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Identifying Ecological Security Patterns Based on Ecosystem Services Is a Significative Practice for Sustainable Development in Southwest China

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Southwest China, which is rich in biodiversity and a wide range of ecosystem services (ESs), is a strong support for local human wellbeing. This area is also one of the key components of the ecological security shelter (ESS) for national ecological security and biodiversity conservation. Due to the combination of man-made and natural factors, Southwest China has suffered serious ecological degradation that directly threatens ecological security which refers to the health status of ecosystems and ESs functions. Mapping ESs-based ecological security patterns (ESPs) is essential for designing conservation strategies that suitably combine regional environment conservation with sustainable utilization. We used the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs Tool) model to identify ecological conservation priority areas which integrated ecological sensitivity (soil erosion sensitivity, rock desertification sensitivity, landslide sensitivity, debris flow sensitivity, and freezing-thawing erosion sensitivity), ecological risk (drought risk, natural disaster risk, and socio-economic risk), and ecological conservation importance (soil conservation, water conservation, and biodiversity conservation importance). In this research, we summarized a new designing framework of ESs-based ESPs. We divided the study area into two zones and four belts including: (A) the alpine steppe and wetland zone, (B) Hengduan Mountain zone, (C) northern shelter belt (Daba-Micang Mountain), (D) central shelter belt (Wumeng-Wuling Mountain), (E) southern shelter belt (southern border of China), and (F) southwestern shelter belt (eastern Himalayas Mountain). Identifying distributions of the ESs-based ESPs has practical significance to improve local human wellbeing and to maintain sustainable development of natural-social ecosystems in Southwest China. Furthermore, ESs-based ESPs are necessary for local administrations to create rationalizing plans on balancing conservation and utilization of natural resources, so that policy-makers can put into place targeted prevention and control measures to limit the development of excessive consumption of natural resources and ecological damages, which is worth promoting.

Keywords: ecological security patterns (ESPs), ecological security shelter (ESS), ecosystem services (ESs), ecological sensitivity, ecological risk, ecological conservation importance, Hengduan Mountain, Southwest China

INTRODUCTION

Predatory exploitation and irrational utilization of natural resources have brought about serious consequences such as climate change. Combining the effects of human activities with climate change has led to complicated changes in ecosystems at the spatial or temporal multi-scale, which bring significant losses and severe impacts to human wellbeing (Zhao et al., 2018). Due to rapid economic development, urbanization, and industrialization, as well as an exponential growth in the population and consumption of energy and materials, natural ecosystems have been severely challenged for several decades in China. In the process of regional development which requires stable natural resources and eco-environmental support, population growth and economic development have led to tremendous pressure on natural ecosystems, causing degradation such as water shortages, soil erosion, carbon loss, biodiversity loss, and habitat fragmentation (Xu et al., 2019). A comprehensive understanding of the effects of ecosystem changes and corresponding security considerations is necessary for establishing regional environmental management policies (Pătru-Stupariu et al., 2020; Xiao Y. et al., 2020). With the aim to protect the fragile ecosystem, reduce natural disasters, and curb ecosystem degradation, local and central governments of China have recently launched a series of ecological policies and projects, such as the Slope Land Conversion Project (SLCP), China's Natural Forest Protection Project (NFPP) (Zinda and Zhang, 2018), Artificial Afforestation, the River Shelterbelt Project (Xiao Y. et al., 2020), and Retire Livestock and Restore Grassland (RLRG) (Wang Y.X. et al., 2018). As the main ecosystem, grassland health affects biodiversity due to the adaption of all native flora and fauna to the long-term evolutionary forces that have shaped these rangeland environments (Harris, 2010). Grassland degradation caused by livestock grazing increased in the late 1990s as several disasters occurred, including Yangtze River floods, the Yellow River running dry increasingly often, and dust-storms and sand-storms originating in western rangelands, which directly damaged ecological security (Harris, 2010). Southwest China, which is rich in biodiversity and has a wide range of ecosystem services (ESs), is a strong support for the sustainable development of the local human wellbeing (Xiao Y. et al., 2020). This area is also one of the key components of the ecological security shelter (ESS) for biodiversity hotspot conservation. A sound management of natural resources is needed if there is to be a sustainable future. Due to the combination of man-made and natural factors, Southwest China regional land cover has changed significantly and now suffers from serious ecological degradation such as severe soil erosion and the tendency to develop rocky desertification (Xiao Y. et al., 2020).

The report to the Eighteenth National Congress of China has indicated that ecological security has become a hotspot in the field of sustainable development strategies (Liu and Chang, 2015). Ecological security is a significant component of ecological civilization, which has been promoted in the overall plan of the cause of socialism, and improved its strategic position in the central government of China (Liu and Chang, 2015; Meng et al., 2021). Because of the increasing global attention being given to ecological security, the need to identify and quantify its underlying causes has sparked heated debate (Zuo et al., 2020). Ecological security, which refers to the health status of ecosystems and ESs functions, is a prerequisite for sustainability and vital for the coordination of biodiversity conservation and social development of natural and semi-natural ecosystems (Lu et al., 2018; Xu et al., 2019). Ecological security assessment (ESA) at a regional scale has emerged in an important manner to become a catalyst for positive economic development and to address the maintenance of regional sustainable development (Zhao et al., 2018). The ESA aims to identify ecosystem's stability, recognizing the ability to maintain ecological security under various scenarios of ecological risks (Zhao et al., 2018). Therefore, it needs to pay more attention to ecological security for safeguarding sustainable conservation and ecological resources utilization, infrastructure, and the ESs at different spatio-temporal scales (Hodson and Marvin, 2009). Ecological security can ensure a state of harmony between the natural ecosystem and social ecosystem, with the focus on safeguarding interactions in these components (Zhao et al., 2018).

Ecological security patterns (ESPs) are a concrete practice considering ecological security in the fields of landscape ecology, urban planning, and landscape design, which should be an implementation of ecosystem-based management (Peng et al., 2018a). The goal of the ESPs is to ensure regional ecological security and improve the dynamic balance of the relationships between natural conservation and social development. The construction of the ESPs is an important approach and basic conservation to achieve regional ecological security. The ESPs refer to the elements of landscapes, such as ecological source patches and connectivity corridors, which are critical to the security and health of ecological processes in multi-scales (Yu, 1996). The ESPs aim to provide an effective spatial approach for maintaining ecological security of natural ecosystems based on the relationship between landscape patterns and ecological processes (Peng et al., 2018a). The ESPs can not only provide basic regional conservation for essential ESs and a healthy environmental condition, but also effectively balance natural resources utilization (Zhao et al., 2018). It is an integrated approach to protecting the regional ecological shelter for sustainability (Peng et al., 2018b; Rozylowicz et al., 2019). The ESPs are able to maintain the integrity of structure, function, and processes in the natural ecosystem. They can also achieve effective control and continuous improvement of ecological environment problems. Rational optimization of the ESPs helps prevent and avoid ecological risk, reducing negative impacts such as environmental degradation (Liu and Chang, 2015). The spatial configuration of the ESPs is formed by strategic points, lines, polygons, and networks that are critical to maintaining ecological processes (Peng et al., 2018a). Mapping the ESPs is necessary for designing conservation strategies that suitably combine regional environment conservation with sustainable utilization.

The methods of selecting ecological security sources based on the ESs and evaluating resistance surfaces for the ESPs construction are well developed and fully consider land degradation and spatial heterogeneity (Peng et al., 2018a). The concept of the ESs has supported a global agenda on sustainability (La Notte et al., 2017; Jiang and Xu, 2019), and has become popular between academics and policy-makers (Raum, 2018; Jiang and Xu, 2019). The ESs can offer a promising framework to evaluate natural ecosystem management policies by making the connection between natural ecosystems and human wellbeing explicit. China has conducted systematic and comprehensive assessments of the ESs changes affected by these conservation policies across various scales, which have already been applied by policy-makers of governments at various levels and sectors (Ouyang et al., 2016). Chinese governments and scientific institutions are implementing ambitious plans across varying scales to improve our understanding and ESs management (Ouyang et al., 2016). It is a practice to design ESs-based ESPs to improve human welfare through increasing the income of local people and helping local communities to rise above poverty levels in Southwest China (Xiao Y. et al., 2020).

In this research, to design ESs-based ESPs from 1990 to 2015 in Southwest China, we documented: (1) a new framework for identifying ESs-based ESPs, (2) changes of multiple ESs, and (3) spatial distributions of the ESs-based ESPs.

MATERIALS AND METHODS

Study Site

With a total area of 22.9×10^5 km^2, the study area covers nearly 24% of the land surface of China, including Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Southeast Tibet, and Southwest Qinghai (83°53′E-112°04′E, 20°54′N-36°21′N) (**Figure 1**). The main geomorphic forms are plateau, mountain, hill and basin, and karst landforms (e.g., trough valley, peak cluster depression, and rift basin), and the hilly area accounts for more than 80% of the study area. The elevation ranges from −5 m (lower than sea level) to 7734 m. Climatic types include tropical rain forest monsoon, tropical subtropical monsoon, subtropical humid monsoon, and plateau mountain climates in Southwest China (Shi et al., 2019). The average annual temperature ranges from 0 to 24°C, and the annual precipitation is from 600 to 2300 mm, decreasing from southeast to northwest. The main types of ecosystems in the study area are forests (broadleaf forest, coniferous forest, and coniferous and broadleaf mixed forest), shrubs (broadleaf shrub, coniferous shrub, and open shrubland), and grasslands (alpine meadow and alpine steppe), accounting for 73.6% of the total area, which can provide multiple ESs such as wildlife habitats, soil and water conservation, biodiversity conservation, and climate regulation.

Data Sources

We downloaded DEM data with a 30 m × 30 m resolution from the United States Geological Survey (USGS)[1] and derived the slope and aspect from the DEM data. Ecosystem-type data (with a 30 m × 30 m resolution) were provided by Aerospace Information Research Institute, Chinese Academy of Sciences. Meteorological data were provided by the Meteorological Center of China Meteorological Administration. We obtained soil data from Chinese soil dataset[2] based on Harmonized World Soil Database version 1.1 (HWSD). Land use and cover change (LUCC) data from 1990 to 2015, settlement distributions (locations of cities, counties, and villages), roads (national highways, provincial highways, county roads, and village roads), and river data (vector) were provided by the "National Tibetan Plateau Data Center" (see text footnote 2). Seismic frequency data were downloaded from China Earthquake Networks Center.[3]

Data Analysis

Integrated Valuation of Ecosystem Services and Tradeoffs Tool Model

The InVEST model (Integrated Valuation of Ecosystem Services and Tradeoffs Tool) was cooperatively developed by Stanford University, World Wide Fund for Nature, and Nature Conservancy. It is an open-source software used to visualize and estimate goods and services from nature on a spatial scale (Wu et al., 2021). The InVEST model allows the quantification, spatial mapping, and in some cases economic valuation of the ESs, as well as the analysis of impacts and trade-offs between alternative ESs management options (Grêt-Regamey et al., 2017; Daneshi et al., 2021). This model runs in a gridded map at an average annual time step which requires relatively low data and expertise, therefore it is appropriate for assessing the impacts of land-use change on multiple ESs (Li et al., 2021). More details can be found in the InVEST user's guide (Sharp et al., 2000).

Ecological Sensitivity Analysis

We selected soil erosion sensitivity, rock desertification sensitivity, landslide sensitivity, and the sensitivity of debris flow and freezing-thawing erosion to evaluate ecological sensitivity in Southwest China. We used the universal soil loss equation (USLE model) to calculate soil erosion sensitivity based on comprehensively considering rainfall erosivity, soil texture, topographic relief, and other factors for evaluating soil erosion sensitivity related to human activities (Lin et al., 2018). Sensitivity

[1] http://earthexplorer.usgs.gov/
[2] http://data.tpdc.ac.cn
[3] https://news.ceic.ac.cn/

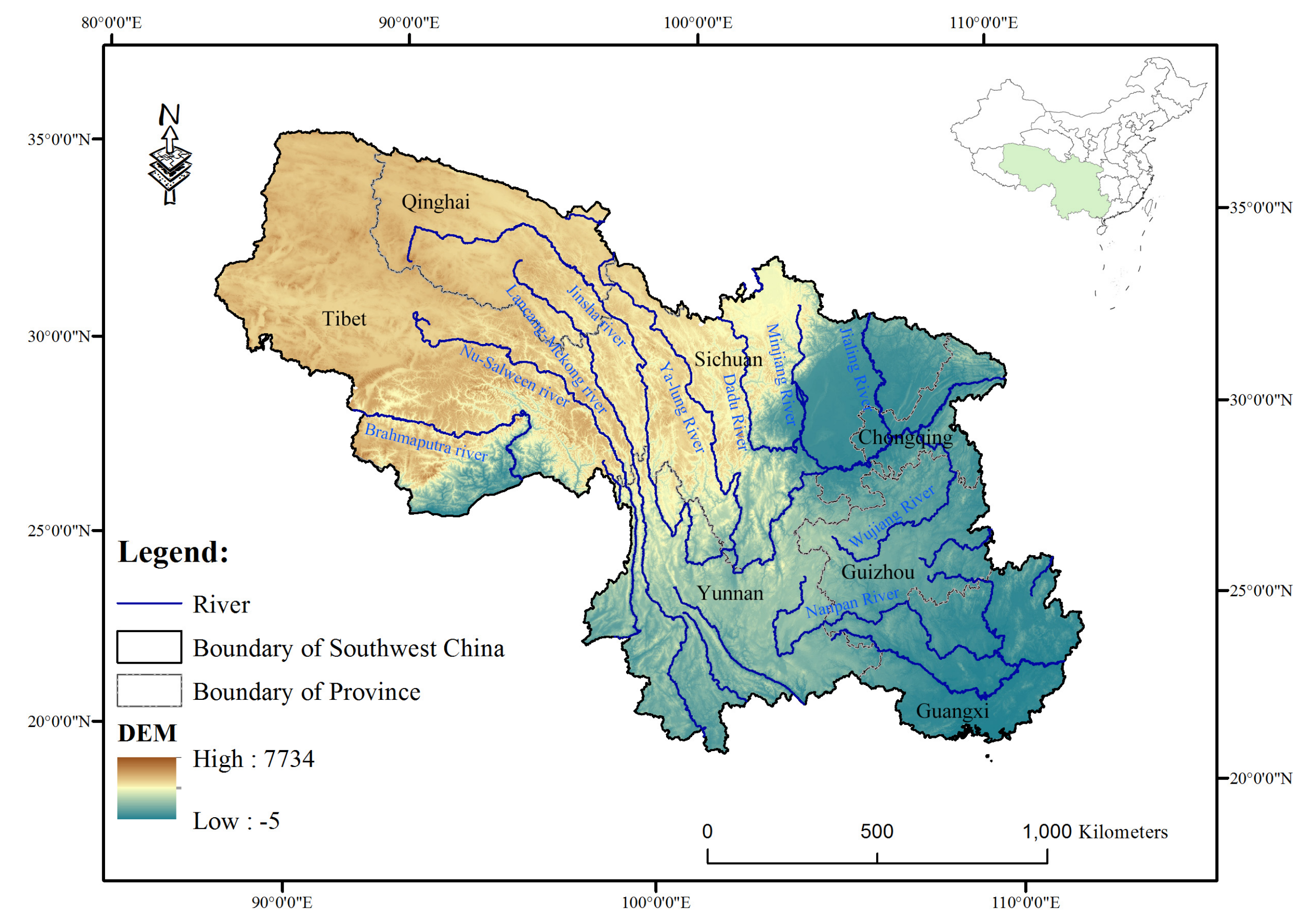

FIGURE 1 | Location of study area.

assessment of rocky desertification depended on whether the area was karst landform, with considering vegetation cover and the lithology element. According to environmental conditions and main inducing factors, we selected the distance from fault line, seismic intensity, slope, rainfall, and other factors to analyze ecological sensitivity (**Supplementary Table 1**).

We selected temperature, rainfall, topography, and vegetation types to evaluate sensitivity of freezing-thawing erosion. By superimposing sensitivity results of the five single factors above, ecological sensitivity grades of the study area were obtained. The calculation formula of ecological sensitivity is as follows:

$$S_i = \mathrm{Max}\,(C_{1i}, C_{2i} \cdots\cdots C_{mi})$$

where, S_i is the ecological sensitivity level of the i-th factor, and C_{1i}, C_{2i} $\cdots\cdots$ C_{mi} are the ecological sensitivity levels of a single factor.

Ecological Risk Analysis

Based on the background characteristics of Southwest China, the risk sources were divided into nature-related risk sources and human-related risk sources. Forest, shrub, grassland and wetland, farmland, and bare land were selected as ecological risk receptors to construct the risk assessment model based on risk sources level, vulnerability, and potential loss of ecosystem (Wang H. F. et al., 2018). The risk sources level was quantitatively evaluated by relevant impact factors. Ecosystem vulnerability was determined by environmental vulnerability, landscape structure vulnerability, and potential losses of ecosystems (**Supplementary Table 2**; Wang H. F. et al., 2018). The calculation formula of ecological risk is listed below:

$$R_i = D_i \times V_u \times V_a$$

where, R_i is the ecological risk value, D_i is risk sources level, V_u is ecosystem vulnerability, and V_a is the potential loss of the ecosystem. We calculated each risk source and divided them into four grades: non-risk, low risk, moderate risk, and high risk. The comprehensive ecological risk of Southwest China was calculated using the spatial analysis toolbox of ESRI ArcGIS 10.2.2.

Assessment of Ecological Conservation Importance

We selected four ESs types which were important to maintain local ecological security, containing soil conservation, flood regulation and storage, water conservation, and biodiversity conservation in Southwest China (**Supplementary Table 3**;

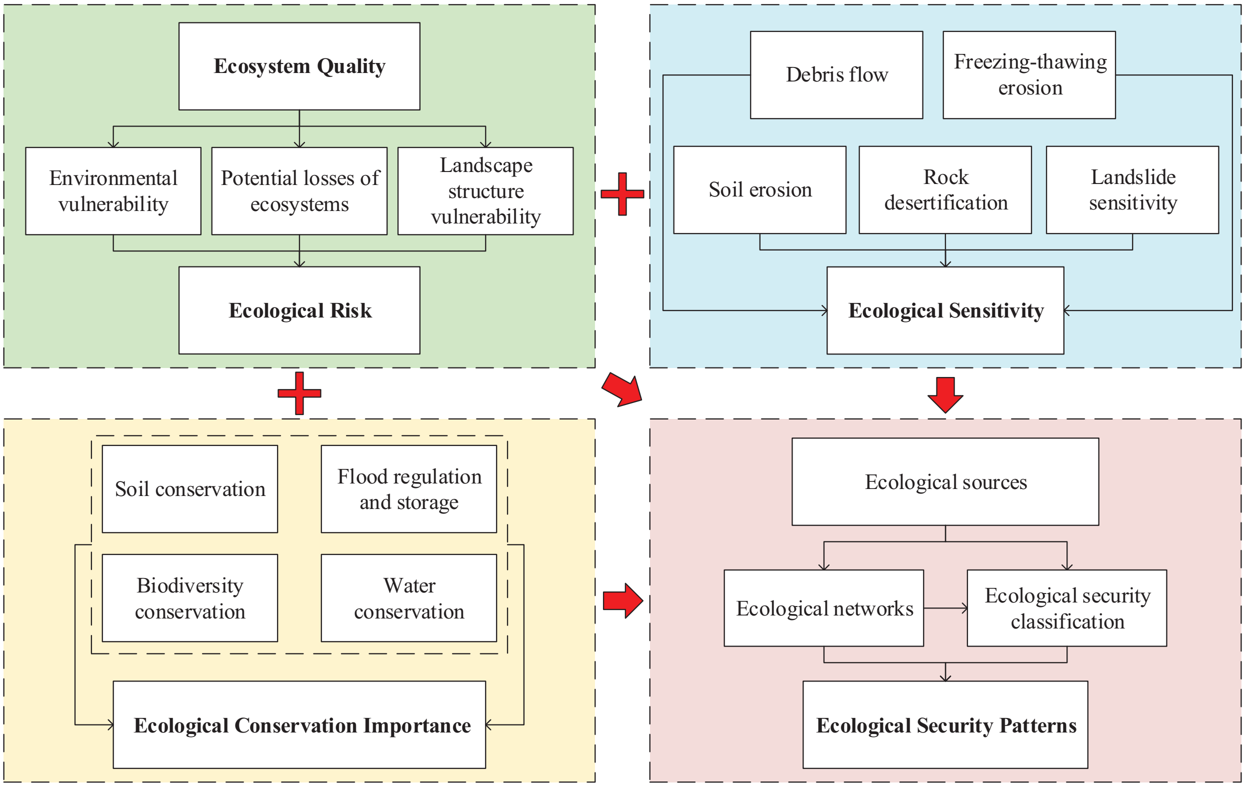

FIGURE 2 | Framework for identifying ecological security patterns based on ecosystem services.

Lin et al., 2018). Soil conservation was evaluated by calculating the amount of potential soil erosion and actual amount of soil erosion. The importance of flood regulation and storage was mainly considered through analyzing the difference of flood regulation and storage capacity in different ecosystems. We used the water balance equation to evaluate water conservation capacity of the ecosystem. We selected important species as indicators and habitat distributions of these species to assess biodiversity conservation patterns using the systematic conservation planning model. The calculation formula of the ESs and conservation importance is below:

$$ES_i = Max\,(D_{1i},\ D_{2i}\cdots\cdots D_{mi})$$

where, ES_i is the importance level of ecological services of the i-th factor, and D_{1i}, $D_{2i}\cdots\cdots D_{mi}$ are the importance of ecological services of single factors.

Framework of Identifying Ecosystem Services-Based Ecological Security Patterns

We focused on spatial distributions of the ESs-based ESPs, which could guide natural resources utilization and sustainable ecological environment development in Southwest China (Liu and Chang, 2015; Liu, 2016; Ye et al., 2018). We designed a new framework to select ecological sensitivity, ecological risk, and ecological conservation importance as basic factors to identify the ESPs of the study area (**Figure 2**).

RESULTS

Changes of Ecological Sensitivity From 1990 to 2015

Regions with increasing soil erosion sensitivity covered a total area of 11.8 × 10^4 km^2, which were located northwest of the study area (mainly in the Kekexili and Changtang national nature reserve) from 1990 to 2015. Regions with decreasing soil erosion sensitivity, with a total area of 27.7 × 10^4 km^2 (12.11% of the study area), were located at Hengduan Mountain, eastern Tibet, and the Three Parallel Rivers Region (TPRR) with the Nu-Salween, Lancang-Mekong, and Jinsha Rivers (**Figure 3A**). The area with increasing rock desertification sensitivity was 33.7 × 10^4 km^2 (10.91% of Southwest China) from 1990 to 2015 and located at Wumeng-Wuling Mountain (**Figure 3B**). The area of increasing landslide sensitivity covered 42.3 × 10^4 km^2 (18.47%) which was mainly located at Hengduan Mountain during the study period (**Figure 3C**). The area of increasing debris flow sensitivity was 46.2 × 10^4 km^2 (20.16%) from 1990 to 2015 and was mainly in Hengduan Mountain and the TPRR (**Figure 3D**). The area of increasing freezing-thawing erosion sensitivity only covered 0.9% (2.01 × 10^4 km^2) of the study area, which was mainly located in Sanjiangyuan National Park

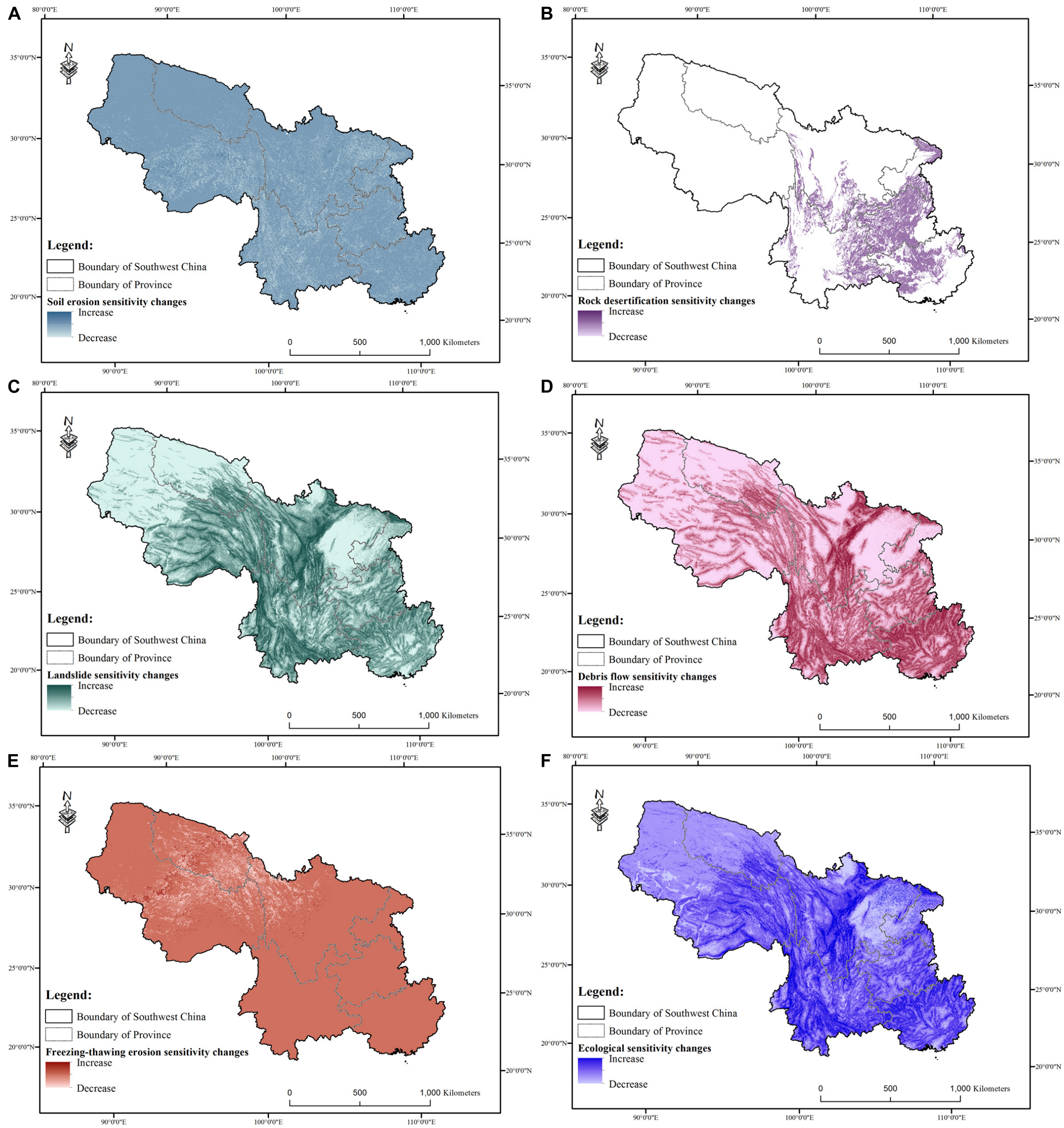

FIGURE 3 | Soil erosion sensitivity **(A)**, rock desertification sensitivity **(B)**, landslide sensitivity **(C)**, debris flow sensitivity **(D)**, freezing-thawing erosion sensitivity **(E)**, and ecological sensitivity **(F)** changes from 1990 to 2015.

during the study period (**Figure 3E**). The area of ecological sensitivity increased to 35.3% of the study area (with an area of 80.9 × 10^4 km^2) which was mainly located at Hengduan Mountain (**Figure 3F**).

Ecological Risk Changes During Study Period

The area of decreasing drought risk covered 86.0 × 10^4 km^2 (37.7% of Southwest China) and the drought risk increasing area was 6.37 × 1^4 km^2 (2.8%) which was located in eastern Tibet from 1990 to 2015 (**Figure 4A**). The deceasing area of natural disaster risk was 14.0 × 10^5 km^2 which covered 61.3% of the study area. With an area of 40.2 × 10^4 km^2, the increasing area of natural disaster risk was located at Hengduan Mountain, eastern Tibet, and the TPRR (**Figure 4B**). The area of socio-economic risk increased to 6.47 × 10^4 km^2 (2.8%) which was mainly located in metropolis and surrounding regions such as Chengdu city (capital of Sichuan province), Lhasa city (capital of Tibet Autonomous Region), Kunming city (capital of Yunnan province), and Guiyang city (capital of Guizhou province) from 1990 to 2015 (**Figure 4C**). With an area of 13.0 × 10^5 km^2, 56.9%

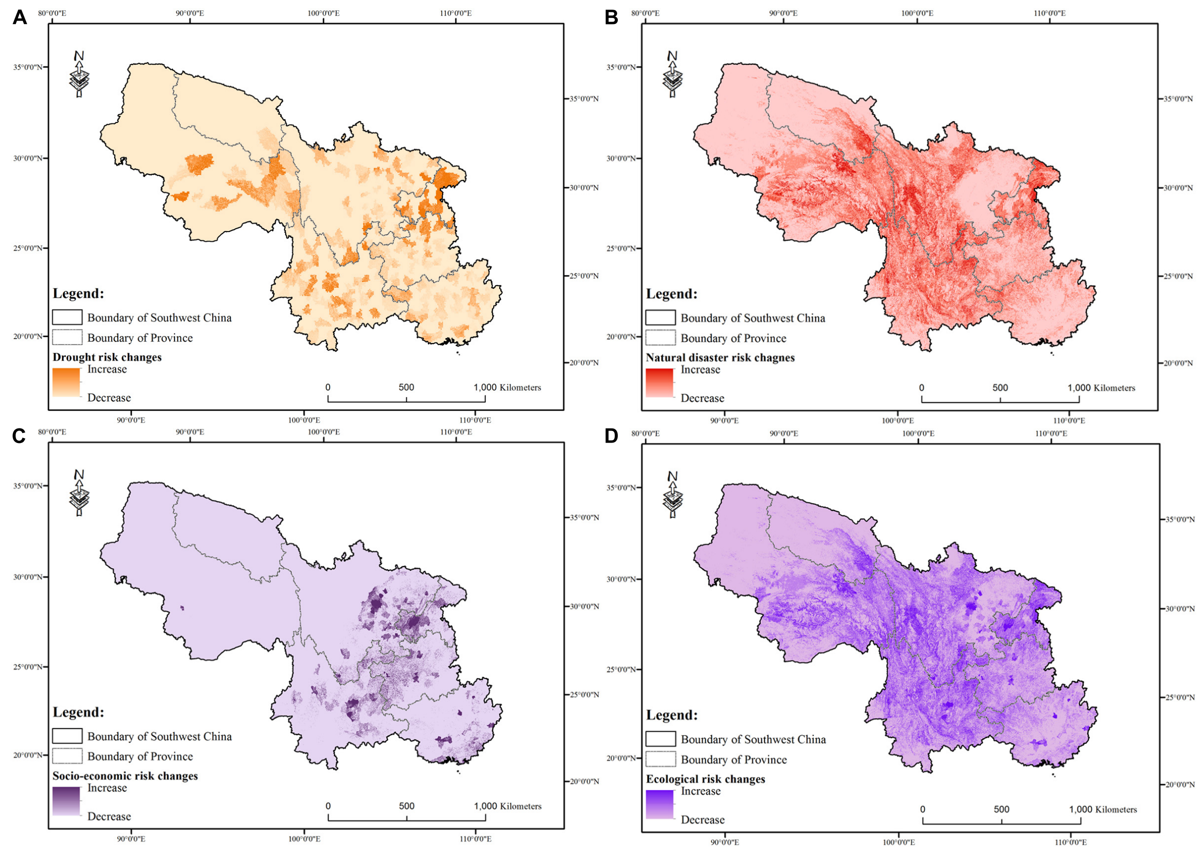

FIGURE 4 | Drought risk **(A)**, natural disaster risk **(B)**, socio-economic risk **(C)**, and ecological risk changes **(D)** from 1900 to 2015.

of the ecological risk study area decreased from 1990 to 2015 which was mainly located at Hengduan Mountain, eastern Tibet, and the TPRR (**Figure 4D**).

Ecological Conservation Importance Changes

The area of soil conservation increased to 12.1% of the study area with a total area of 27.7 × 10^4 km^2 which was located at eastern Tibet, Hengduan Mountain, and the TPRR from 1990 to 2015 (**Figure 5A**). With an increasing area of 51.7 × 10^4 km^2, 2.9% of the study area with flood regulation and storage increased which was located northwest of the study area (mainly around lakes such as Namtso Lake, Silin Co Lake, and so on) (**Figure 5B**). Covering an area of 62.9 × 10^4 km^2 (44.29%), the increasing area of water conservation was mainly located at Hengduan Mountain, southeastern Tibet, and the TPRR (**Figure 5C**). The area of biodiversity conservation importance only increased to 1.50 × 1^4 km^2 (0.7%) which was in southeastern Tibet and the TPRR region (**Figure 5D**). Biodiversity conservation importance was unchanged in the regions, covering 98.90% of the study area from 1990 to 2015. The increasing area of ecological conservation importance was 14.3 × 10^5 km^2 (62.52%) which was mainly located at Hengduan Mountain, southeastern Tibet, and the TPRR (**Figure 5E**).

Spatial Distributions of the Ecosystem Services-Based Ecological Security Patterns

Based on three levels of ecological sensitivity, ecological risk, and ecological conservation importance, the ESs-based ESPs of Southwest China contained of two zones and four belts for local sustainable development, A: alpine steppe and wetland zone, B: Hengduan Mountain zone, C: northern shelter belt (Daba-Micang mountain), D: central shelter belt (Wumeng-Wuling mountain), E: southern shelter belt (southern border of China), and F: southwestern shelter belt (eastern Himalayas mountain) (**Figure 6**). With a total area of 73.9 × 10^4 km^2, key areas of the ESs-based ESPs covered 32.2% of Southwest China (**Table 1**).

DISCUSSION

Necessity to Identify Ecosystem Services-Based Ecological Security Patterns

In the context of global climate change and anthropogenic disturbances, socio-economic development will lead to more prominent eco-environmental problems (degradation and

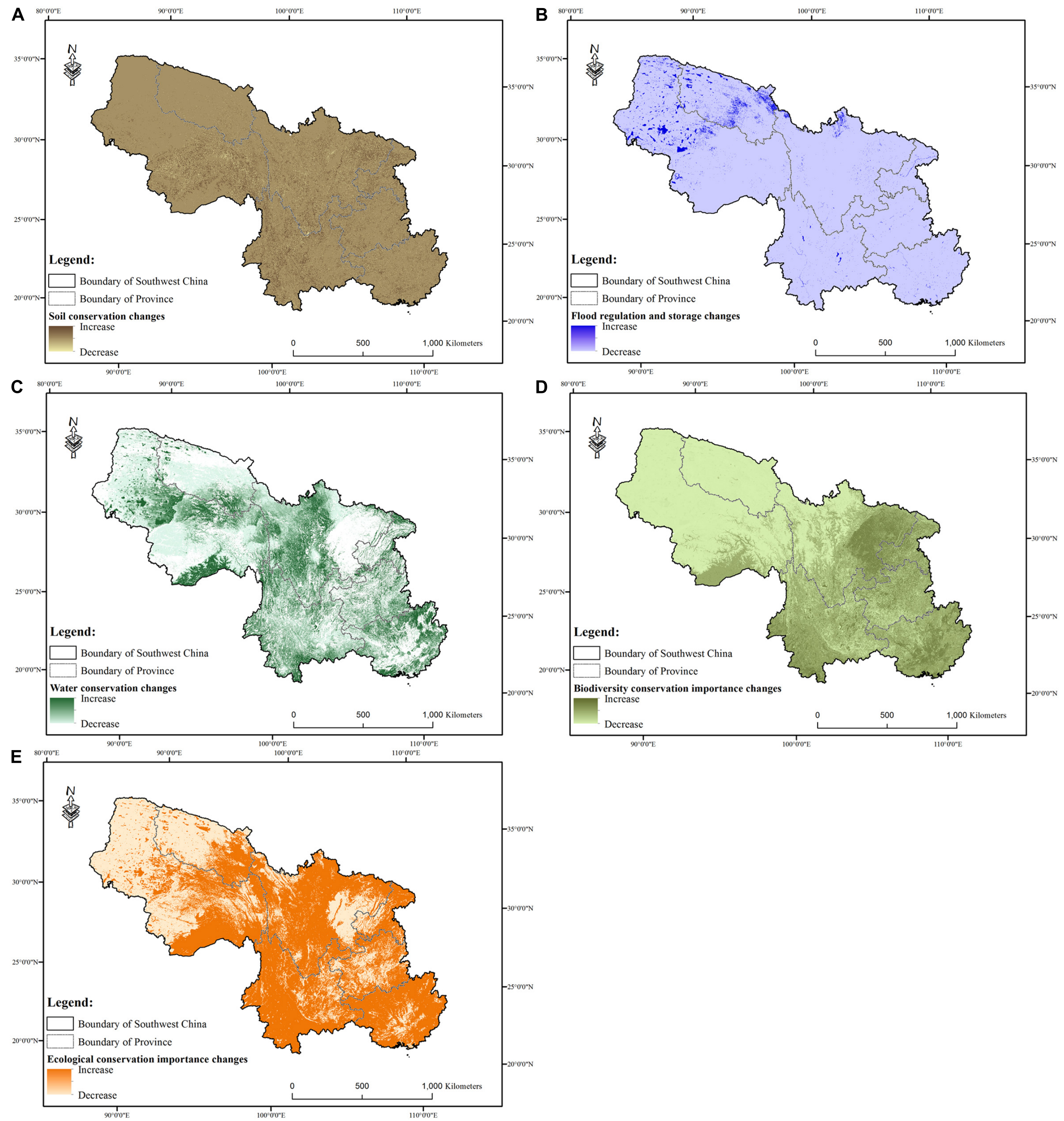

FIGURE 5 | Soil conservation **(A)**, flood regulation and storage **(B)**, water conservation **(C)**, biodiversity conservation importance **(D)**, and ecological conservation importance changes **(E)** in Southwest China during the study period.

fragmentation) (Liu, 2016; McDonald, 2018). The expansion and aggravation of these problems have led to an imbalance in the structure and function of ecosystems, which poses a threat to human safety, ecological security, and seriously hinders sustainable socio-economic development (Deng et al., 2021; Sun et al., 2021). This may also lead to the damage of ESs and reduction of ecological security level (Zhang et al., 2020). Therefore, in order to maintain ecological security it is necessary for scientists and governments to pay more attention to and recognize the great significance of ecological security in terms of both theory and practice on a global scale (Liu, 2016; Yu and Chen, 2021; Zhou D. et al., 2021). Aiming to solve problems

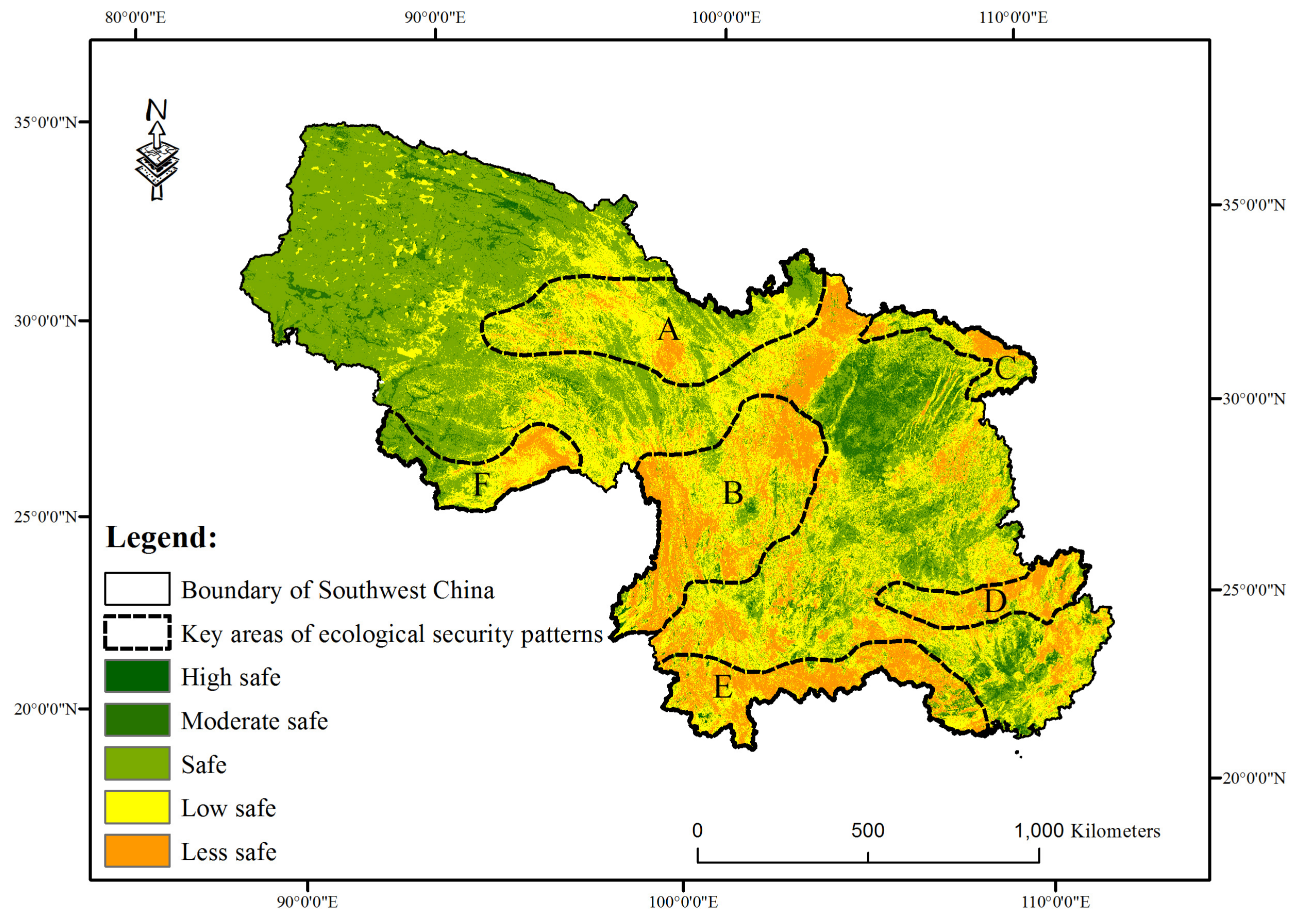

FIGURE 6 | Distributions of the ESs-based ESPs in Southwest China.

of ecological security, China governments have carried out a series of projects and plans such as ecological regionalization, ecological function zoning, ecological protection red line projects, and optimization of protected areas (Liu and Chang, 2015; Liu, 2016; He et al., 2018; Gao et al., 2020; Liu et al., 2021). Researching ESs-based ESPs is an effective path to maintain and improve the ecological security of Southwest China which plays an essential role in the ESS (Wang et al., 2020). ESS construction is a national plan to maintain ecological security function and improve ecological environment in China (Sun et al., 2012; Wang et al., 2017).

TABLE 1 | Area and percentage statistics of ecological security patterns in Southwest China.

Number	Name	Area (10^4 km^2)	Percentage of study area (%)
A	Alpine steppe and wetland zone	20.1	8.7
B	Hengduan Mountain zone	22.6	9.8
C	Northern shelter belt	4.4	1.9
D	Central shelter belt	6.8	2.9
E	Southern shelter belt	12.7	5.5
F	Southwest shelter belt	7.4	3.2
	Total	73.9	32.2

The ESs-based ESPs are regarded as an effective method for strengthening the integrity of natural and socio-economic ecosystems by combining and arranging relationships of ecological processes and the ESs (Yu, 1996; Fan et al., 2021). The ESs-based ESPs are mainly focused on ecological functions and thus ESs, and possible changes in land use patterns (He et al., 2005; Sun et al., 2021). The ESs-based ESPs, which can synthetically consider human wellbeing and ecological conservation, are of theoretical and practical significance for scientific research and government regulation. With fragile ecological conditions and serious disasters, characterized by complex topography, diverse ecosystems, and rich biodiversity, Southwest China is the key area for studying complex surface processes and ecosystem evolution, an important ESS zone of China (Liu, 2016). Designing ESs-based ESPs is an important part of strategies for regional development in China, and is becoming an important agenda for governments (Ye et al., 2018; Wu R.D. et al., 2019). The ESs-based ESPs should be used as the basic ecological line which plays an important role in controlling the disorderly development of local social economy and maintaining regional ecological security (Sun et al., 2012;

Wang et al., 2017; Peng et al., 2018a). In this study, we took into account ecological sensitivity, ecological risk, and ecological conservation importance to evaluate ecological security of Southwest China. We confirmed two zones and four belts as the main structure of ESs-based ESPs to maintain ecological security in Southwest China. Results showed that Hengduan Mountain has a high level of ecological sensitivity and ecological risk and an increasing level of ecological conservation importance. Hengduan Mountain is more likely to have eco-environmental problems under the influence of unforeseeable human activities and extreme climates (Sun et al., 2020, 2021; Xiao Y. et al., 2020). It should be of great concern to governments to deal with future climate changes and sustainable development.

Beneficial to Human Wellbeing

Natural ecosystems can provide supply, support, regulation, and cultural services to humans which are vital to human survival and development, and use capabilities of the ESs to reflect ecological security status (Pogue et al., 2020; Jiang et al., 2021; Sun et al., 2021). Human wellbeing is tied to the capacity of natural and altered ecosystems to produce a wide range of goods and services, which have always depended on the ability to respond to environmental change (Pecl et al., 2017). Recently, identifying ESs-based ESPs in biodiversity hotspots has attracted the attention of policy-makers, which can balance human wellbeing and ecosystem conservation. Effective construction and maintenance of the ESs-based ESPs can contribute to the integrity of ecosystem structure and function, biodiversity conservation, and human wellbeing improvement (Ye et al., 2018). The ESs-based ESPs can benefit ecosystems to sustain human existence and development, can also promote sustainable development, and eventually improve levels of ecological security (Liu, 2016; Ye et al., 2018; Wang et al., 2020). The ESs-based ESPs can be seen as a trade-off and synergy between ecological conservation and socio-economic development (Cochran et al., 2020; Deng et al., 2021). Designing ESs-based ESPs should be preliminarily integrated into many aspects of national and local-level government affairs, such as economic development plans, institution constructions, land-use plans, environment impact assessments, and environmental conservation policies (Wu R.D. et al., 2019). Quantifying ESs-based ESPs and revealing their spatial distributions are beneficial to stakeholders, decision-making, and improvement of human wellbeing.

Fully considering improvement of human wellbeing to identify the ESs-based ESPs is of practical importance for ecological civilization construction which is an essential means of achieving sustainable development, especially in Southwest China (Meng et al., 2021). To enhance people's livelihoods, governments of China have introduced a policy of ecological compensation named central fiscal transfer payments, which is also a regional strategy for ecological compensation (Sun et al., 2020, 2021). Ecological compensation policies should focus on rationally allocating and investing these subsidies in ecological conservation and welfare improvement to address the prevailing prioritization of human wellbeing over ecosystem conservation, especially in the ESs-based ESPs areas (two zones and four belts) (Wu X. et al., 2019; Sun et al., 2021). Specifically, the engagement of low-income sections of the population in ecological management and conservation work as forest rangers, grass guards, and wildlife watchers provides poor people with stable incomes in the ESs-based ESPs (Sun et al., 2021; Xu et al., 2021).

Significance for Practical Aspects of Sustainable Development

Although governments have made great efforts toward ecological conservation and carried out a variety of ecological plans such as the NFPP, the SLCP, and the construction of nature reserves, regional sustainable development is still not achieved (Wu X. et al., 2019). Those policies only focus on ecological functions and natural ecosystems conservation (especially habitat and biodiversity conservation) and lack consideration of human wellbeing, leading to partial policy rigidity. Hence, it is of vital importance for improving ecological policies effectiveness to balance natural ecosystem conservation and human wellbeing (Kang et al., 2021; Zhao X.M. et al., 2021). Human social systems and natural ecosystems impact the ecological security situation together and ecological conservation increasingly needs to be linked to human wellbeing improvement (Gao et al., 2021). Identifying the ESs-based ESPs is a potential solution and pathway to support ecological conservation and improve human wellbeing. We suggest that the ESs-based ESPs (especially the two zones and four belts) for sustainable development should be used as the core areas to carry out a series of projects of ecological conservation, ecological restoration, and ecological compensation based on comprehensive consideration of ecosystem conservation and human wellbeing improvement. It is beneficial to maintain the stability of ecological security and to promote the ESS. The top priorities for developing an ecological civilization in China are identifying core areas (ecological sources), strengthening ecological conservation, and improving human wellbeing (Xiao S.C. et al., 2020; Meng et al., 2021). In this regard, constructing ESs-based ESPs is a substantial step forward in achieving policy goals (Xiao S.C. et al., 2020; Dong et al., 2021). Designing ESs-based ESPs is also beneficial to construction and optimization of protected areas in China. It is a "win-win" environmental conservation scheme for sustainable development that supports both human wellbeing and ecosystem conservation, which can be used as the basic guiding principle of sustainability strategies. Policy-makers should start from the perspective of ESs-based ESPs before creating sustainable development plans to protect key ecological patches in the region first. And then, it can be rationally developed, constructed, and utilized in the remaining areas after defining the relevant conservation scope to solve the conflict between regional ecological security and socio-economic sustainable development (Kang et al., 2021).

In total, this research may provide a new way to balance ecological conservation and human wellbeing for conducting sustainable development.

CONCLUSION

In this research, the ESPs were identified by using an ESs-based designing framework in Southwest China. The results showed that the increased area of ecological sensitivity was mainly located at Hengduan Mountain, the decreased area of ecological risk was located at Hengduan Mountain, eastern Tibet, and the TPRR, and the increased area of ecological conservation importance was located at Hengduan Mountain, southeastern Tibet, and the TPRR. There were two zones and four belts that could be utilized to maintain ecological security in Southwest China. As the cornerstone to build the ESs-based ESPs, governments should pay more attention to Hengduan Mountain which was the key component to alleviate ecological sensitivity and ecological risk and to enhance ecological conservation importance in the study area. These findings provided a foundation to explore a new management pathway for maintaining ecological security and enhancing human wellbeing. Further study should concentrate on the analysis of the contribution of the ESs-based ESPs to the construction of the ESS, especially in biodiversity conservation hotspots. Furthermore, the method used in this study could also be used to quantitatively evaluate whether ESs-based ESPs were necessary to create rationalizing plans by local administrations on balancing natural resources conservation and utilization. In total, based on the ESs-based ESPs, policy-makers can make targeted prevention and control measures to limit the development of natural resources that result in excessive consumption and ecological damages, which is worth promoting.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

XS, YX, and GL designed the research. All authors collected data in the field. YL, YS, HC, SZ, QW, and MY performed the analysis. XS drafted the manuscript. All authors contributed to the interpretation of the results and to the text.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.810204/full#supplementary-material

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