the existing technology;
- The production possibility boundary is not fixed, which will shift inward or outward migration with the input of economy and technology.

This paper cites the production possibility boundary curve for the ecosystem with fixed natural resources to quantitatively investigate the trade-off and synergy relationship between ecosystem services in southwest Guangxi. Take the two ecosystem services of vegetation NPP and water conservation in southwest Guangxi as an example to make production possibility boundaries. Pareto curves between the two services were calculated and produced, first calculating the inter-annual mean of vegetation NPP and water conservation data using ArcGIS's metastatistic tool, dividing the annual vegetation NPP data from the annual water conservation data to obtain a layer where each cell raster was the ratio of the corresponding geographical vegetation NPP and water conservation. The resulting ratio layer, average annual vegetation NPP and annual water conservation layer were sampled and then exported as an Excel table.

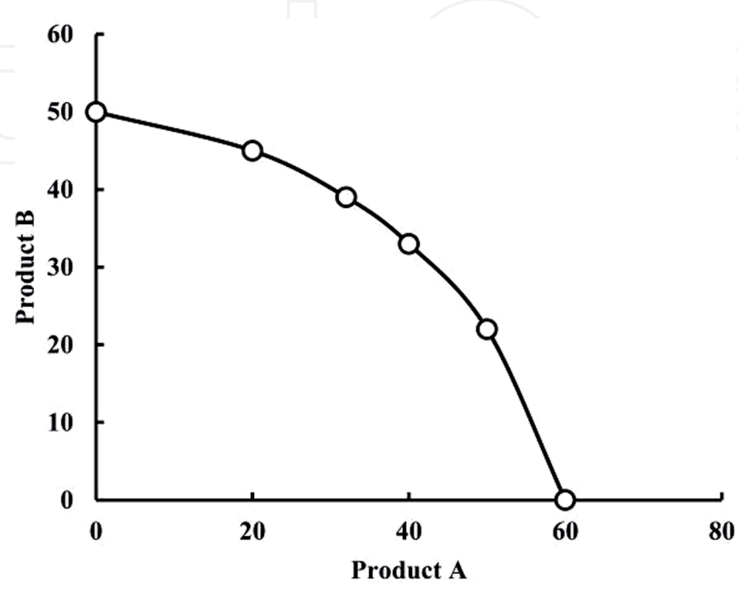

Figure 2.
Production possibility frontier (PPF) curve.

In the table, the vegetation NPP and water conservation ratio were sorted in ascending order, and the annual vegetation NPP and water conservation were summed in proper order, and then the Pareto efficiency curve was drawn according to the results.

4. Result analyses

4.1 Inter-annual changes of different ecosystem services in southwest Guangxi

4.1.1 Inter-annual change law of NPP in southwest Guangxi

The change trend of vegetation NPP in southwest Guangxi from 2000 to 2018 (**Figure 3**) showed the overall growth trend. The entire annual NPP fluctuated between 300 and 500 gC/m^2 a, with an annual growth rate of 3.781 gC/m^2 a in 2018, fluctuating upward trend in 2000–2006, gradual downward trend in 2006–2009 and 2009–2013 in 2019. The maximum appeared in 2018, showing a fluctuating upward trend in 2000–2006; a gradual downward trend in 2006–2009; a phenomenon of repeated alternation in 2009–2013.

In different lithological backgrounds, the overall trend of the mean in the study area was consistent with the non-karst region, generally consistent with the karst region, slightly from high NPP in 2005 and low in 2006 and 2016. The annual NPP in non-karst region was greater than the annual NPP in karst region. Among them, the NPP growth rate in non-karst regions was 5.852 gC/m^2 a, 3.188 gC/m^2 a in the karst region, indicating that the non-karst region in southwest Guangxi had a greater impact on NPP growth.

4.1.2 Inter-annual changes of water conservation in southwest Guangxi

Statistics on the changes in the mean value of water conservation area in southwest Guangxi in 2000–2018, as shown in **Figure 4**, shows the increase of water conservation in southwest Guangxi. The change trend of water conservation in karst landform and non-karst landform in 19 years is consistent with the overall study

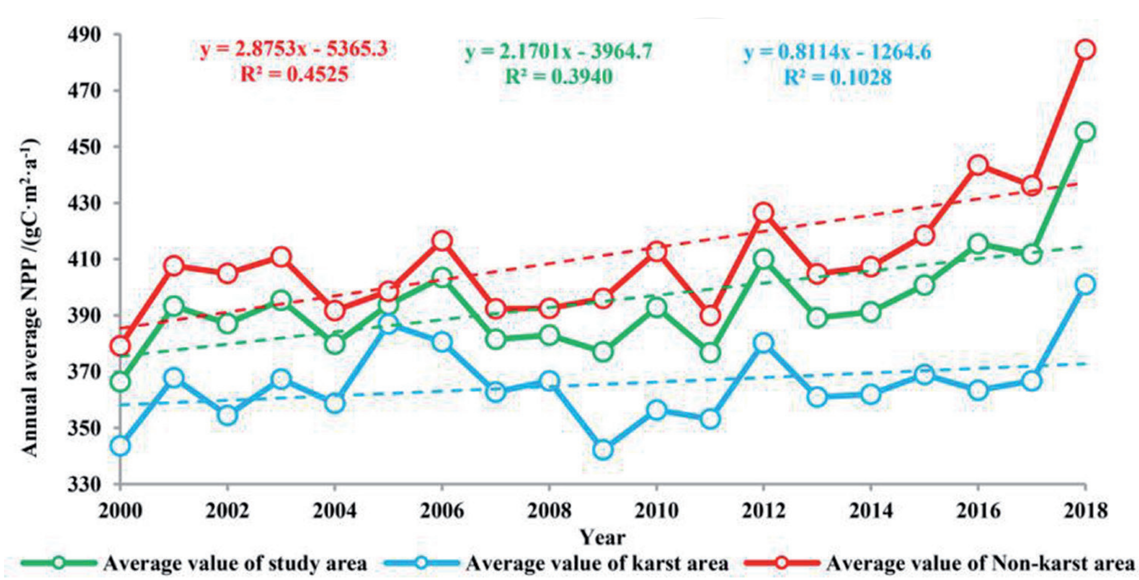

Figure 3.
The average change trend of NPP under different lithological backgrounds in southwest Guangxi from 2000 to 2018.

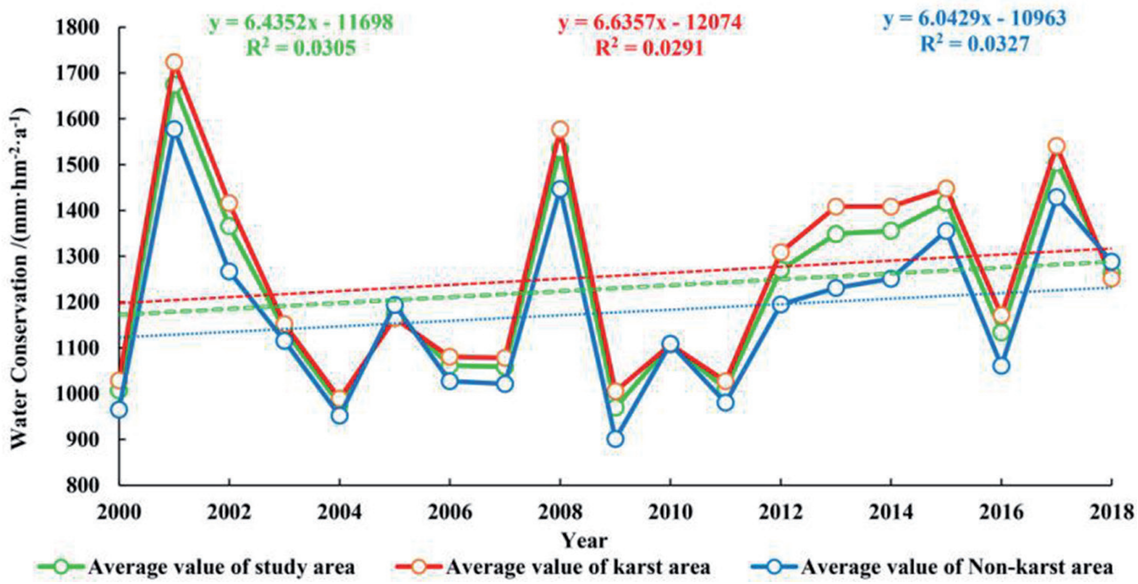

Figure 4.
Inter-annual mean variation of water conservation in southwest Guangxi.

area as a whole. Between 2000 and 2018, the water conservation in the study area was increased by 255.88 mm·hm^{-2}·a^{-1}, study area to 1230.16 mm·hm^{-2}·a^{-1}. Among them, water conservation in 2001 was the maximum in 19 years, higher than the mean in 444.76 mm·hm^{-2}·a^{-1}; water conservation in 2009 was the minimum in 19 years, lower than the mean in 260.18 mm·hm^{-2}·a^{-1}.

4.1.3 Inter-annual changes of soil conservation in southwest Guangxi

Through the ArcGIS statistical tool, the changes of karst landforms, non-karst landforms and soil retention in the whole region in different years were shown in **Figure 5**. The analysis found that the soil retention in southwest Guangxi was upward, with the soil retention in the karst landform more significant, and the change rate was that the soil retention (4.77/a) was greater than the whole region (2.23/a), and greater than the non-karst soil retention (0.93/a), in which the soil retention in the non-karst landform was generally consistent with that in the whole region. During 2000–2018, the range of soil retention variation to 65.38–96.88 t·hm^{-2}·a^{-1}, collectively increased 22.73 t·hm^{-2}·a^{-1}, with a mean of 79.19 t·hm^{-2}·a^{-1}. In 2016, soil retention fell to a minimum (65.38 t·hm^{-2}·a^{-1}), reached a maximum (96.88 t·hm^{-2}·a^{-1}) in 2017. Therefore, the soil retention maintained a rapid increase from 2016 to 2017. Overall, soil retention in the study area was wavy. 2000–2002, soil retention increased 22.46 t·hm^{-2}·a^{-1}; 2005–2007, soil retention reduced 20.11 t·hm^{-2}·a^{-1}, with its reduction rate 6.70/a; 2015–2018, soil retention showed a change in decrease to rise, and 2015–2016, soil retention reduced 17.26 t·hm^{-2}·a^{-1}, which was the worst decline in soil retention in 19 years, after increased change.

4.2 The spatial distribution pattern of ecosystem services in southwest Guangxi

4.2.1 The average annual NPP spatial distribution pattern in southwest Guangxi

According to the spatial distribution map of inter-annual average vegetation in southwest Guangxi from 2000 to 2018 (**Figure 6**), the average NPP of vegetation in southwest

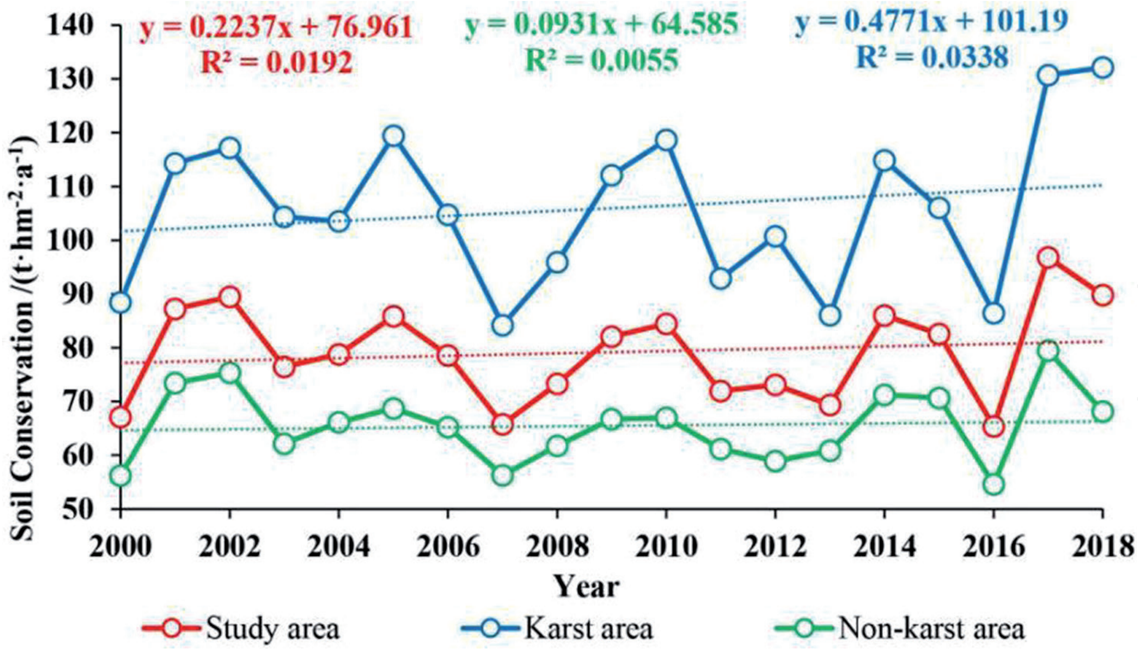

Figure 5.
Inter-annual changes of soil conservation in southwest Guangxi.

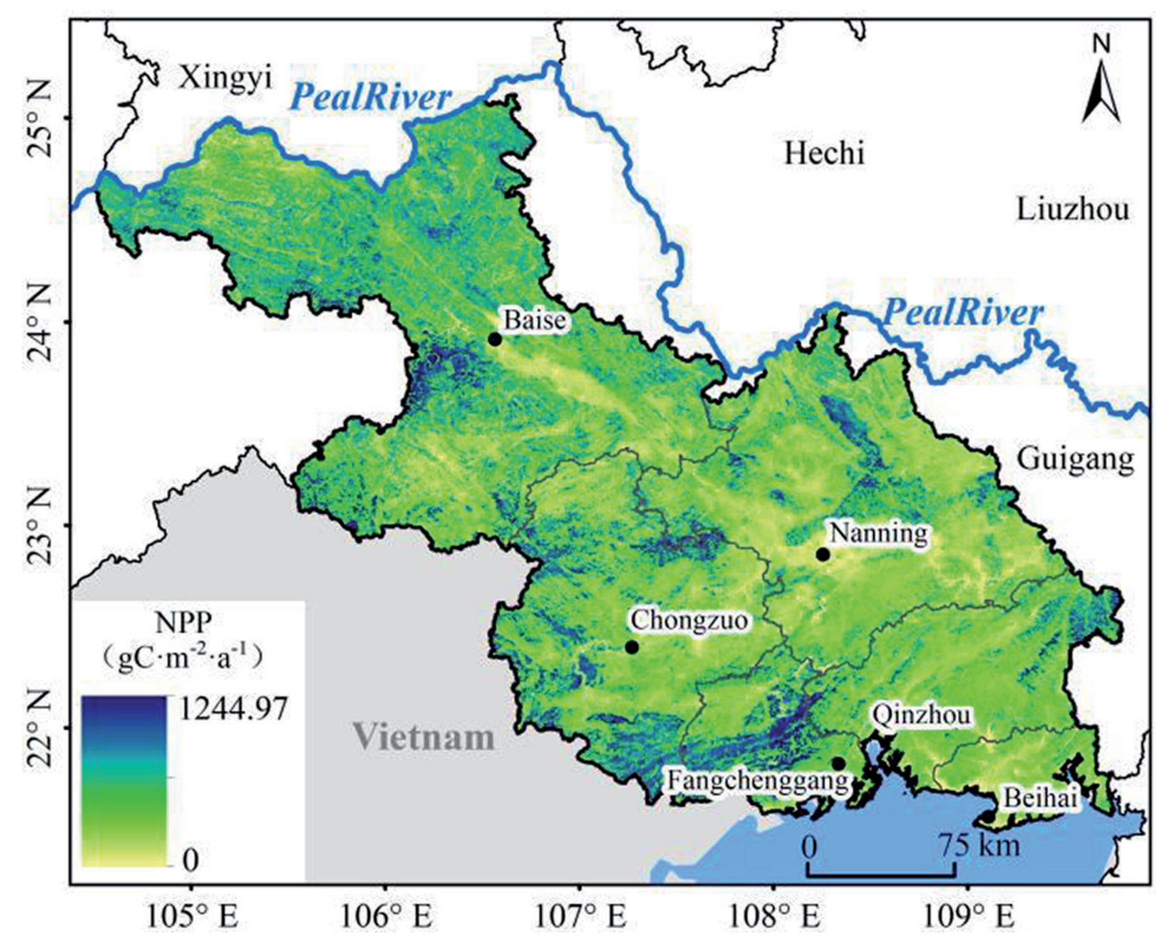

Figure 6.
Inter-annual distribution of vegetation NPP in southwest Guangxi from 2000 to 2018.

Guangxi was 394.95 gC/m^2 a in 19 years, decreasing from east to west and from northwest to southeast. The differences in the spatial distribution of the vegetation NPP in different areas in southwest Guangxi are also more obvious. The vegetation of Shiwan mountains in the middle of Fangchenggang city and Dawanglin mountains in the western marginal area of Baise City has high annual NPP. Due to the lush vegetation of Shiwan and Dawangling mountains, and other forest areas, less human activity and high vegetation productivity, the average annual NPP of these two prefecture-level cities is Fangchenggang city 490.18 $gC/m^2\cdot a$ and Baise city 437.73 $gC/m^2\cdot a$, respectively. The larger range of NPP mean in southwest Guangxi is around 300–1000 $gC/m^2\cdot a$, mainly concentrated in the northwest, west and south of southwest Guangxi, and is also distributed in parts of the east. Nanning, distributed in southwest central Guangxi, and Beihai, in southeastern Guangxi, are greatly affected by human activities, with urban expansion, low vegetation coverage and small productivity. The annual average of these two prefecture-level cities is Nanning city 330.13 $gC/m^2\cdot a$ and Beihai city 253.40 $gC/m^2\cdot a$, respectively.

4.2.2 The average annual spatial distribution pattern of water conservation in southwest Guangxi

By calculating the inter-annual mean of water conservation for each raster in the study area, the raster plot (**Figure 7**) can analyze the spatial distribution characteristics of water conservation in southwest Guangxi. 2000–2018 inter-annual mean of water conservation was between 34.60 and 2099.46 $mm\cdot hm^{-2}\cdot a^{-1}$, with a mean of 1230.16 $mm\cdot hm^{-2}\cdot a^{-1}$.

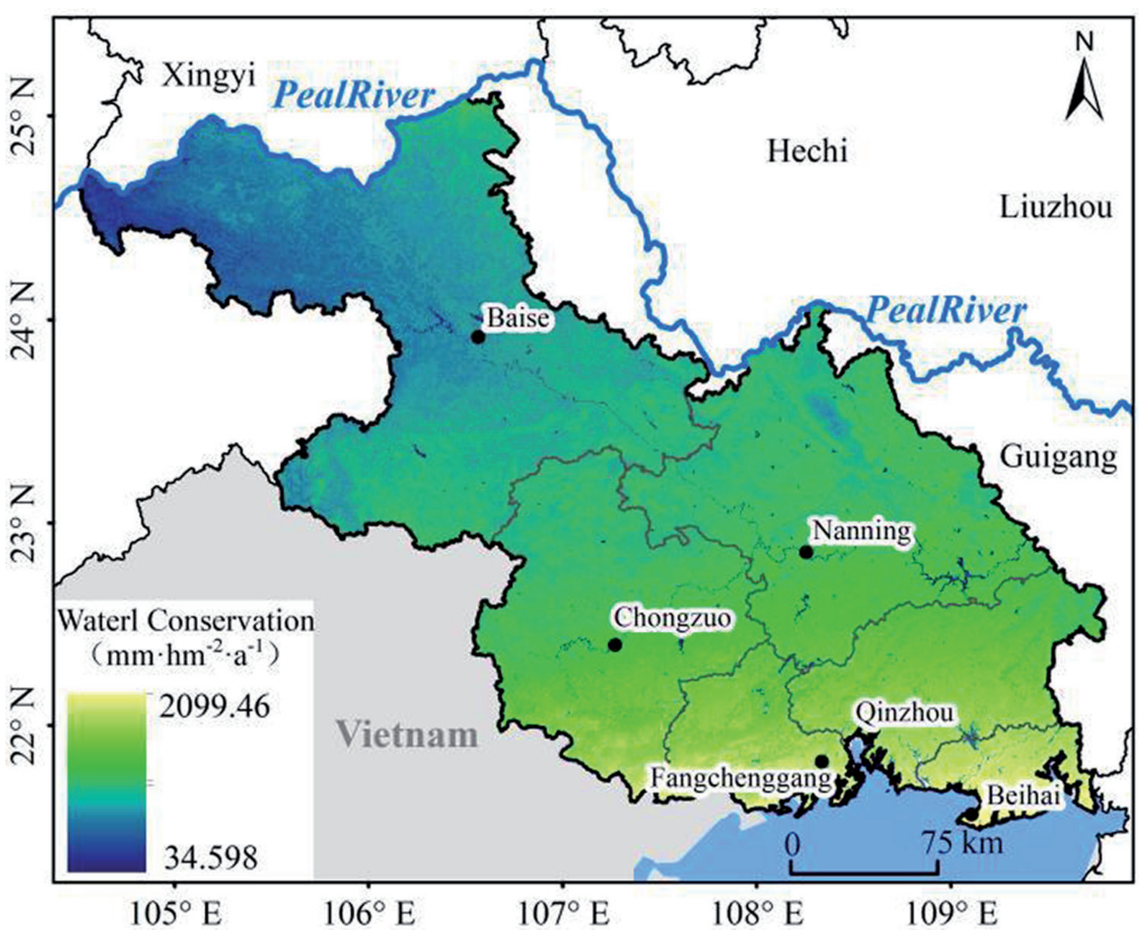

Figure 7.
Inter-annual mean distribution of water conservation mass in southwest Guangxi.

Overall, the high-value area of water conservation is in the south of the study area, and the low-value area is in the north of the study area. Its spatial changes show a decreasing trend from the south to the north. Analysis found that the distribution of water conservation at all levels in the research area is relatively regular, and the higher value area is concentrated in Ningming county, Fusui county of Chongzuo city and Yongning County, Heng county of Nanning city and other some areas, accounting for 21.93% of the total area, while the high-value area accounted for 14.33% of the area, concentrated in Fangchenggang city, Qinzhou city and the southern area of Beihai city. Qinbeifang area is located near the sea, with more extensive fisheries. More artificially fishing farms established, so to some extent, it can be regarded as the regional water conservation capacity, and the precipitation in the research area is mostly concentrated in the southern region. The median value area was concentrated in the central region of the study area, mainly in Chongzuo City and Nanning City, accounting for the vast majority of the area, and also in the eastern cities of Baise city. Low and lower value areas collectively accounted for 30% of the total study area, with the median value (33.74%) being the most, followed by lower value (23.56%), higher value (21.93%) and the lowest.

4.2.3 The average annual spatial distribution pattern of soil conservation in southwest Guangxi

Soil conservation is influenced by factors such as topography, soil nature and precipitation erosion force, showing spatially different spatial regional differentiation characteristics. The inter-annual mean was calculated from soil retention from 2000 to 2018 by the ArcGIS software to obtain **Figure 8**. As can be seen from the figure, the range of soil retention was 0–2074.04 $t \cdot hm^{-2} \cdot a^{-1}$, with an average 79.18 $t \cdot hm^{-2} \cdot a^{-1}$, standard deviation of 104.77. In the inter-annual spatial distribution map of soil conservation, the high values were distributed in the west of southwest Guangxi and scattered, but the Shiwan mountains in Fangchenggang city are relatively concentrated, because the vegetation coverage of Shiwan mountains is high, which plays a large role in maintaining the soil. The middle of the study area was a low-value distribution, such as the central residential living zone of Baise City, the southwest of Nanning City and the vast area of Beihai City, which indicated a large connection between human activity and soil conservation.

4.3 Ecosystem service trade-off in the southwest Guangxi

4.3.1 The trade-off relationship between vegetation NPP and water conservation

From the production possibility boundary curve of vegetation NPP and water conservation (**Figure 9**), there is an obvious synergy relationship between vegetation NPP and water conservation in southwest Guangxi, and one of the ecosystem services will be improved, and the other ecosystem services will also be improved. Analyzing the relationship between vegetation NPP and water conservation, as in **Figure 9**, vegetation NPP increased by 2,003,924 $gC \cdot hm^{-2} \cdot a^{-1}$ from point a to point b, water conservation grew by 5,713,864 $mm \cdot hm^{-2} \cdot a^{-1}$, and vegetation NPP increased by 1,873,433 $gC \cdot hm^{-2} \cdot a^{-1}$ from b to point c, water conservation grew with 8,306,689 $mm \cdot hm^{-2} \cdot a^{-1}$. Comparing the two ecosystem services of a–b interval and b–c interval, the change in a–b stage is relatively slow, indicating that water conservation with the change of vegetation NPP began to increase slowly, and then increases gradually. From this change trend, the growth of vegetation NPP will cause an increase in water conservation, so it shows that vegetation NPP and water conservation in southwest Guangxi show a synergistic relationship.

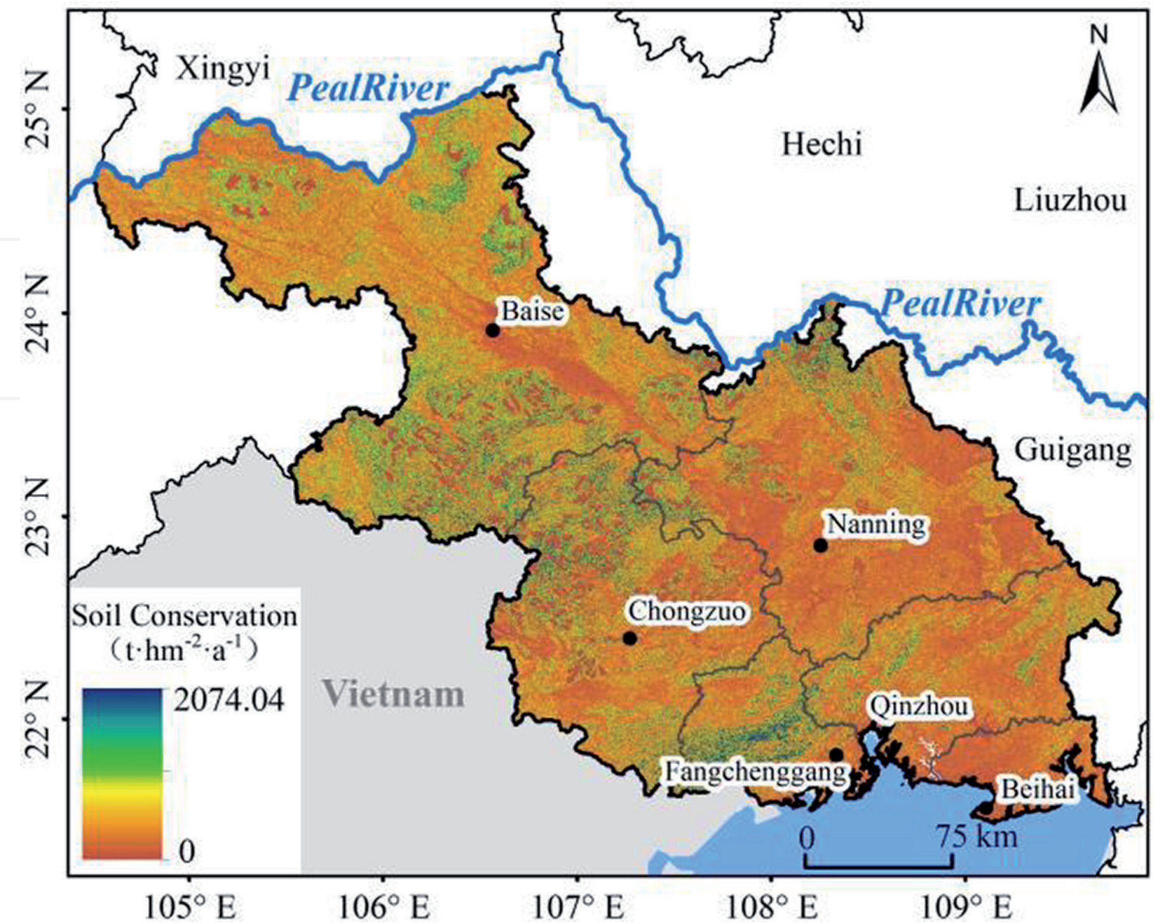

Figure 8.
Inter-annual mean distribution of soil conservation in southwest Guangxi.

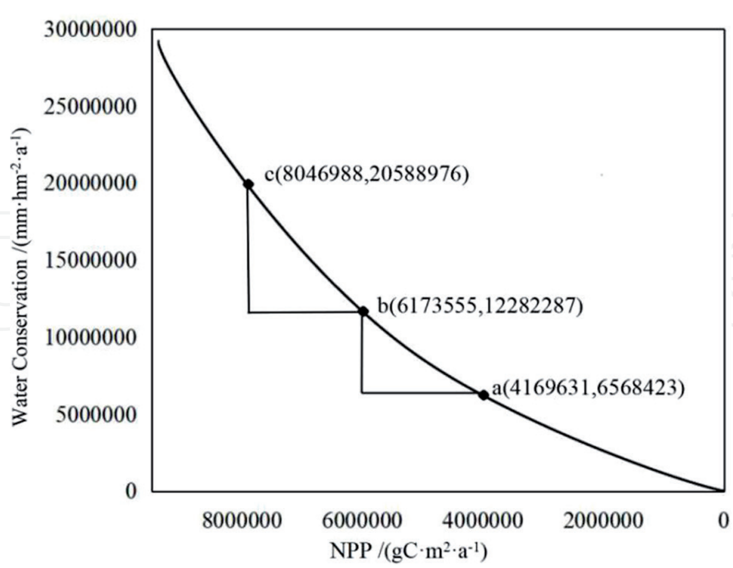

Figure 9.
The PPF curve of vegetation NPP and water conservation.

4.3.2 The trade-off relationship between vegetation NPP and soil conservation

Using ArcGIS and Excel software to count the values of vegetation NPP and make the production possibility boundary of the two services, obtain **Figure 10**,

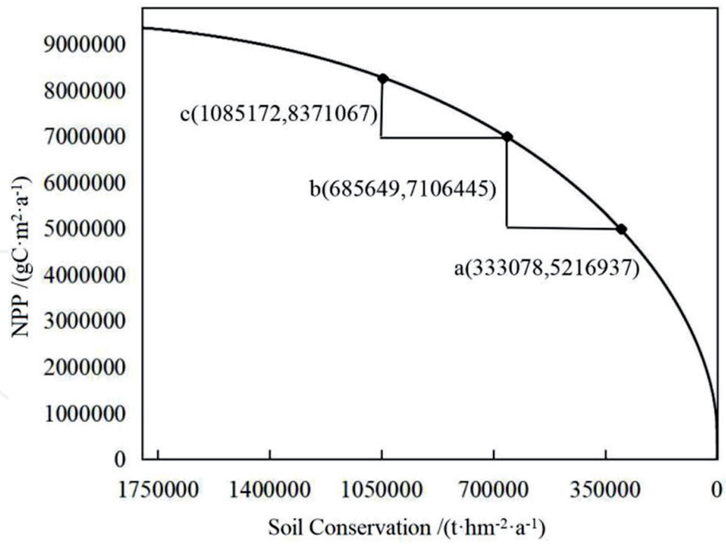

Figure 10.
The PPF curve of vegetation NPP and soil conservation.

which shows a synergistic relationship between the vegetation NPP in the southwest of Guangxi and soil retention. At the front end of the curve (i.e., the lower right corner of the curve), the soil retention remains at 0 and the vegetation NPP has gradually been increased. Three points were randomly selected on the production possibility boundary of vegetation NPP and soil retention to form two groups of change intervals. The change interval of analysis is as follows: by a–b interval, soil retention increment of 352,571 $t{\cdot}hm^{-2}{\cdot}a^{-1}$, vegetation NPP from 5,216,937 to 7,106,445 $gC{\cdot}hm^{-2}{\cdot}a^{-1}$, increment 1,889,508 $gC{\cdot}hm^{-2}{\cdot}a^{-1}$; by the interval from point b to c, vegetation NPP increased by 1,264,622 $gC{\cdot}hm^{-2}{\cdot}a^{-1}$, while the increment in soil retention 399,523 $t{\cdot}hm^{-2}{\cdot}a^{-1}$. Soil conservation shows the same trend with the change of vegetation NPP, indicating that one of the services is improved, and the other service also improved, showing a synergy relationship (e.g., more vegetation will mean more conserved soil because of less erosion and less exposed slopes).

4.3.3 The relationship between soil conservation and water conservation

By making the production possibility boundary between soil conservation and water conservation in southwest Guangxi (**Figure 11**), the trend of PPF curves with the one of vegetation NPP and soil conservation were generally similar, and when water conservation accumulated to 57,883 $mm{\cdot}hm^{-2}{\cdot}a^{-1}$, soil conservation only changed from 0 to 27. The production possibility boundary was still analyzed using three points into two change intervals, namely a–b and b–c intervals, and analyzing the change of service within the two intervals. In the a–b interval, the soil conservation increased from 144,106 to 533,141 $t{\cdot}hm^{-2}{\cdot}a^{-1}$, and water conservation from 12,714,849 to 21,002,026 $mm{\cdot}hm^{-2}{\cdot}a^{-1}$. In the b–c interval, increments of the soil conservation were 593,935 $t{\cdot}hm^{-2}{\cdot}a^{-1}$, and increments of water conservation were 5,625,893 $mm{\cdot}hm^{-2}{\cdot}a^{-1}$. Comparison of the a–b and b–c intervals revealed that the change rate of the a-b interval was somewhat faster than the b–c interval. On the whole, soil conservation and water conservation in southwest Guangxi will cooperate in 2000–2018. If soil conservation is improved, water conservation will also be improved.

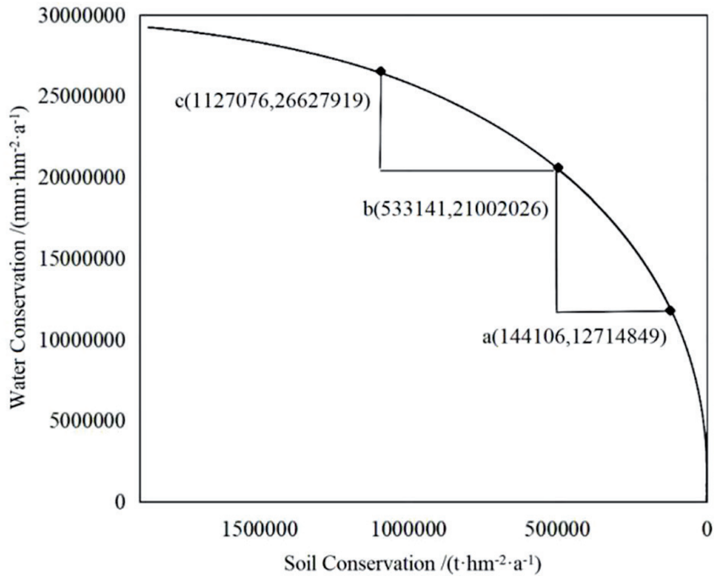

Figure 11.
The PPF curve of soil conservation and water conservation.

5. Conclusions

Vegetation NPP in southwest Guangxi increased from 2000 to 2018. The whole NPP annual average fluctuated between 300 and 500 gC/m^2 a, with an annual growth rate of 3.781 gC/m^2 a. The vegetation NPP average in southwest Guangxi was 394.95 gC/m^2 a in the past 19 years.

In 2000–2018, the vegetation NPP in southwest Guangxi generally showed a decreasing spatial distribution pattern from east to west and from northwest to southeast. In the past 19 years, the vegetation NPP has increased in most areas of southwest Guangxi. NPP shows a growing area of about 56,776 km^2, accounting for 59.35% of southwest Guangxi. The area of NPP, with a decreasing trend of about 38,887 km^2, accounts for 40.65% of southwest Guangxi.

The quality of water conservation and its value in the research area show a fluctuating trend, with the growth rate of water conservation quality 255.88 mm·hm^{-2}·a^{-1}, and the growth rate of water conservation value 97,725.88 yuan hm^{-2}·a^{-1}.

Soil conservation has increased in southwest Guangxi, with the obvious increase of soil retention in the karst landscape, and the change rate is ranked that the amount of soil retention (4.77/a) is greater than the whole region (2.23/a), and greater than the amount of non-karst landform (0.93/a), which is generally consistent with the soil retention in the whole region.

Vegetation NPP in southwest Guangxi and soil conservation, water conservation, soil conservation and water conservation are synergistic. In other words, to improve any of the three services, and other services will also be increased.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] Daily GC. Nature's Services: Societal Dependence on Natural Ecosystems. Washington DC: Island Press; 1997

[2] Fu B, Zhou G, Bai Y, et al. The main terrestrial ecosystem services and ecological security in China. Advances in Earth Science. 2009;**24**(6):571-576

[3] Zheng H, OuYang Z, Zhao T, et al. The impact of human activities on ecosystem services. Journal of Natural Resources. 2003;**18**(1):118-126

[4] Qin K. Study on the Ecosystem Service Trade-off and Synergy between Guanzhong and Tianshui Economic Zone Based on Scenario Simulation. Xian: Shaanxi Normal University; 2016

[5] Board MA. Millennium Ecosystem Assessment. Washington, DC: New Island; 2005

[6] Gonzalez-Ollauri A, Mickovski SB. Providing ecosystem services in a challenging environment by dealing with bundles, trade-offs, and synergies. Ecosystem Services. 2017;**28**(12):261-263

[7] Board MEA. Millennium ecosystem assessment—Ecosystems and human well-being: Wetlands and water synthesis. Physics Teacher. 2005;**34**(9):534-534

[8] Constanza R, Darge R, de Groot R, et al. The value of the world's ecosystem services and natural capital. World Environment. 1999;**25**(1):3-15

[9] Costanza R, Darge R, de Groot R, et al. The value of the world's ecosystem services and natural capital. Nature. 1997;**387**(6630):253-260

[10] Ruijs A, Wossink A, Kortelainen M, et al. Trade-off analysis of ecosystem services in Eastern Europe. Ecosystem Services. 2013;**4**:82-94

[11] Nagenda H, Reyers B, Lavorel S. Impacts of land change on biodiversity: Making the link to ecosystem services. Current Opinion in Environmental Sustainability. 2013;**5**(5):503-508

[12] Van Jaarsveld AS, Biggs R, Scholes RJ, et al. Measuring conditions and trends in ecosystem services at multiple scales: The Southern African Millennium Ecosystem Assessment (SAfMA) experience. Philosophical Transactions of the Royal Society, B: Biological Sciences. 2005;**360**(1454):425-441

[13] Barbier EB, Koch EW, Silliman BR, et al. Coastal ecosystem-based management with nonlinear ecological functions and values. Science. 2008;**319**(5861):321-323

[14] Yang X, Zhou Z, Li J, et al. Trade-offs between carbon sequestration, soil retention and water yield in the Guanzhong-Tianshui Economic Region of China. Journal of Geographical Sciences. 2016;**26**(10):1449-1462

[15] He M. Space and Temporal Difference Analysis of the Ecological Effect of Land Change in Yan'an City. Xian: Shaanxi Normal University; 2018

[16] Sun Y, Ren Z, Zhao S, et al. Spatial and temporal changing analysis of synergy and trade-off between ecosystem services in valley basins of Shaanxi Province. Acta Geographica Sinica. 2017;**72**(3):521-532

[17] Ewuketu L, Aaron-Hogan J, Cao M, et al. Precipitation influences on the net primary productivity of a tropical seasonal rainforest in Southwest China: A 9-year case study. Forest Ecology and Management. 2020;**467**(2):118153

[18] Nianpeng H, Yu Q, Wu L, et al. Carbon and nitrogen store and storage potential as affected by land-use in a *Leymus chinensis* grassland of northern China. Soil Biology and Biochemistry. 2008;**40**(12):2952-2959

[19] Zhao MS, Heinsch FA, Nemani RR, et al. Improvements of the MODIS terrestrial gross and net primary production global data set. Remote Sensing of Environment. 2004;**95**(2): 164-176

[20] Liu S. Wetland Ecosystem Services Evaluation Based on InVEST Model. Harbin: Harbin Normal University; 2019

[21] Liu J, Fu B, Zhang C, et al. Assessment of ecosystem water retention and its value in the upper reaches of Minjiang River based on InVEST model. Resources and Environment in the Yangtze Basin. 2019;**28**(3):87-95

[22] Wu G, Lin H, Zeng H. Responses of soil conservation function to ecosystem changes: An assessment based on RS and GIS in Changting County, Fujian Province. Acta Ecologica Sinica. 2017;**37**(1):321-330

[23] Stosch KC, Quilliam RS, Bunnefeld N, et al. Quantifying stakeholder understanding of an ecosystem service trade-off. Science of the Total Environment. 2018;**651**(2): 2524-2534