Appendix C: Scenario-Based Analysis of Ecological Compensation Standard in Xijiang Basin

Report of the NCAVES Project

United Nations

System of Environmental Economic Accounting

Scenario-based Analysis of Ecological Compensation Standard in Xijiang Basin

Research Center for Eco-Environmental Sciences,

Chinese Academy of Sciences

July 2020

Table of Contents

1 Policy context

With rapid urbanization, the contradictions between environmental protection and social-economic development have intensified with massive degradation of natural ecosystems and loss of ecosystem services. In addition, the imbalance in the ecological protection investment and the occupation of ecological benefits increases the contradictions between ecological protectors and beneficiaries, which affects the sustainable development between upstream and downstream regions.

Ecological compensation is a market-based mechanism, mainly relying on economic means that aim to coordinate and regulate the interests of stakeholders and achieve ecological protection and economic development (Sun et al., 2017). Watershed ecological compensation can help coordinate the social and economic interests between the upstream and downstream regions, which can harmonize the relationships between human and nature through realizing Pareto improvements of environmental and social-economic benefits. Recently, China has been actively exploring the ecological compensation mechanism and has exerted great efforts to advance the implementation of the policy. In 2014, the revised 'Environmental Protection Law of the People's Republic of China' stated clearly that China should establish and improve the compensation system for ecological protection. In May 2016, the General Office of the State Council issued the 'Opinions on Improving the Compensation Mechanism for Ecological Protection', clarifying that by 2020, a diversified compensation mechanism shall be initially established, and an ecological protection compensation system befitting China's national conditions shall be basically established. In December 2016, the Ministry of Finance joined three other departments to jointly issue the 'Guiding Opinions on Accelerating the Establishment of a Compensation Mechanism for Horizontal Ecological Protection of the Upstream and Downstream Basins (Opinions)'. The Opinions proposes that by 2020, a horizontal ecological protection compensation mechanism will be initially established in cross-provincial river basins that have important drinking water functions and ecological service values, with clear beneficiaries and a strong upstream and downstream compensation goal. To this end, numerous pilot projects will be built to explore their feasibility. In 2017, the report of the 19th National Congress expressly stated the aim to 'perfect the recuperation system of cultivated land, prairies, forests, rivers and lakes, and establish a market-oriented and diversified ecological compensation mechanism', making the establishment of ecological compensation mechanism an important part of the system reform of ecological civilization.

After the heavy floods in major river basins during 1998 (Zong and Chen, 2000), a consequence of extensive logging and sloped land cultivation (Tao et al., 1998), emergency was given to find a sustainable solution for maintaining ecosystem services. In this context, the initial idea of ecological compensation was adopted by the decision makers, resulting in the revision of the National Forest Law of China for proposing the establishment of a national fund to remunerate ecological benefits of forests. This is the institutional origin of ecological compensation in China, after which several ecological protection and restoration projects were initiated (e.g., the Grain to Green project and the Payments for Ecological Benefits of Non-Commercial Forest project). In practice, following the Grain to Green project which was initiated in 1999, other ecological protection programs and ecological compensation schemes have been piloted, improved and implemented regionally or national-wide (Yang et al., 2013; Yin et al., 2013; Yin et al., 2014). Based on these practices, a range of policies were gradually developed at provincial and ministerial scales to guide the establishment of ecological compensation scheme.

Among these policies, two policy documents on ecological compensation schemes were issued by the central government in 2016. One is the Guidelines on Improving Ecological Compensation Mechanism, which sets out the overall framework on ecological compensation in China, with emphasis on the building schemes for the protection of different ecological environments including non-commercial forest, natural grassland, wetland, desert, marine, arable land and key eco-functional zones. Another policy document is the Guidelines for Facilitating Lateral Mechanism of Ecological Compensation between Upper and Down

Streams of Cross Province River, which specifies the importance of the central government in providing financial support based on provincial agreements and contributions (MOF et al., 2016).

To consolidate the achievements of ecological conservation and restoration projects, several compensation schemes have been developed as long-term mechanisms. For example, the projects including the Grain to Green Project[1], the Natural Forest Protection project, the Returning Grazing Land to Grassland project, invest in both conservation engineering and subsidizing relevant farmers. When implementing these projects, participating households receive compensation within specific periods, as well as financial supports for ecological protection and restoration.

Currently, the ecological compensation schemes in China focus on five aspects, i.e. ecological compensation on key national eco-functional zones, non-commercial forests, grassland conservation, the environmental restoration of mining sites, and watershed conservation. Watershed

[1] To balance the relationship between ecosystem protection and social-economic development, the Chinese government implemented an unprecedented ecological protection and restoration project in 1999 with an important component based on payment for ecosystem services, the Grain-To-Green project. The project contains four models of restoration, i.e. afforestation of farmland, establishment of fruit tree plantations, afforestation of degraded land, and conservation of natural forest, which have led to the establishment of approximate 3.0 million ha area of forest in China's 25 provinces. The affected areas have generally shown a reversal of ecosystem degradation and have made significant achievements in ecosystem restoration. To compensate residents of project areas for their loss of income, the government has implemented payment for ecosystem services, such as subsidies for afforested farmland and compensation for the cost of seedlings and restoration work. Farmers who stop farming on marginal or degraded farmland or who can no longer harvest forest products, and who instead establish or conserve forest or grassland, receive a payment per unit area that they restore.

ecological compensation has attracted the most attention from researchers and policy makers in China. Most previous studies on watershed ecological compensation have obtained insights into water pollution control, water conservation and sustainable water supply, while some other studies focus on relevant theories including legal systems for supporting watershed ecological compensation, and the role of watershed ecological compensation schemes in reconciling regional development. Some local governments have developed guidelines on watershed payments, most of which address the concerns about water pollution issues (Liu and Feng, 2015; Li et al., 2016). In practice, examples of watershed ecological compensation have been implemented mainly between prefectural governments and these schemes were designed as mechanisms for rewarding protectors and penalizing polluters. Therefore, these practices have produced a range of legislation on watershed payments in provinces like Jiangsu, Zhejiang, Jiangxi, Fujiang and Hebei (Long and Li, 2015).

In February 2019, the ‘Outline of the Development Plan for Guangdong-Hongkong-Macao Great Bay’ stated that, efforts will be given to the establishment of an important economic support belt with the Guangdong-Hongkong-Macao Great Bay as the leading area, the Pearl-Xi River Economic Belt as the hinterland, to drive the development of the Central-Southern and Southwestern regions of China, as well as the Southeast and South Asia. With the implementation of the national strategic decision, the importance of the Xijiang river basin has been further enhanced. Therefore, the coordination of ecological protection and social-economic development is of great importance for the development of the Pearl – Xi River Economic Belt.

Xijiang River is located in the upper reaches of the Pearl River Basin and is the main tributary of the Pearl River. It originates from the Maxiong Mountain of the Wumeng Mountain Range, Qujing City, Yunnan Province. Flowing through Guizhou and Guangxi, the 2074.8 km long river flows into the South China Sea in Foshan City, Guangdong Province. It has a drainage area of 356,000 km^2, of which 58% is in Guangxi Zhuang Autonomous Region (referred to 'Guangxi' in the report). The status of the ecological environment in Guangxi plays a crucial role in the local sustainable development, as well as the whole basin.

To protect the ecological environment, Guangxi has invested large amounts of manpower, material and financial resources in a variety of fields, such as water resource conservation, water pollution and soil erosion control. During the past twenty years, the Grain to Green Project employed in Guangxi has restored over 1.02×10^6 ha of forests, and specifically, the restoration of the forests at river sources and banks functioned effectively in soil erosion control. Since 2016, the local government has innovated the pollution control models for livestock breeding and invested nearly 3 billion CNY to strengthen the pollution control and comprehensive environmental improvement of the Nanliu River Basin in Guangxi. During 2008 – 2015, the central and local governments issued a special investment plan of over 2.7 billion CNY for comprehensive control of rocky desertification in Guangxi. In November 2018, the Ministry of Ecology and Environment and the Ministry of Natural Resources passed the "Ecological Protection Red Line Plan", which accounts for over one quarter of the area under the jurisdiction of Guangxi. The great investment in ecological and environmental protection and restoration has made Guangxi lost many opportunities for social-economic development.

In view of the importance of ecological compensation in sustainable development of local society and economy and the construction of ecological civilization, Guangxi has carried out ecological compensation practices in many fields, including the compensation for the ecological benefits of forests, the control of soil erosion and rocky desertification, the protection and restoration of water environment and the establishment of ecological function conservation areas. Simultaneously, a variety of ecological compensation policies has been proposed. In 2007, the Department of Finance of Guangxi issued the 'Measures for the Collection and Use of the Compensation for Water and Soil Conservation Facilities and for the Control of Soil Erosion'. In 2013, Guangxi increased the compensation standard for the state- and collective-owned public welfare forests by 0.36 billion CNY. In 2014, the autonomous region added 6 counties to the list of key ecological function conservation areas with transfer payments. In August 2014, the Guangxi and Guangdong governments co-signed the “Agreement on the Cooperation of Cross-border Water Environment Protection in the Jiuzhou River Basin”. In March 2015, the two parties jointly introduced the ‘Jiuzhou River Basin Water Environment Compensation Implementation Plan’. In March 2016, Guangxi and Guangdong signed the ‘Agreement on Horizontal Ecological Compensation for the Upstream and Downstream of the Jiuzhou River Basin (2015-2017)’, marking the pace of horizontal ecological compensation between the two provinces.

After years of exploration, Guangxi has made achievements in ecological compensation. However, due to the mechanism deficiencies, the interests of ecological benefit providers have not been guaranteed well.

Firstly, determining the benefits of different regions with varying ecosystem service supply and values is of great importance for calculating the standards of ecological compensation. However, the ecosystem service value evaluated by estimating the biophysical supply of ecosystem services has a deviation from the actual benefits due to the uncertainty of evaluation method. Determining the compensation thresholds with different future scenarios by considering local policies related to sustainable development plans and the synthetic impacts of natural and human activities could provide valuable reference for the implementation of ecological compensation policy.

Secondly, the existing laws are scattered in different departments or different levels of local legislations, which apply different standards of ecological compensation. Most of the current laws are in principle with little meaning for practices. The diversity of compensation standards with different payments for the same issue put constrains to the uniform and practicability of the laws.

Thirdly, the existing watershed ecological compensation policies are limited to water-related ecosystem services. Calculation of eco-compensation standards based on ecosystem services considers a single type of ecosystem service like water yield or water purification services. Extending the form and scope of ecological compensation policy for other fields and multiple ecosystem services could benefit the improvement of ecological compensation mechanism.

Fourthly, regional characteristics can be observed for the biophysical and social-economic conditions and differences exist in the attributes of specific compensation object. For example, ecological public welfare forest can be divided into state-owned, collective and private public welfare forests according to the ownership. The existing policies mainly aim at a single object or a single type of ecosystem, and ignore the differences of regional characteristics and the diversification of the attributes of compensation objects, which may lead to the lack of fairness among stakeholders.

As the core of ecological compensation mechanisms, the standards of ecological compensation are closely associated with the implementing efficiency of ecological compensation policies. To further improve the ecological compensation mechanism and advance its implementation in the Xijiang basin, it is necessary to carry out a scenario-oriented research on the ecological compensation standards in order to provide decision support for the protection of ecological environment, especially in the context of climate changes. In this study, based on the sustainable development goals and planning of Guangxi, particularly in terms of promoting the protection and restoration of ecosystems, future scenarios were projected by coupling climate changes and human activities. The spatial and temporal variation in the biophysical supply and values of multiple ecosystem services in the context of natural and human disturbances were analyzed. Combined with social-economic characteristics, ecological compensation standards and potential changes of compensation thresholds accounting for different development scenarios were analyzed. Results of this study could provide a scientific basis for the formulation and the implementation of ecological compensation policy in Xijiang River Basin. Specifically, 1) the synthetical analysis of multiple ecosystem services, instead of a single type of ecosystem service, gives more comprehensive expression to the benefits that the ecosystems supply to humans; 2) the consideration of social-economic characteristics during the calculation of ecological compensation standards helps to assimilate the payment capacity of local residents for the compensation policy, which makes the compensation policy much more practical; 3) as the structure and processes of ecosystems are strongly associated with changes in environmental factors, which affect the function and the biophysical supply of different ecosystem services, the incorporation of external influences due to climate changes and human activities into the scenario-analysis could better reflect the variation in ecosystem services, thereby increasing the accuracy of ecological compensation standards.

2 Research scheme

2.1 Objectives

(1) Clarify the spatial patterns and historical evolution characteristics of different land covers in the Xijiang river basin.

(2) Quantify the importance of biodiversity conservation, and the spatial-temporal distribution characteristics in the biophysical supply and value of ecosystem services in the Xijiang river basin.

(3) Explore how the use of the SEEA framework can support the scenario-based assessment of ecosystem services.

(4) Calculate the ecological compensation standard by exploring potential trends of ecosystem services with the coupling effects of future climate

and land cover changes.

2.2 Contents

(1) Conversion characteristics of land cover patterns

Data on climate, soil, hydrology, biology, population, economy and territorial planning of the Xijiang river basin will be collected, and databases of biophysics and social-economy will be built. The spatial distribution and conversion characteristics of different land cover types from 1995 to 2015 will be analyzed. The impacts of environmental factors on the occurrence of land cover types will be analyzed, and the drivers of land cover changes will be identified.

(2) Spatial-temporal changes of biodiversity and ecosystem services

Based on the spatial patterns of different land cover types, important habitat spaces will be identified with index of rare and endangered species. Different assessment models will be applied to estimate the biophysical supply of ecosystem services including water yield, water retention, flood mitigation, water purification, soil retention and carbon sequestration. The spatial and temporal changes of the importance of biodiversity conservation and the biophysical supply of ecosystem services will be characterized. Comparative analysis will be performed on the applicability of different ecosystem service models. Ecosystem service value and its spatial and temporal changes will be quantitatively assessed.

(3) Ecosystem service-based standards of ecological compensation

Future land cover patterns with different development targets, including ecological protection priority, economic development priority and business as usual, will be projected. Combined with different greenhouse gas emission targets in the future, coupled land cover and climate change scenarios will be constructed for 2035, and changes of ecosystem services in relation to the baseline under different scenarios will be analyzed. Coupling the assessment on ecosystem services with ecological protection cost, ecological compensation standards and their changes in the context of combined effects of land cover and climate changes will be calculated. Preliminary recommendations on watershed ecological compensation policy will be proposed.

2.3 Technique route

The technique route of the study was shown in Figure 2.1. Following an extensive collection of datasets, local databases and ecosystem extent account were established. Based on synthetic analyses, three scenarios of future land cover changes were projected for 2035, and the spatial distribution of different land cover types was analyzed. Climate data containing precipitation and temperature were refined to form two future scenarios according to the management targets of carbon dioxide emissions. Coupled with land cover changes, six future scenarios were projected for ecosystem service assessments. Afterwards, the biophysical supply was quantified for different ecosystem services using different assessment models, based on which ecosystem service accounts were developed. Simultaneously, comparison analysis was carried out in terms of the model accuracy and applicability for the Xijiang basin. On this basis, the costs of ecological protection were calculated. Finally, changes of ecological compensation standards under different scenarios were analyzed.

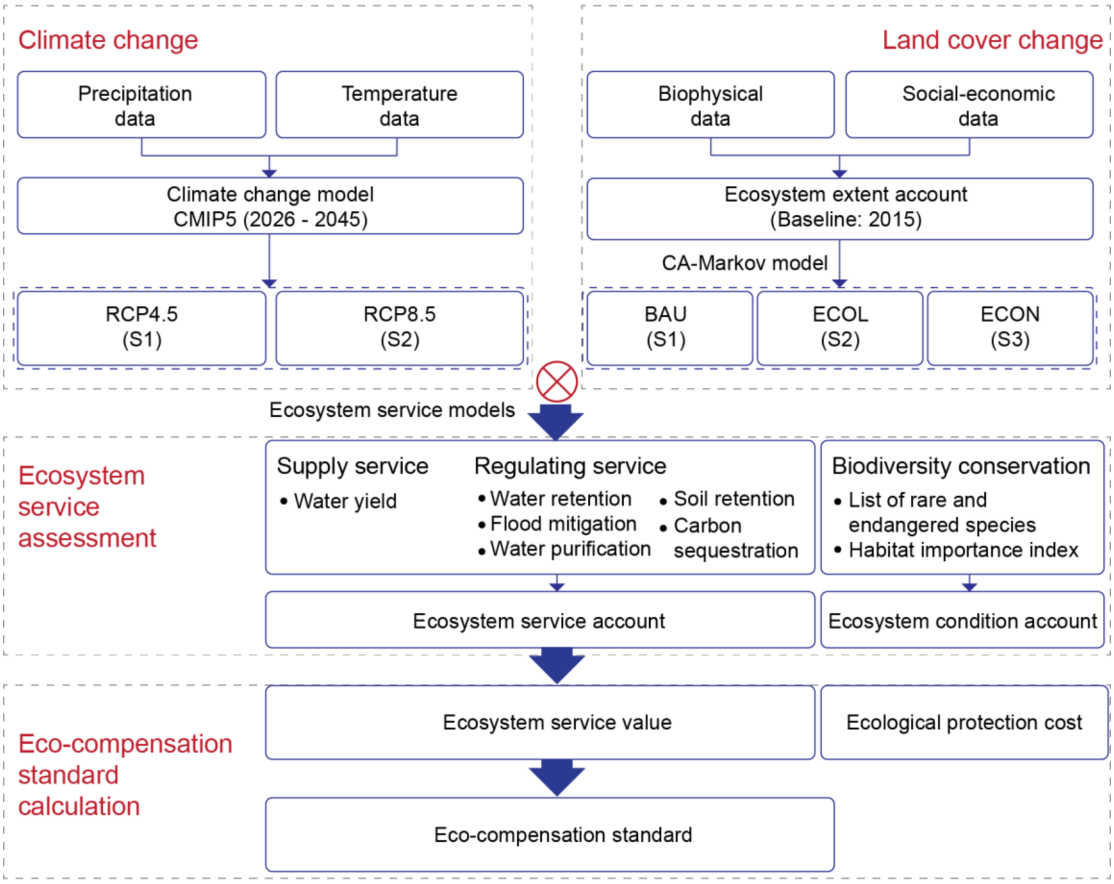

Figure 2.1. Technique route

2.4 Data and methods

2.4.1 Study area

(1) Biophysical characteristics

As the longest river in the South China, Xijiang river originates from Maoxiong mountain in Qujing city, Yunnan province, flows east through Guizhou and Guangxi provinces, and enters the South China Sea in Foshan city, Guangdong province (Figure. 2.2). The Xijiang river is 2074.8 km in length and has a catchment of approximate 3.6×10^5 km^2. The Xijiang river basin has a subtropical monsoon climate, with an annual average temperature of 21.3 °C and an annual average rainfall of 1537.1 mm.

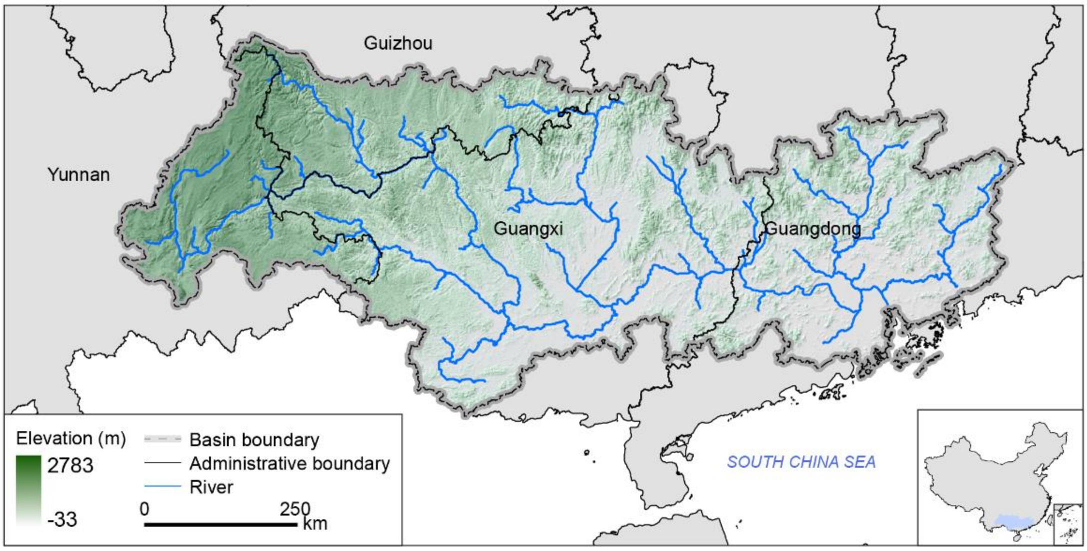

Figure 2.2. Location of Xijiang river basin

(2) Social-economic characteristics

The Xijiang river basin connects two major economic zones, i.e. the Southwest China economic zone and the South China economic zone. The difference of industrial structure reflects the difference of economic development levels in different regions and contributes to the unbalance of economic development in the basin. The primary industry occupies a dominate position in the upstream region, while the secondary and tertiary industry account for a relatively larger proportion of the downstream total GDP. The key economic activities in the upstream regions are tobacco growing and tourism for Yunnan, mineral resource processing and liqueur brewing for Guizhou, hydro-electric power industry, sugar industry and building materials processing for Guangxi. Compared to other regions of the basin, the downstream Pearl river delta region, characterized by geographical advantages of convenient transportation, as well as good industrial and agricultural foundation, high levels of science and technology and wide connection with foreign countries, has become one of the regions with a relatively higher degree of economic openness and the strongest economic vitality in China. The Xijiang river basin plays an important strategic role in the process of national and regional development. Compared to Guangdong province which is located in the downstream region of the Xijiang river basin, the economic development of Yunan, Guizhou and Guangxi in the upper reaches is relatively backward. In 2018, the Xijiang river basin had a total population of 91 million and gross domestic product of 8650 billion, of which Guangdong accounted for over 70%, which was almost 3 times higher than that of the upstream regions.

2.4.2 Data collection and analyses

(1) Design and simulation of future scenarios

a) Data collection

Land cover pattern is a stage result of nature and human activity. The rapid processes of urbanization and population growth have changed the spatial pattern of land cover and affected the biogeochemical cycle of water and nutrient. Ecosystems, especially aquatic ecosystems in a watershed, have low resistance to climate changes and are sensitive to atmospheric precipitation. Moreover, the rapid development of society and economy in the watershed exacerbates water disasters such as flood and drought. Therefore, changes in land cover and precipitation were used to indicate the influence of human activities and climate changes on ecosystem services and ecological compensation standard by synthetically considering data availability and model requirements. Data and sources used for scenario simulation were listed in Table 2.1.

Table 2.1 Data and sources used for land cover and climate simulations

Name	Type	Description	Source
Land cover	Raster	Land cover 1995, 2005 and 2015 from manually visual interpretation of satellite images.	Resource and Environmental Science and Data Center. China Ecosystem Assessments and Ecological Security Database.
DEM	Raster	SRTM1 16 digital elevation model with a spatial resolution of 30 m.	NASA Shuttle Radar Topography Database
Slope	Raster	Extracted from the DEM data using the surface analysis tool in ArcGIS.	DEM data was obtained from NASA Shuttle Radar Topography Database
Road	Vector	National roads, provincial roads, railways and urban main roads. Euclidean distance to the nearest rood was calculated using the distance tool in ArcGIS.	Google image 2018
River	Vector	Extracted from the DEM data using the surface analysis tool in ArcGIS and calibrated with Google image 2018.	DEM data was obtained from NASA Shuttle Radar Topography Database. Google image 2018
POI	Vector	Point shapefiles of city center and residents. Euclidean distance to the nearest city center or resident was calculated using the distance tool in ArcGIS.	Google image 2018
Precipitation	Raster	Precipitation in the year 2015 and annual average precipitation from 2026 to 2045, with a resolution of 1 km.	Guangxi Meteorological Administration. Earth System Grid Federation, (ESGF-CoG) World Climate Database
Soil clay fraction	Raster	Extracted from the Harmonized World Soil Database (HWSD) with a spatial resolution of 1 km.	HWSD v1.2
Population	Raster	Grid data of population with a spatial resolution of 1 km.	Resource and Environmental Science and Data Center.
GDP	Raster	Grid data of GDP with a spatial resolution of 1 km.	Resource and Environmental Science and Data Center.

b) Scenario design

Two representative concentration pathways (RCPs), i.e. RCP4.5 and RCP8.5, with different targets for future CO_2 emission were selected for the projection of future climate scenarios in 2035. The RCP8.5 represents an extreme scenario with the highest level of greenhouse gas emission. This scenario indicates that by 2100 the CO_2 concentration will be 3 – 4 times higher than that before the industrial revolution, and the radiation intensity will reach 8.5 W m^{-2}. The RCP4.5 represents an intermediate stable scenario, indicating that since 2080, the carbon emission rate would be decreased, and the radiation intensity will reach 4.5 W m^{-2}. Climate changes has significant effects on a variety of environmental factors including the temperature and precipitation patterns of China (Chen, 2013). As the RCP4.5 scenario is relatively consistent with the trend of economic development of China (Chen and Lin, 2010), it was selected in this study to address the future climate change. Considering the requirements of inputs by different models, climate datasets containing annual average precipitation and annual average temperature during 2026 – 2045 were used for ecosystem service assessments.

Compared to natural factors, the changes of the demand for living space (i.e., residential areas, recreation areas, office and business areas) caused by policy implementation, economic development and population growth have stronger impacts on the types and patterns of different land covers (Gan et al., 2004). In 2019, the ‘Plan for Establishing and Implementation Supervising of the Territorial Space System of Guangxi’ clarified adhering principle of giving priority to ecology and promoting the protection and restoration of ecosystems, and pointed out that by 2035, a spatial pattern with ecological space characterized by a landscape of picturesque scenery will be formed basically. Considering the spatial planning and space demand of sustainability development of Guangxi, three scenarios of future land cover changes with the 2015 data as the baseline were projected from the perspectives of promoting social-economic development and improving ecological benefits during the next 20 years (2015-2035).

Business As Usual (BAU)

In this scenario, the historical trend of land cover changes from 1995 to 2015 was assumed to continue without any change in the environmental and economic development policies during 2015 - 2035. With the scenario set, it is possible to provide a benchmark for the comparison of different land policy consequences.

Ecological Protection Priority (ECOL)

Ecological lands, providing a wide range of ecosystem services directly or indirectly, serve as a nature base for human survival. In this study, ecological lands refer to the land to which are attributed the goal of maintaining regional ecological security and supporting and protecting the benign development, stability and sustainability of the main ecosystems (Li et al., 2020). The ECOL scenario focuses on the protection and restoration of ecological lands including forest, grassland and wetland during 2015 - 2035. Assumptions are made that the protection and restoration of ecological lands will be enhanced during this period and the social - economic development of different regions give priority to ecological protection and restoration to maximize the benefits that ecosystems provide to humans. Although future changes occurred in a variety of aspects, this study focuses on the variations in climate and land pattern, which show significant impacts on ecosystem types and ecological processes, and consequently affect the biophysical supply of ecosystems. During the model processes, the areas of ecological lands were expanded by increasing the transformation rates of other land cover types and decreasing the loss rates of ecological lands in the transformation matrix. As an important parameter of the CA-Markov model, the transformation rates in the transformation matrix quantify the land-cover changing characteristics from historical changes, after which the model allocates the estimated amount of change per each land type based on the transformation rate matrix in the future (Eastman, 2012). Considering the operating simplicity and the popularity in researches relating to land-pattern simulations, the transformation rates were used as calibrating parameters for different land types in this study.

Economic Development Priority (ECON)

This scenario was embodied with an assumption that industrial structure development, technological innovations and adoption of policy measures that would lead to urbanization and economic growth would be focused. During the model processes, the area of built-up lands, which refer to construction lands, was expanded by increasing the transformation rates of other land cover types (e.g., forest land, grassland and wetland).

In this study, a total of six scenarios with coupled climate and land cover changes were analyzed (Figure. 2.3). Comprehensive analyses of the ecosystem services under different scenarios could provide information on the effects of climate changes and land cover changes on ecological benefits and help to identify sensitive areas in respond to potential changes of future natural and human disturbances, which are helpful for space optimization and management. With scenario-oriented data, ecological compensation standards between the upstream and downstream regions were calculated, which could provide scientific basis for the implementation of watershed ecological compensation policy.

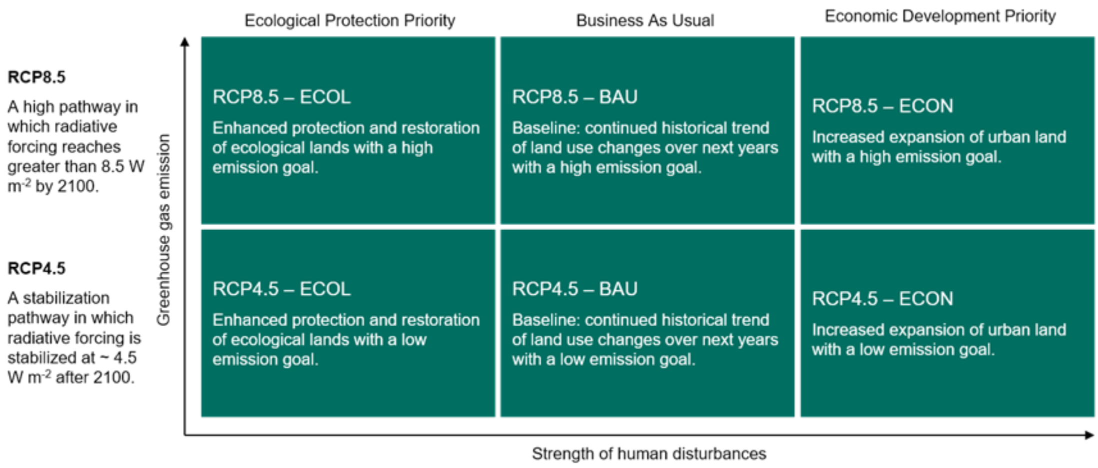

Figure 2.3. Scenarios of future land cover and climate (BAU, business as usual. ECOL, ecological protection priority. ECON, economic development priority)

c) Scenario simulation

To eliminate system error, the rainfall data with two representative concentration pathways of RCP4.5 and RCP8.5 were amended using a Delta parameter method (Navarro-Racines et al., 2020). To determine the parameters, forecast results of the rainfall in 2015 for each meteorological station were extracted based on the latitude and longitude information. By comparing the extracted rainfall data of 2015 with the monitoring data for each meteorological station, it was found that the rooted mean square error (RMSE) decreased by 34% (Figure. 2.4), indicating that the result could better reflect the rainfall changes in the basin and the calibrated parameters could be used for the amendment of future rainfall data.

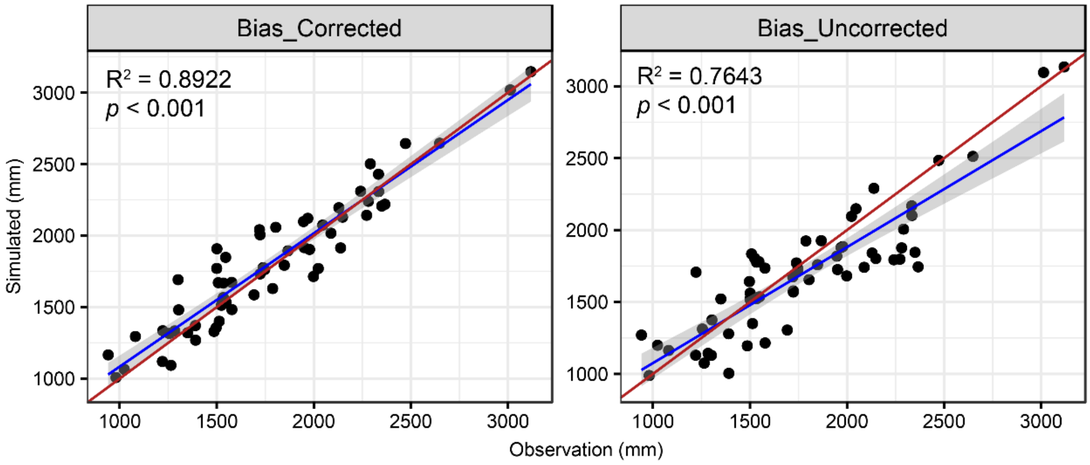

Figure. 2.4. Comparison of simulated and observed rainfall for different meteorological stations (The red solid line represents y = x)

Simulation of the land cover changes was processed based on the interpreted data of 1995 and 2005, as well as different environmental factors related to land cover changes, including elevation, slope, precipitation, soil clay fraction, distance to city center, distance to residents, distance to river, distance to road, population and GDP. With the CA-Markov model, the spatial pattern of land cover 2015 was simulated and compared to the interpreted result to evaluate the model accuracy. Then, the model was run with a baseline land cover data of 2015 and a time step of 20 years. The land cover patterns of 2035 with different management priorities were projected by adjusting the transformation rates among different land cover types.

CA-Markov model is composed of cellular automata (CA) and Markov reaction chain. The model combines CA's capacity of simulating the spatial variation of a complex system and the advantage of Markov reaction chain in predicting long-term status of a system. In this study, the multiple criteria evaluation module of the CA-Markov model was used to generate a spatial suitability distribution map for each land cover type by incorporating biophysical and social-economic environmental factors (Figure 2.5). Changes in land cover are partly due to the impacts of climate change and physiographic conditions (Birhanu et al., 2019). Among the environmental factors that produce landscape patches, elevation and slope may affect soil, cause water loss and landslides, and give a variety of topographical features (Sarma and Barik, 2010; Lu et al., 2014). Soil texture properties like soil clay fraction are important components influencing soil erosion, which affects the distribution and structure of species, as well as ecological processes like water balance and nutrient utilization (Pi et al., 2020). Previous studies indicated that changes in land cover patterns are largely affected by social-economic factors including population, GDP and distances to transportation network and infrastructures (Li et al., 2017). While urbanization brings economic opportunities and improves life quality, it is also associated with adverse impacts on sustainable land management. The more people there are, the larger is the area of built-up land needed for residence and livelihood. The increasing gross products of the secondary and tertiary industries lead to an increase in demand for urban land conversion, resulting in losses of natural ecosystems. In addition, the transportation network plays an important role in shaping the spatial form of the study region, and areas with good accessibility to transportation network faces greater pressure from ecosystem disturbances caused by urban land conversion (Rodrigue et al., 2017). In this study, a total of 10 factors - elevation, slope, precipitation, soil clay fraction, distance to city center, distance to residents, distance to river, distance to road, population and GDP - were considered according to data availability and previous studies on land cover patterns. Suitability maps were generated to define the suitability of each pixel for transition to any land cover types. Each pixel in the suitability maps has a value that ranges from 0 to 255, with 0 representing unsuitable and 255 representing highly suitable area for a particular land cover type (Pontius and Malanson, 2005). Based on the biophysical and socio-economic factors selected, suitability maps for different land cover types combined into an atlas which was used as an input file of the model.

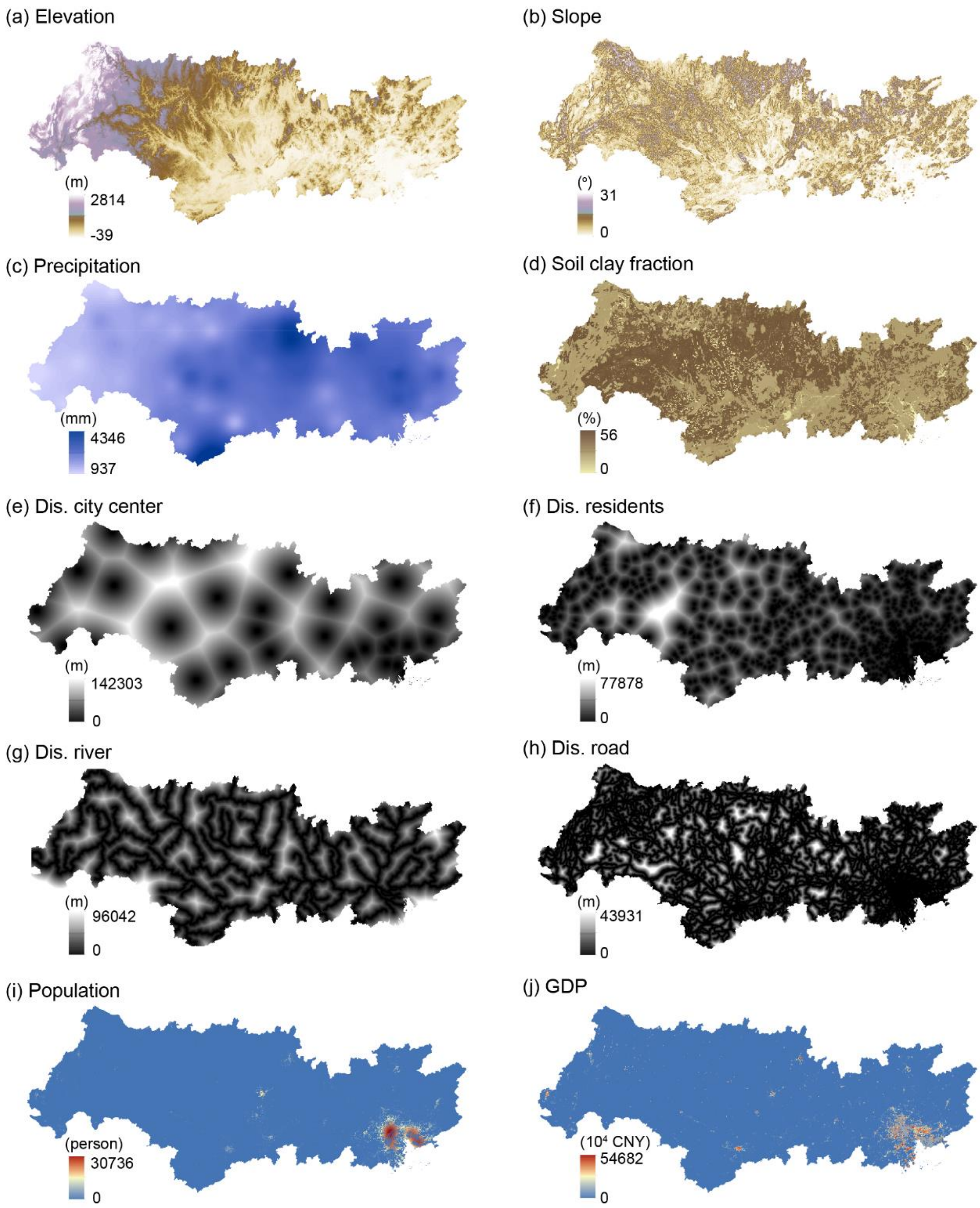

Figure 2.5. Environmental factors used for land cover simulation

The accuracy for the simulated 2015 land cover was evaluated by considering the consistency of land quantity and the similarity of spatial position with those of the interpreted land cover. Here, the consistency of land quantity refers to the consistency of simulated and interpreted areas for different land cover types, while the similarity of spatial position refers to the similarity of simulated and interpreted land cover types at a certain pixel. With a metric of Kappa, comparison in the areas and types between the simulated and interpreted land cover was carried out to evaluate the model performance. The model performance was considered as good, general and poor with the criteria of Kappa > 0.75, 0.40 < Kappa ≤ 0.75 and Kappa ≤ 0.40, respectively.

(2) Assessment of biodiversity conservation

a) Data collection

Assessment of biodiversity conservation was performed by quantifying the importance of threatened species habitats. The main data and sources were listed in Table 2.2.

Table 2.2. Data and sources used for biodiversity assessment

Name	Type	Description	Source
Spatial distribution of rare and endangered species	Vector	Names and spatial distribution of rare and endangered species.	International Union for Conservation of Nature (IUCN). Birdlife International.
Land cover	Raster	Data of interpreted land cover of 1995 and 2015 and simulated land cover of 2035, with a spatial resolution of 1 km.	Resource and Environmental Data Cloud Platform. China Ecosystem Assessments and Ecological Security Database
DEM	Raster	SRTM1 16 digital elevation model with a resolution of 30 m.	NASA Shuttle Radar Topography Database

b) Data analyses

A total of 73 species with threatening categories of critically endangered

(CR), endangered (EN) and vulnerable (VU) were selected to map the important areas for biodiversity conservation. The species list contained 25 amphibians, 37 birds and 11 mammals (Table 2.3).

Table 2.3. Species biodiversity account for Xijiang basin for 2015.

	Species richness	**Threatening status**			**Distribution (km2)**
Taxon		CR	EN	VU	
Amphibians	25	1	10	14	7.9 - 323858
Birds	37	5	12	20	558.2 - 323858
Mammals	11	4	2	5	6.9 - 323858
TOTAL	73	10	24	39	

Note: CR, critical endangered. EN, endangered. VU, vulnerable. The distribution represents the minimum and maximum distribution area of different taxon.

The framework for quantifying the importance of biodiversity conservation was shown in Figure 2.6. To facilitate the calculation of species abundances from a spatial perspective, the spatial distribution of different species was transformed into raster format, and spatial analyses on the species abundances and environmental factors were conducted with the raster calculation tool in ArcGIS. Because the range maps of different species contained unsuitable habitats, overlay analysis was conducted to refine the potential habitats for each species based on specific distribution area, elevational range and land cover type. To categorize the importance of biodiversity conservation, different weights (CR, 3; EN, 2; VU, 1) were assigned to the pixels representing the studied species according to their threatening levels (Xu et al., 2017). Important areas for biodiversity conservation were identified by summing up weighted potential habitats for each taxon (Xu et al., 2017). For each taxon, the summed values were normalized separately and the maximum value of each pixel among the taxon layers was used to indicate the overall importance for biodiversity conservation.

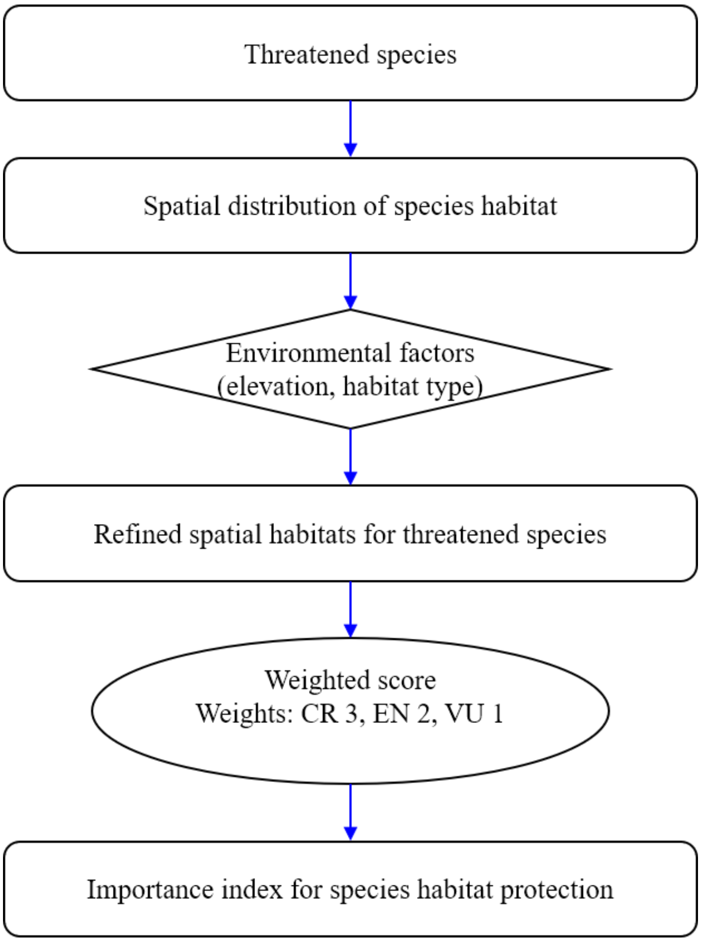

Figure 2.6. Framework for the quantification of the overall importance of biodiversity conservation.

(3) Quantification of the biophysical supply of ecosystem services

The type and the biophysical supply of ecosystem services have significant impacts on the calculation of ecological benefits, thus affecting eco-compensation standards. On the one hand, river serves as the basis for the division of watersheds and plays an important role in linking the upstream and downstream regions, as well as different geological units of a watershed. On the other hand, the water quality and quantity and the hydrological characteristics are of great importance to the construction and maintenance of ecological security and contribute to the formulation of eco-compensation in a watershed. Therefore, ecosystem services in this study were selected from the perspectives of hydrology and water quality and quantity, and by considering the sustainable development planning of the watershed. Finally, the biophysical supply of six ecosystem services, including water supply, water retention, flood mitigation, water purification, soil retention and carbon sequestration, were quantified. Data sources and assessment models for different ecosystem services were listed in Table 2.4.

Table 2.4. Data and sources used for different ecosystem service assessment models

Data	Type	Description	Source	Model	Ecosystem service
Land resources					
Land cover	Raster	Interpreted land cover data of 1995 and 2015 and simulated land cover data of 2035, with a spatial resolution of 1 km.	Resource and Environmental Data Cloud Platform. China Ecosystem Assessments and Ecological Security	Empirical model	Water Retention, Flood mitigation
			Database	InVEST	Water Yield, Water Purification, Soil Retention, Carbon Sequestration
				SWAT	Water Yield
Meteorology					
Precipitation	Raster	Annual average data of 1980 – 2010, 2015 – 2018 and 2026 – 2045, with a spatial resolution of 1 km, were used for historical characteristic simulation, current analysis and future scenario projection, respectively.	Global Precipitation Climatology Project Database V2 (1980 - 2010).	Empirical model	Water Retention
			National Meteorological Information Center (2015 - 2018). ESGF-CoG	InVEST	Water Yield, Water Purification
			WorldClim Database (2026 - 2045)	SWAT	Water Yield
Rainfall events	ACSII	Rainfall depth greater than 0.1 mm	Guangxi Meteorological	Empirical	Water Retention

		(http://drought.unl.edu/MonitoringTools/USRainDaysandDryDays.aspx)	Administration. National Meteorological Information Center.	model	
Storm rainfall	Raster	Rainfall depth greater than 30 mm within 12 hours (China Meteorological Administration)	Guangxi Meteorological Administration. National Meteorological Information Center.	Empirical model	Flood mitigation
Reference evapotranspiration	Raster	Annual average evapotranspiration data of 1980 – 2010 was used for historical characteristic simulation. Current analysis and future scenario projection were performed based on the evapotranspiration data calculated from rainfall of 2015 – 2018 and 2026 – 2045, respectively, using the method in a previous literature. The data has a spatial resolution of 1 km.	Global Precipitation Climatology Project Database Version 2 (1980 - 2010) (Valiantzas, 2018)。	Empirical model InVEST	Water Retention Water Yield
Temperature, humidity, wind speed	Vector	Daily data from 2015 to 2018	Guangxi Meteorological Administration. National Meteorological Information Center.	SWAT	Water Yield
Soil					
Soil type	Raster	1 km spatial resolution	HWSD v1.2	SWAT	Water Yield
Available water content	Raster	1 km spatial resolution	HWSD v1.2	InVEST	Water Yield
Physical attributes	mdb	Particle size, bulk density, hydrology group, surface reflectance etc.	HWSD v1.2	SWAT	Water Yield
Rainfall erosivity	Raster	Calculated based on the annual average precipitation data of 1980 – 2010, 2015 – 2018 and 2026 – 2045 using the method in a previous literature. The spatial resolution is 1 km.	(Renard and Freimund, 1994)	InVEST	Soil Retention
Soil erodibility	Raster	Calculated based on the soil texture data in HWSD v1.2 using the	(Williams et al., 1983)	InVEST	Soil Retention

		method in a previous literature. The spatial resolution is 1 km.			
Soil depth	Raster	1 km spatial resolution	HWSD v1.2	InVEST	Water Yield
Carbon density	ACSII		Li Xu, Nianpeng He, Guirui Yu. Datasets of carbon density for China terrestrial ecosystems. 2010.	InVEST	Carbon Sequestration
Topography					
DEM	Raster	SRTM1 16 digits elevation model with a spatial resolution of 30 m.	NASA Shuttle Radar Topography Database	Empirical model	Water Retention
				InVEST	Water Purification, Soil Retention
				SWAT	Water Yield
Hydrology					
River flow	Vector	Daily flow from 2016 to 2018.	Guangxi Water Resources Department	SWAT	Water Yield
Storm runoff	Raster	Calculated based on the annual average data of storm rainfall 1980 – 2010, 2015 – 2018 and 2026 – 2045, with a spatial resolution of 1 km.	(Ouyang et al., 2016)	Empirical model	Flood Mitigation
Reservoir storage	ACSII	Water storage of Large I and Large II reservoirs in Guangxi.	Guangxi Water Resources Department	Empirical model	Flood Mitigation

a) Provisioning service

To evaluate the model applicability, comparison was conducted between the InVEST and SWAT models in estimating water yield. The SWAT model ran with the three major processes, i.e. construction of basic databases, division of hydrological response units and model performance evaluation.

1) Construction of basic databases

Soil database

The soil input file was generated through coordinate conversion and mask extraction based on the HWSD v1.2 database. The spatial patterns of major soil attributes were shown in Figure 2.7. Among the soil attributes, soil names were redefined according to the USDA soil classification standard (USDA, 1999). Soil bulk density and saturated water conductivity were determined based on soil texture and organic matter content using the Soil-Plant-Air-Water tool. Effective filed water holding capacity was obtained by subtracting the wilting amount from the saturated filed water holding capacity (Saxton and Rawls, 2006). Soil erodibility factor (K) was calculated based on soil texture and organic carbon content with the following equation (Williams, 1990):

$$\mathrm{K}=\left(0.2+0.3\exp\left(-\frac{0.025SAN}{100}\right)\right)\left(\frac{SIL}{CLA+SIL}\right)^{0.3}\left(1.0-\frac{0.25C}{C+\exp\left(3.72-0.95C\right)}\right)\left(1.0-\frac{0.7SN}{SN+\exp\left(-5.51+22.9SN\right)}\right)$$

Where, K is soil erodibility factor. SAN, SIL and CLA are the contents of sand, silt and clay (%). SN = 1 – SAN/100. C is organic carbon (%).

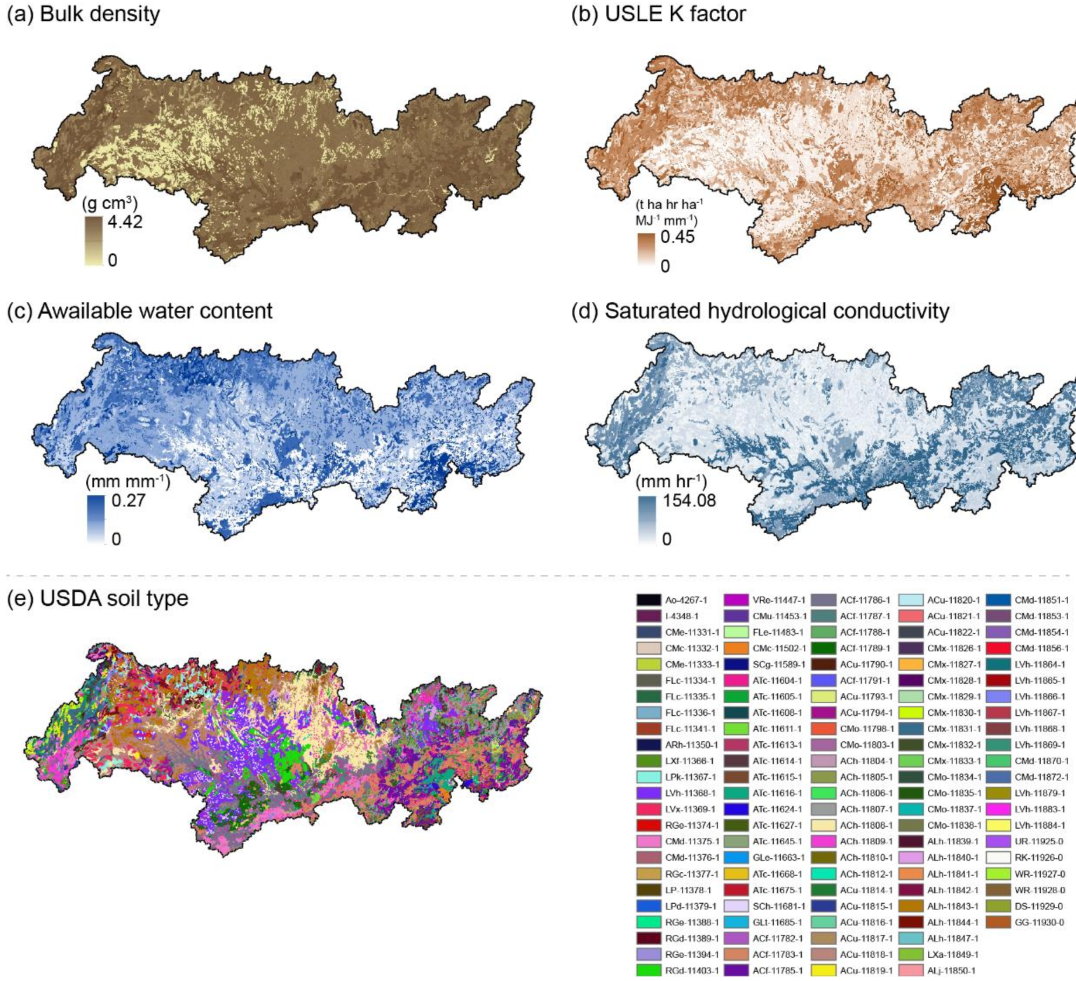

Figure 2.7. Spatial patterns of soil major physical attributes

Climate database

Daily data of precipitation, humidity and wind speed, from 2015 to 2018, were used for the SWAT model. For the projection of future climate conditions, the annual average data relating to the variables mentioned above from 2026 to 2045 were used. With the SWAT Weather tool, climate input files were generated for different meteorological stations (Figure 2.8).

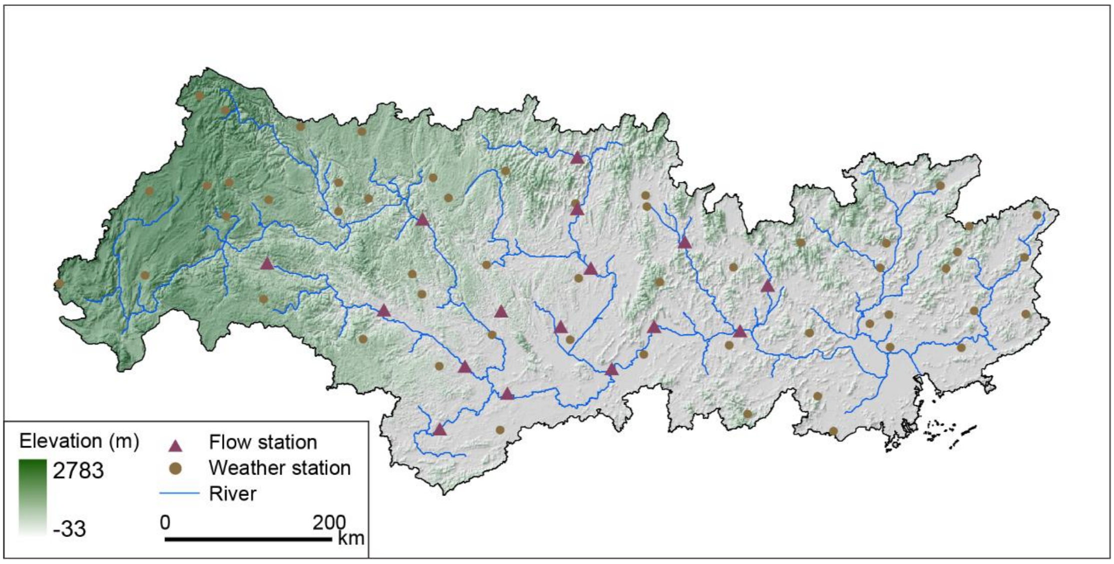

Figure 2.8. Spatial distribution of hydrological and meteorological stations

2) Division of hydrological response units

The ArcSWAT platform was used to reclassify the land cover, land slope and soil types to form corresponding input files that could be recognized by the model. According to the description on the characteristics of SWAT land types (Liu et al., 2011), the land covers were reclassified into six types, i.e. FRSD, RNGB, RICE, WATR, URHD and BARR, which stand for forest land, grassland, agricultural land, built-up land and bare land, respectively. Based on the slope classification standard of GTOPO30 (Chesworth et al., 2008), and the topographical characteristics of the watershed, the land slope was reclassified into four grades, i.e. 0 – 15%, 16 – 30%, 30 – 45% and > 45%. The reclassified soil type file generated in the basic soil database was directly used as the mode input. With the thresholds of 5%, 5% and 20% for the reclassified data of land cover, soil type and land slope, respectively (Duan et al., 2019), overlay analysis was performed to form hydrological response units.

3) Model performance evaluation

Calibration and validation

Sensitivity analysis was performed using the method of global sensitivity analysis (Koo et al., 2020). Parameters were selected according to previous literatures (Abbaspour et al., 2015; Kumar et al., 2017; Ayivi and Jha, 2018), and the sensitivity of the parameters were shown in Figure 2.9. Modelling analyses were carried out with data of 2016 for system warmup, 2017 for calibration and 2018 for validation. The SUFI-2 algorithm was used to estimate the best fit for each parameter (Table 2.5)

Table 2.5. Sensitivity and operation for SWAT model parameters

Parameter	Fitted	Unit	Operation	Sensitivity order	Description
CN2.mgt	-0.707		Weighted	8	Soil permeability
GWQMN.gw	8.542	mm	Add	6	Threshold water depth for return flow
GW_REVAP.gw	0.145		Replace	5	Groundwater revap coefficient
REVAPMN.gw	2.372	mm	Replace	9	Threshold water depth for percolation
ALPHA_BF.gw	0.798	1/d	Replace	2	Baseflow alpha factor
ESCO.hru	0.978		Replace	7	Evaporation compensation factor
SOL_AWC.sol	0.022	mm/mm	Weighted	3	Plant available water content
SOL_K.sol	-0.186	mm/h	Weighted	4	Saturated hydro-conductivity
CH_K2.rte	18.689	mm/h	Replace	1	Effective hydro-conductivity

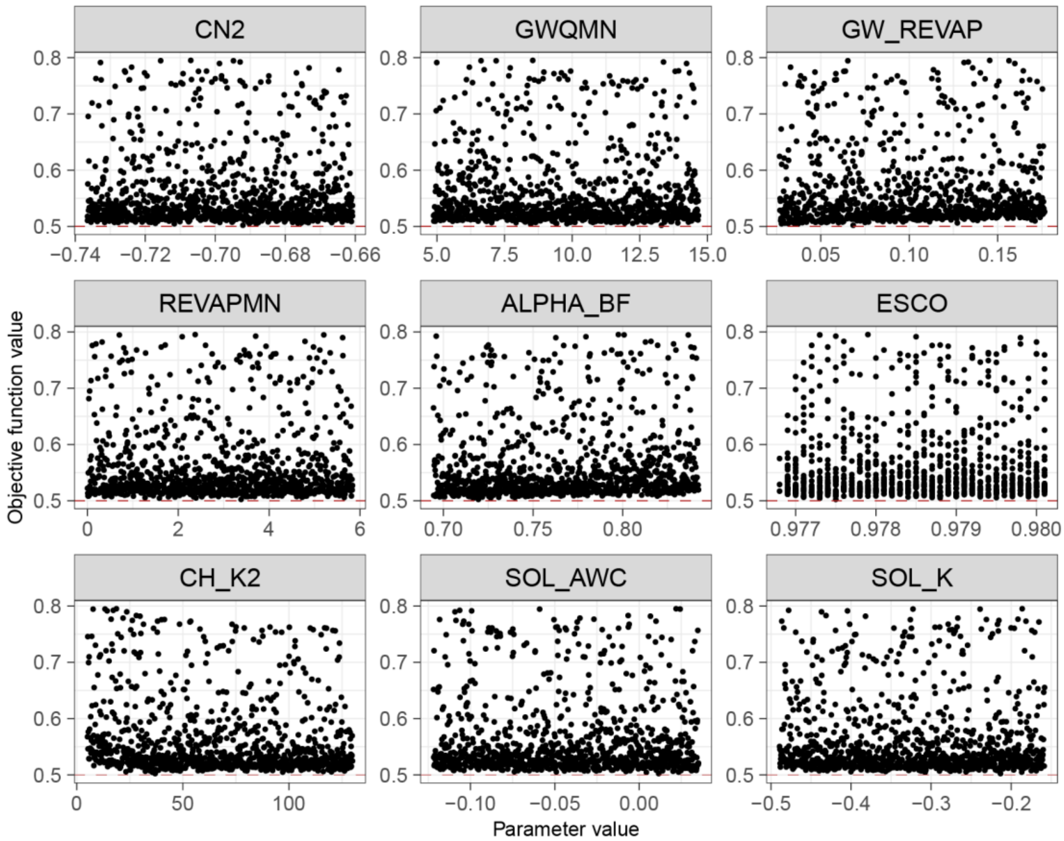

Figure 2.9. Changes of objective function values for different parameters

Accuracy evaluation

To evaluate the model accuracy, determination coefficient (R^2) and Nash efficiency coefficient (NS) were used to analyze the covariation between simulated and observed values, and the overall model efficiency, respectively. The R^2 and NS values were determined according to the equations below:

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}(Q_{o,i} - Q_{avg})(Q_{p,i} - Q_{pavg})}{\left[\sum_{i=1}^{n}(Q_{o,i} - Q_{avg})^2 \sum_{i=1}^{n}(Q_{p,i} - Q_{pavg})^2\right]^{1/2}} \right\}^2$$

$$\mathrm{NS} = 1 - \frac{\sum_{i=1}^{n}(Q_{o,i} - Q_{p,i})^2}{\sum_{i=1}^{n}(Q_{o,i} - Q_{avg})^2}$$

Where, $Q_{o,i}$ is the observed flow (m^3 s^{-1}). $Q_{p,i}$ is the simulated flow (m^3 s^{-1}). Q_{avg} is the average of observed flow (m^3 s^{-1}). Q_{pavg} is the average of simulated flow (m^3 s^{-1}). The model performance was categorized as low consistent, medium consistent and highly consistent with the criteria of $R^2 \leq 0.50$, $0.50 < R^2 \leq 0.70$ and $0.70 < R^2 \leq 1.00$, respectively; and poor, general and good with the criteria of $NS \leq 0.50$, $0.50 < NS \leq 0.65$ and $0.65 < NS \leq 1.00$, respectively.

b) Regulating service

The models and parameters used for quantifying the biophysical supply of ecosystem services were listed in Table 2.6.

Table 2.6. Models and parameters for ecosystem service assessments

Ecosystem service	**Description**	**Model**	**Parameter**
Provisioning service			
Water yield	The quantity of fresh water that an ecosystem contributes to the welfare of society.	$WY_i = \left(1 - \frac{AET_i}{P_i}\right) \times P_i \times 10^{-3} \times A_i$	WY_i is the volume of water yield for ecosystem i (m^3). AET_i is the actual evapotranspiration of ecosystem i (mm). P_i is the annual average precipitation of ecosystem i (mm). A_i is area of ecosystem i (m^2).
		$WY_{tn} = WY_n + \left(\sum_{n=1}^{t}(P_n - R_n - AET_n - W_n - T_n)\right) \times 10^{-3} \times A$	WY_{tn} is the water yield at day n (m^3). WY_n is the initial water volume at day n (m^3). t is time (day). P_n is the rainfall depth at day n (mm). R_n is the surface runoff at day n (mm). AET_n is the actual evapotranspiration at day n (mm). W_n is the percolation and lateral flow at day n (mm). T_n is the groundwater recharge entering aquifers at day n (mm). A is the unit area (m^2).
Regulating service			
Water retention	The ability of ecosystems to intercept or store water resources from precipitation.	$WR_i = (P_i - R_i - AET_i) \times 10^{-3} \times A_i$	WR_i is the biophysical supply of water retention by ecosystem i (m^3). P_i is the rainfall depth of ecosystem i (mm). R_i is the storm runoff of ecosystem i (mm). AET_i is the actual evapotranspiration of ecosystem i (mm). A_i is the area of ecosystem i (m^2).
Flood mitigation	The ability of ecosystems to	$\mathrm{FM} = FM_{vegetation} + FM_{lakes} + FM_{reservoir}$	FM is the biophysical supply of flood mitigation (m^3).

	reduce flood risk by reducing flood peaks.		$FM_{vegetation}$ is the flood mitigation capacity of natural habitats (m^3). FM_{lakes} is the flood mitigation capacity of lakes (m^3). $FM_{reservoir}$ is the flood mitigation capacity of reservoirs (m^3),
	a) Flood mitigation capacity of natural habitats	$FM_{vegetation} = \sum_{i=1}^{n}(P_i - R_i) \times A_i$	$FM_{vegetation}$ is the flood mitigation of natural habitats (m^3). $P_{i,}$ is the rainfall depth of ecosystem i (mm). $R_{i,}$ is the storm runoff of ecosystem i (mm). A_i is the area of ecosystem i (m^2). n is the number of ecosystems.
	b) Flood mitigation capacity of lakes	$FM_{lakes} = e^{4.904} \times A^{0.927} \times 0.36$	FM_{lakes} is the flood mitigation capacity of lakes (m^3). A is the area of lakes (m^2).
	c) Flood mitigation capacity o reservoir	$FM_{reservoir} = C_t \times 0.35$	$FM_{reservoir}$ is the flood mitigation of reservoir (m^3). C_t is the total capacity of reservoir (m^3).
Water purification	The capacity of ecosystems to reduces the pollutants entering receiving water bodies.	$WP_i = Load_i \times (1 - NDR_i)$	WP_i is the amount of pollutants reduced by ecosystem i (kg). $Load_i$ is pollutant loading (kg). NDR_i is delivery ratio of pollutant.
Soil retention	The capacity of ecosystems to reduce the erosion energy of rainfall and soil erosion.	$SR_i = R_i \times K_i \times L_i \times S_i \times (1 - C)$	SR_i is the amount of soil retained by ecosystem i (t). R is rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}). K is soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}). L is slope length factor (unitless). S is topographic gradient factor (unitless). C is a crop-management factor (unitless).
Carbon sequestration	The capacity of ecosystems to alleviate the increased CO_2 concentration and greenhouse effect.	$ACS_i = (BCS_{i,t2} - BCS_{i,t1})/(t_2 - t_1)$ $BCS_i = BCD_i \times A_i$	ACS_i is the carbon sequestration of ecosystem i (t yr^{-1}). $BCS_{i,\ t1}$ and $BCS_{i,\ t2}$ are the carbon storage in year t1 and year t2, respectively (t). BCS_i is the carbon storage of ecosystem i (t). BCD_i is the carbon density of ecosystem i (t m^{-2}). A_i is the area of ecosystem i (m^2).

Water retention

Water retention refers to the water retained in ecosystems within a certain period (one year for this study). The assessment model based on water balance processes was revised from the InVEST model (Kareiva et al., 2011; Sharp et al., 2016), where main parameters include precipitation, storm runoff, evapotranspiration and the area of ecosystems as defined by land cover. To eliminate the effects of interannual fluctuations during a certain period, average annual precipitation was used. The storm rainfall was defined as water depth greater than 30 mm within 12 hours according to the China Meteorological Administration.

Flood mitigation

Flood mitigation refers to the volume of natural habitats, lakes and reservoirs that regulate stream flows and mitigate flooding by reducing flood peaks and storing water temporarily. For natural habitats, the capacity of natural habitats in reducing flood risk was assessed based on data including precipitation, storm runoff and the area of the ecosystem. For lakes, an empirical model which considers the hydrological conditions was used (Ouyang et al., 2016). The model was constructed based on the relationship between available storage capacity and lake area (Wang and Dou, 1998; Rao et al., 2014c), since the data on lake area is closely related to water regulating capacity and is much easier to acquire. For reservoirs, an empirical model based on the relationship between flood control storage capacity and total storage capacity was used (Rao et al., 2014b).

Water purification

Water purification refers to the total amount of pollutants (total nitrogen and total phosphorus in this study) that were prevented from entering streams. The assessment model was revised from the InVEST model which calculates a nutrient delivery ratio (NDR), which represents the ability of downstream pixels to transport nutrient without retention (Sharp et al., 2016). Briefly, the topography features (e.g., land slope) are used to estimate the hydrological connectivity (IC), which represents how likely nutrient on a pixel is likely to reach the stream. Meanwhile, the proportion of nutrient that is not retained by downstream pixels (NDR_0) is calculated based on the maximum retention efficiency of different lands between a pixel and the stream. Then, the surface NDR for each pixel is calculated as an exponential function of the IC and NDR_0 parameters.

Soil retention

Soil retention refers to the soil retained by the ecosystems within a certain period (one year for this study). Soil retention was calculated using the Universal Soil Loss Equation (USLE) and the InVEST model, which considers the effects of rainfall erosivity, soil erodibility, slope length and gradient and vegetation cover on soil erosion processes. Rainfall erosivity reflects the potential for raindrops and runoff to induce soil erosion and was calculated with a modified Fournier Model (Renard and Freimund, 1994). Soil erodibility reflects the sensitivity of soil particles to erosive forces and was calculated with an Erosion/Productivity Impactor Calculator using the soil clay, silt, sand and organic carbon content data (Williams et al., 1983; Zhang et al., 2008). The topographic factors including land slope and gradient reflects the effects of terrain on soil erosion and were calculated using different slope segments (Liu et al., 1994; Rao et al., 2014a). The vegetation cover factor describes the effect of vegetation on soil erosion through its biophysical characteristics like community structure and cover. The vegetation cover factor was acquired from previous literatures, where different ecosystem types (Liu et al., 1999; Wei et al., 2002; Rao et al., 2014a).

Carbon sequestration

Carbon sequestration refers to carbon sequestered by terrestrial ecosystems and thereby slowing down the current rate of increase of atmospheric carbon dioxide (Piao et al., 2009), while carbon storage refers to the carbon remaining in terrestrial ecosystems. In this study, with a Lookup Table approach (Xu et al., 2018), the dynamics of carbon storage in the aboveground biomass, belowground biomass and surface soil (0 – 20 cm) were examined for the forest, grassland, cropland and wetland ecosystems, and the average annual carbon sequestration from 1995 to 2015 was estimated for the terrestrial ecosystems.

(4) Assessment of ecosystem service value

Based on the biophysical supply of ecosystem services, valuation of the ecosystem services was performed using the method reported by Ouyang et al. (2016). The models and parameters were listed in Table 2.7.

Table 2.7. Models and parameters for the valuation of ecosystem services

Ecosystem service	**Description**	**Model**	**Parameter**	**Sources**
Water yield	Valuation based on the construction cost of reservoir.	$V_{wp} = Q_{wp} \times c$	V_{wp} is the value of annual water yield service (CNY yr^{-1}). Q_{wp} is the volume of annual water yield (m^3 yr^{-1}). c is the cost of unit storage capacity of reservoir (CNY m^{-3}).	1) Q_{wr} is estimated by ecosystem service model. 2) c is from the datasets of unit storage capacity (2015) calculated by the Forest Bureau.
Water retention	Valuation based on the construction cost of reservoir.	$V_{wr} = Q_{wr} \times c$	V_{wr} is the value of annual water retention service (CNY yr^{-1}). Q_{wr} is the amount of water retained annually (m^3 yr^{-1}). c is the cost of unit capacity of reservoir (CNY m^{-3}).	1) Q_{wr} is estimated by ecosystem service model. 2) c is from the datasets of unit storage capacity (2015) calculated by the Forest Bureau.
Flood mitigation	Valuation based on the construction cost of reservoir.	$V_{fm} = Q_{fm} \times c$	V_{fm} is the value of annual flood mitigation service (CNY yr^{-1}). Q_{fm} is the volume of water stored by lakes, reservoirs and swamp annually (m^3 yr^{-1}). c is the cost of unit capacity of reservoir (CNY m^{-3}).	1) Q_{fm} is estimated by ecosystem service model. 2) c is from the datasets of unit storage capacity (2015) calculated by the Forest Bureau.

Water purification	Valuation based on the cost of industrial treatment of water pollutants.	$V_{npc} = \sum_{i=1}^{n} Q_{npc} \times c_i$	V_{npc} is the value of annual water purification service (CNY yr^{-1}). Q_{npc} is the amount of pollutants reduced by ecosystems annually (t yr^{-1}). c_i is the treatment cost of pollutant i (CNY t^{-1}).	1) Q_{npc} is estimated by ecosystem service model. 2) c_i is from the datasets of treatment cost of total nitrogen and total phosphorus in the Law of Environmental Protection Tax 2018.
Soil retention	Valuation based on the reduction of sediment deposition and non-point pollution.	$V_{sr} = V_{sd} + V_{pd}$	V_{sr} is the value of soil retention. V_{sd} is the value of reducing sediment deposition. V_{pd} is the value of reducing non-point pollutants.	
		$V_{sd} = \lambda \times \frac{Q_{sr}}{\rho} \times c$	Q_{sr} is the amount of soil retained by ecosystems annually (t yr^{-1}). c is the dredging cost of reservoir (CNY m^{-3}). λ is sediment deposition coefficient. ρ is soil bulk density (g m^{-3}). C is the concentration of total nitrogen and total phosphorus in soils (%).	1) Q_{sr} is estimated by ecosystem service model. 2) c is from the datasets of earthwork cost per unit area excavated for soil types I and II in "Water Conservancy Construction Project Budget Quota, Ministry of Water Resources of the People's Republic of China" (2002 I) 3) ρ and C_i are from China Soil Science Database
		$V_{pd} = \sum_{i=1}^{n} Q_{sr} \times c_i \times p_i$	Q_{sr} is the amount of soil retained by ecosystems (t yr^{-1}). c is the dredging cost of reservoir (CNY m^{-3}). P_i 为 is the degradation cost of environmental engineering (CNY t^{-1}).	1) Q_{sr} is estimated by ecosystem service model. 2) c is from the datasets of earthwork cost per unit area excavated for soil types I and II in "Water Conservancy Construction Project Budget Quota, Ministry of Water Resources of the People's Republic of China" (2002 I) 3) P_i is from the datasets of "Notice on

				adjustment of standards for collection of sewage charges" and "Collection standards and calculation method for sewage charges" released by the National Development and Reform Commission.
Carbon sequestration	Valuation based on afforestation cost.	$V_{cs} = Q_{cs} \times CM$	V_{cs} is the value of annual carbon sequestration (CNY yr^{-1}). Q_{cs} is the amount of carbon sequestrated by ecosystems annually (t yr^{-1}). *CM* is the cost of carbon sequestration by artificial forestation (CNY t^{-1}).	1) Q_{cs} is estimated by ecosystem service model. 2) CM is from previous literature (Lu et al., 2018)。

(5) Calculation of ecological compensation standards

a) Determination of the upper and lower limits of ecological compensation

A cost-benefit analysis method was used to calculate the ecological compensation standards for the Xijiang basin. The protection of natural ecosystems is one of the main goals of ecological compensation and would bring about certain economic loss. As an important component for calculating the lower limits of ecological compensation standards, the ecological protection costs were calculated using data relating to the prevention and control of water pollution, the comprehensive treatment of water and soil conservation, and forestry construction. In the production and life of society, human make the biological system in nature produce beneficial influence on the production and living conditions and environments according to the law of ecological balance. This influence is related to the fundamental and long-term interests of human survival and social development. Ecological balance and the benign and efficient circulation of ecosystems are the foundation of ecological benefits, which are defined as the contribution of ecosystems to social well-being (EPA, 2006). In a broad sense, ecological benefit has great similarity with ecosystem service which reflects the benefits that humans derive from ecosystems. As the basis of ecological compensation, the value of the upstream ecosystem services was determined to estimate the ecological benefits that should be shared by the whole basin. The conceptual diagram of calculating ecological compensation standard was illustrated in Figure 2.10.

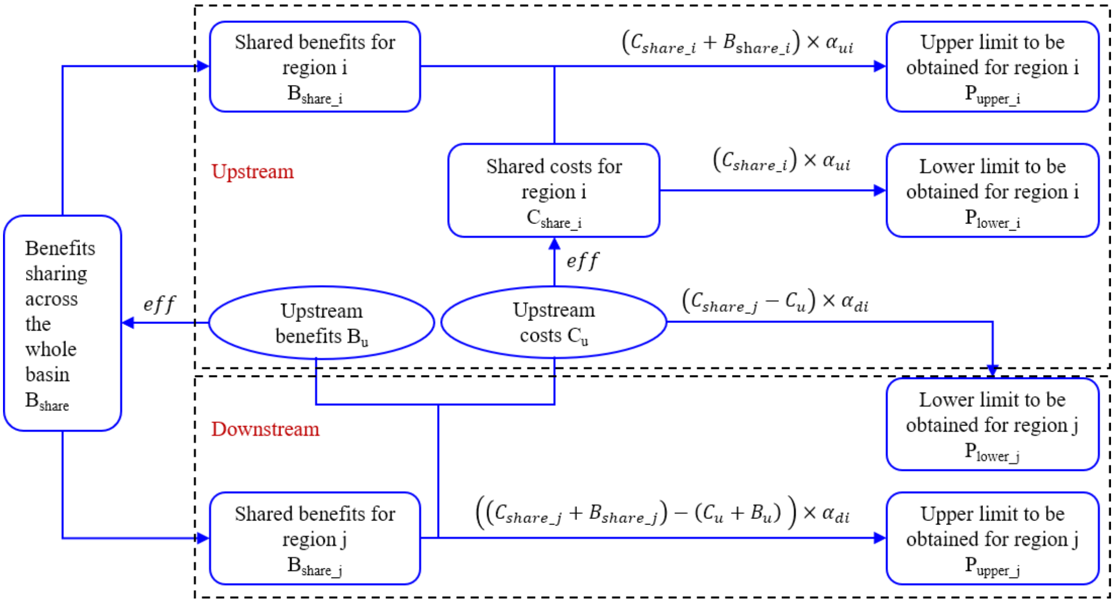

Figure 2.10. Technique rote for calculating eco-compensation standards. The *eff* is sharing coefficient for the upstream benefits or costs among different regions of the whole basin. The α_{ui} and α_{di} are the demand coefficients for ecological compensation for the upstream and downstream regions, respectively.

The downstream region enjoys the ecosystem services provided by the upstream region and is the beneficiary of ecological protection. For the upstream region, ecological protection practices including the protection and restoration of ecological environments, the reduction and comprehensive control and protection of water pollution and soil erosion, improve the quality of the upstream ecological environments and promote the adjustment of local industrial structure. Therefore, the upstream region is also the beneficiary of ecological protection. Considering the principle of fairness between the upstream and downstream regions, the ecological benefits and the costs during ecological protection practices of the upstream region should be shared by the upstream and downstream regions. In this study, the proportional value of ecosystem services accounted by different regions in relation to those by the whole basin was calculated as the sharing coefficients of ecological benefits. In addition, the level of economic development affects the payment capacity of a region, thus affecting the implementation of ecological compensation policy. To make ecological compensation policy more practical, a demand intensity coefficient was determined as a correction factor for the compensation thresholds. While the sharing coefficient reflects the difference in ecological compensation obtained by different regions, the demand coefficient reflects the urgency of obtaining ecological compensation and ecological protection by different regions (Gao et al., 2019). The sharing coefficient and demand coefficient were calculated as below (Tian et al., 2019).

$$eff_i = \frac{ESV_i}{\sum_{i=1}^{n} ESV_i}$$

$$\alpha_i = \frac{2\arctan\,(ESV_i/G_i)}{\pi}$$

Where, eff_i is the sharing coefficient for region i. α_i is the demand coefficient for region i. ESV_i is the total value of ecosystem services for region i (10 000 CNY). G_i is the GDP for region i (10 000 CNY). The arc-tangent function was used to avoid concentration of ecological compensation in an individual administrative unit.

For upstream region i, the upper (EC_{upper_ui}) and lower (EC_{lower_ui}) limits of ecological compensation that region i obtained were:

$$EC_{upper\_ui} = (C_u + B_u) \times eff_{ui} \times \alpha_{ui}$$
$$EC_{lower\_ui} = C_u \times eff_{ui} \times \alpha_{ui}$$

Where, B_u and C_u are the upstream benefits and costs, respectively (10 000 CNY). The B_u is calculated as the sum of upstream ecosystem service value (10 000 CNY). The C_u is calculated as the sum of upstream ecological protection and restoration cost (10 000 CNY). The eff_{ui} and α_{ui} are the sharing coefficient and demand coefficient, respectively.

For downstream region i, the upper (EC_{upper_di}) and lower (EC_{lower_di}) limits of eco-compensation that region i obtained were:

$$EC_{upper\_di} = (C_u + B_u) \times (eff_{di} - 1) \times \alpha_{di}$$
$$EC_{lower\_di} = C_u \times (eff_{di} - 1) \times \alpha_{di}$$

Where, B_u and C_u are the upstream benefits and costs, respectively (10 000 CNY). eff_{di} and α_{di} are the sharing coefficient and demand coefficient, respectively.

b) Determination of ecological compensation priority

Considering the varying roles in ecological protection that different regions play and the uneven levels of economic development among different regions, the urgency of the need for compensation funds is different among different regions. To alleviate the emergency of economic development and to reduce the risk of rapid decline in ecosystem service value in relatively underdeveloped regions, priority should be given to a region with a relatively high demand of ecological compensation. The priority for the implementation of ecological compensation policy was calculated based on the method of density distribution, which has been used for a wide range of assessment studies and could reflect the spatial heterogeneity in target variables (the α metric in this study) among different regions. The priority was categorized as general (lower 25%), medium (central 50%) and high (upper 25%).

3 Results and discussion

3.1 Conversion characteristics of land cover patterns

3.1.1 Land cover types and historical conversion characteristics

The areas of forest, wetland, cropland and built-up land in the Xijiang river basin appeared to increase during 1995 – 2015. In 2015, the four land cover types accounted for 3.1 - 54.9% of the total area of the basin in 2015 (Table 3.1), and increased by 1.7 – 77.6% as compared to those in 1995, with both the proportional area and the most increase found for the built-up land. The increase of forest land mainly routed from the conversion of cropland and forest land (Table 3.2), which accounted for approximately half of the new areas, respectively. The increase of cropland mainly routed from the conversion of forest land, while the conversion of grassland accounting for almost 20% of the increased cropland areas was also an important contributor to the increase of cropland areas. The conversion of cropland accounted for 42.7% and 55.7% of the increased wetland and forest land areas, respectively, which was the major source of the latter land cover types. In addition, the conversion of forest land accounting for approximately one third of the total increased area was also an important contributor to the increase of built-up land. In 2015, the grassland accounted for less than 10% of the total area of the basin, which was decreased by 43.7% as compared to that in 1995. During 1995 – 2015, most of the grassland were converted into forest, which accounted for over half of the loss of grassland. In addition, approximately one third of the grassland were converted into cropland, which was also an important contributor to the loss of grassland.

Table 3.1. Ecosystem extent account for the Xijiang basin during 1995 – 2015 (Unit, km^2)

		Ecosystem types					
		Forest	Grassland	Cropland	Wetland	Built-up land	Bare land
		T1.1	T2.1	T3.1	T4.1	T5.1	T6.1
Opening extent		167380	48628	90219	8354	9143	134
	Additions to extent	69299	19502	54108	7548	12866	1340
	Expansions	69299	19502	54108	7548	12866	1340
	Reductions in extent	58727	40794	53459	5784	5772	127
	Regressions	58727	40794	53459	5784	5772	127
	Net change in extent	10572	-21292	649	1764	7094	1213
Closing extent		177952	27336	90868	10118	16237	1347

Note: The opening extent refers to the system extent in 1995, while the closing extent refers to the ecosystem extent in 2015.

Table 3.2. Ecosystem extent change matrix during 1995 – 2015 for the Xijiang basin (Unit, km^2)

			Opening Extent						
			Forest	Grassland	Cropland	Wetland	Built-up land	Bareland	**Closing**
			T1.1	T2.1	T3.1	T4.1	T5.1	T6.1	
Closing Extent	Forest	T1.1	108653	28659	37150	1912	1521	57	**177952**
	Grassland	T2.1	13227	7834	6050	87	123	15	**27336**
	Cropland	T3.1	37763	10304	36760	2553	3449	39	**90868**
	Wetland	T4.1	2924	715	3236	2570	666	7	**10118**
	Built-up land	T5.1	3829	995	6820	1213	3371	9	**16237**
	Bare land	T6.1	984	121	203	19	13	7	**1347**
	Opening		**167380**	**48628**	**90219**	**8354**	**9143**	**134**	**323858**

Note: The opening extent refers to the system extent in 1995, while the closing extent refers to the ecosystem extent in 2015.

3.1.2 Environmental impacts on land cover distribution

The transition in land cover is not a stationary pattern, nor is it deterministic (Lambin and Meyfroidt, 2010). Changes in the spatial distribution of land covers are driven by a wide range of environmental factors relating to the local biophysical and social-economic characteristics. Different environmental factors exert varying impacts on one land cover type, while changes in the spatial distribution of one land cover type responses nonlinearly to varying environmental factors (Pontius and Parmentier, 2014). To quantify the impacts of biophysical and social-economic factors and evaluate the difference in the impacts of these factors on the land cover distribution, a logistic regression model, which has been widely used as an important tool in previous literatures (Feng et al., 2016; Osman et al., 2016; Islam et al., 2018), was used to evaluate the impacts of biophysical and social-economic factors on the spatial distribution of different land cover types. The overall model performance was evaluated with a metric of AUC which stands for the area under the relative-operating-characteristic (ROC) curve. The AUC varies between 0 – 1 and the higher the AUC is, the better the model fitting performance is. As a result, The model fitted well as indicated by high AUC values of 0.778 – 0.980 for different land cover types (Figure 3.1). The fitness was higher for forest and grassland which had relatively higher AUC values than 0.9, but lower for built-up land and bare land which had relatively lower AUC values.

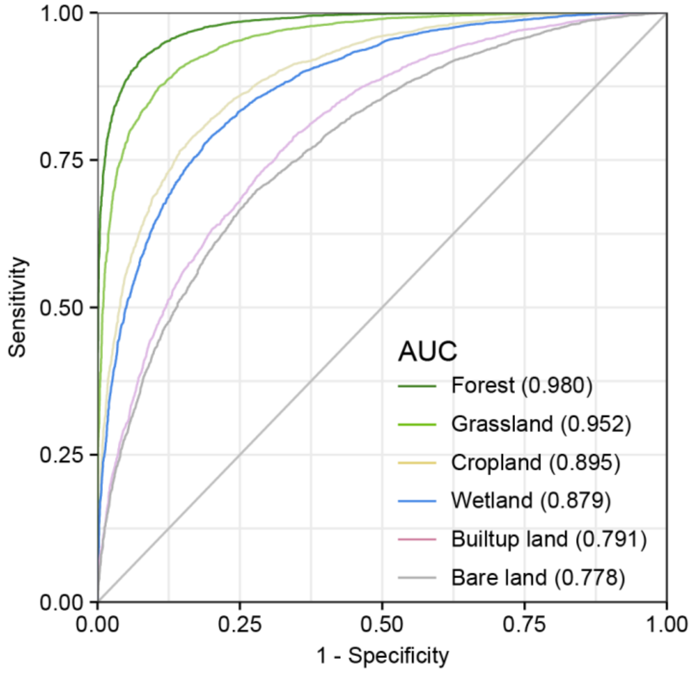

Figure 3.1. Relative operating characteristic **(**ROC) curves of logistic regression models for different land cover types

Changes in the biophysical and social-economic conditions had significant effects on the distribution of different land cover types. Land slope was found to be with the largest contribution to the spatial distribution of forest, grassland and cropland, while the distance to rivers and population density were found to be with the largest contribution to the spatial distribution of wetland and built-up land, respectively. Among the environmental factors investigated, the distribution of forest land was positively affected by elevation, slope, rainfall, soil texture and the distance to roads, but negatively affected by the distance to rivers and population density (Table 3.3). The grassland mainly distributed in areas with high elevation, low slope, low population density and transportation density.

The distribution of cropland was positively affected by the distance to roads, but negatively affected by elevation, slope, the distance to rivers and population density. In addition, the cropland distributed in areas where the density of population and transportation facilities were low. The major contribution of the distance to rivers factor to the distribution of wetlands could be related to the hydrological characteristics of wetlands. Moreover, the wetlands distributed in areas with low elevation and slope and low population density. The built-up land was concentrated in flat areas with low elevation and slope, but high population density, and distributed in areas close to city centers and urban main roads, but far away from rivers. The areas where the bare land distributed were characterized by low elevation and slope, long distance to rivers, but short distance to roads and low population density.

Table 3.3. Coefficients of logistic regression models for different land cover types

	Ecosystem types					
Environmental factor	Forest	Grassland	Cropland	Wetland	Built-up land	Bare land
Biophysics						
Elevation	0.141	0.112	-0.136	-0.231	-0.130	-0.102
Slope	0.427	-0.236	-0.470	-0.240	-0.141	-0.122
Rainfall	0.230					
Soil clay fraction	0.147					
Spatial accessibility						
Distance to city center			0.252	0.210	-0.119	
Distance to residents						
Distance to rivers	-0.204		-0.373	-0.483	0.104	0.272
Distance to roads	0.215	0.230	0.274	0.210	-0.301	-0.114
Socio-economic condition						
Population density	-0.179	-0.202	-0.182	-0.202	0.340	-0.107
GDP						
Constant	0.950	0.785	0.760	0.887	0.822	0.816

Note: Empty cells indicate no significant impacts were found at a significance level of 0.05.

3.1.3 Characteristics of future land cover patterns

(1) Model simulation and evaluation

Based on the land cover data of 1995 and 2005 (Figure 3.2), the spatial distribution of land cover in 2015 was simulated by assigning a contiguity filter of 5 × 5, an error ratio of 0.1, which are the main parameters in the model structure.

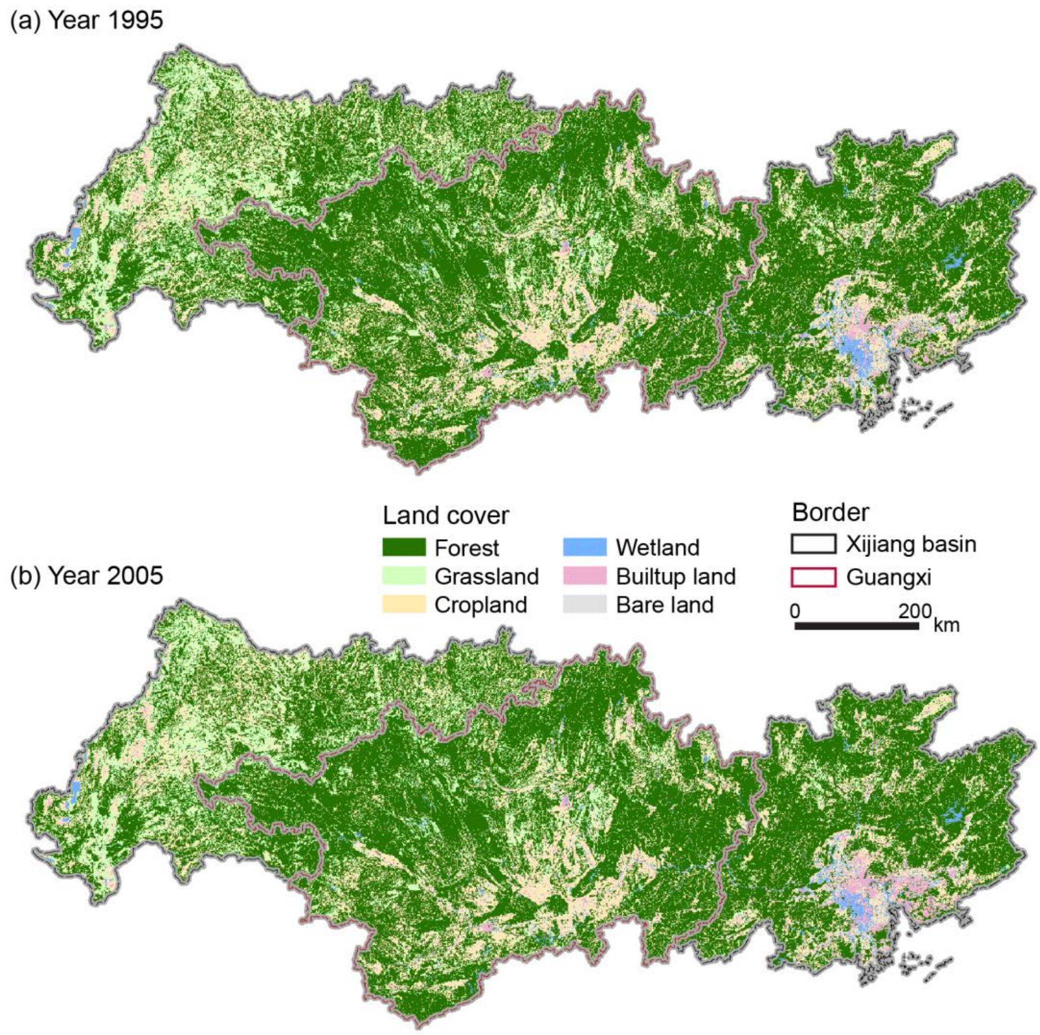

Figure 3.2. Spatial distribution of the land cover in 1995 and 2005.

The filter, which is integral to the action of CA component, is used to generate a spatial explicit contiguity – weighting factor to change the state of cells based on its neighbors, while the proportional error ratio indicates the bias of predicted results with the reference cells (Eastman, 2012). In this study, the parameter values were retrieved from previous literatures (Fu et al., 2018; Mondal et al., 2020). The simulated and interpreted land cover patterns in 2015 were shown in Figure 3.3.

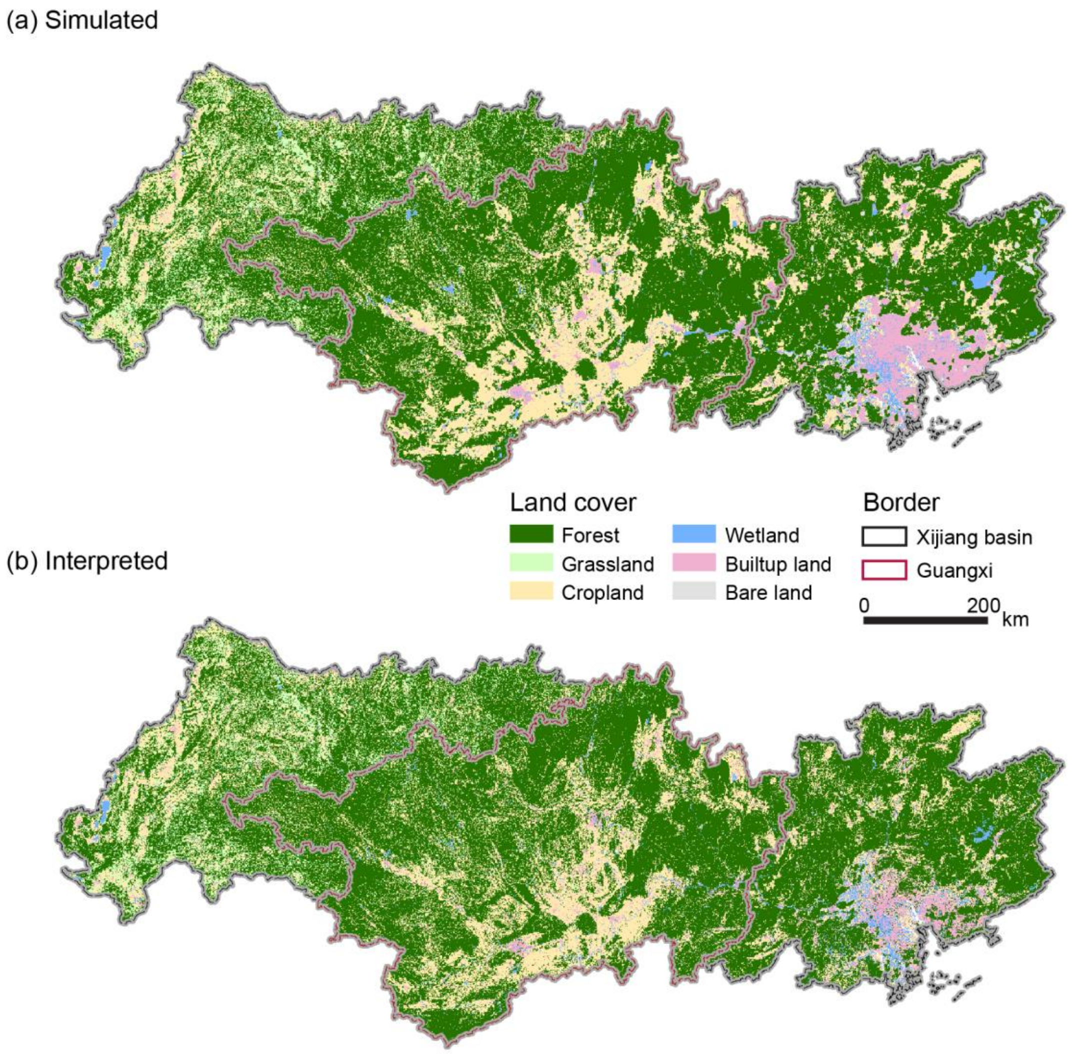

Figure 3.3. Spatial distribution of simulated and interpreted land cover in 2015

Analysis of the difference in the land cover type of 2015 between the simulated and the interpreted results for each grid cell indicated that the model performed well with a Kappa value of 0.857 and Chi-square value of 3.29×10^6. Comparison of the simulated distribution with those interpreted for each land cover showed an overall match on the quantity of different land cover types. The model discrepancy between the simulated and interpreted area for each land cover revealed a relatively high error for the built-up land (Figure 3.4. 18.1%), and an overall underestimation for the forest land (-6.0%) and grassland (-0.8%), suggesting that the model accuracy in predicting the changes of land cover areas is associated with the type of land cover.

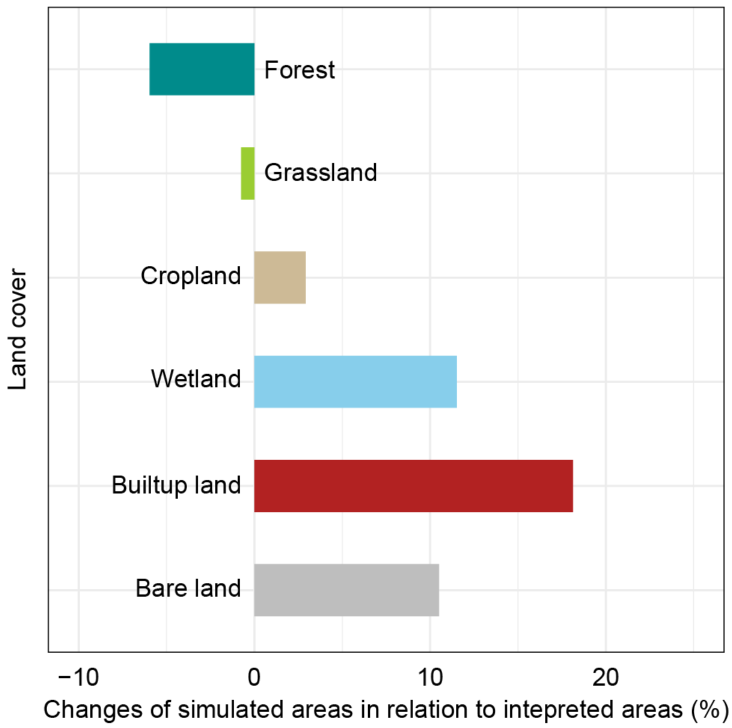

Figure 3.4. Comparison between the simulated and interpreted areas of different land cover types in 2015

(2) Projection of future land cover patterns

The areas of forest, grassland and wetland under different scenarios were estimated to be 1.71×10^5 – 1.84×10^5 km^2, 2.01×10^4 – 2.83×10^4 km^2 and 1.00×10^4 – 1.29×10^4 km^2, respectively (Table 3.4). There was significant difference in the changes of land cover types under different scenarios. Taken the land cover data of 2015 as a baseline, the areas of ecological lands (forest, grassland and wetland) under the ECOL scenario increased by 3.5 – 27.5% in the year 2035, where the greatest increase was found for wetlands. The increases of forest and wetland under the ECOL scenario were almost 4 and 3 times higher than those under the BAU scenario. Under the ECON scenario, the areas of ecological lands were estimated to decrease as compared to the baseline, with the most decrease found for grassland. The areas of cropland and built-up land under different scenarios were estimated to be 8.38×10^4 – 9.25×10^4 km^2 and 1.36×10^4 – 2.85×10^4 km^2, respectively. Compared to the baseline, the cropland and built-up land were projected as decreasing by 7.8% and 16.0%, respectively, under the ECOL scenario, but increasing by 0.5% and 75.4%, respectively, under the ECON scenario. The increases of ecological lands under the ECOL scenario concentrated in Guangxi and northern Guangdong, while the increases of cropland and built-up land under the ECON scenario concentrated in the central and north parts of Guangxi and the north part of Guangdong (Figure 3.5).

Table 3.4. Areas and proportion of different land cover types under different scenarios of 2035.

	Area (km^2)				Proportion (%)			Changes in relation to 2015 (%)		
	2015	BAU	ECOL	ECON	BAU	ECOL	ECON	BAU	ECOL	ECON
Forest	177952	179636	184366	170520	55.5	56.9	52.7	1.0	3.6	-4.2
Grassland	27336	20684	28292	20121	6.4	8.7	6.2	-24.3	3.5	-26.4
Cropland	90868	92482	83807	91335	28.6	25.9	28.2	1.8	-7.8	0.5
Wetland	10118	11208	12900	10034	3.5	4.0	3.1	10.8	27.5	-0.8
Built-up land	16237	17391	13644	28487	5.4	4.2	8.8	7.1	-16.0	75.4
Bare land	1347	2457	849	3361	0.8	0.3	1.0	82.4	-37.0	149.5

Note: BAU, ECOL, ECON represent the future scenarios of business as usual, ecological protection priority and economic development priority, respectively.

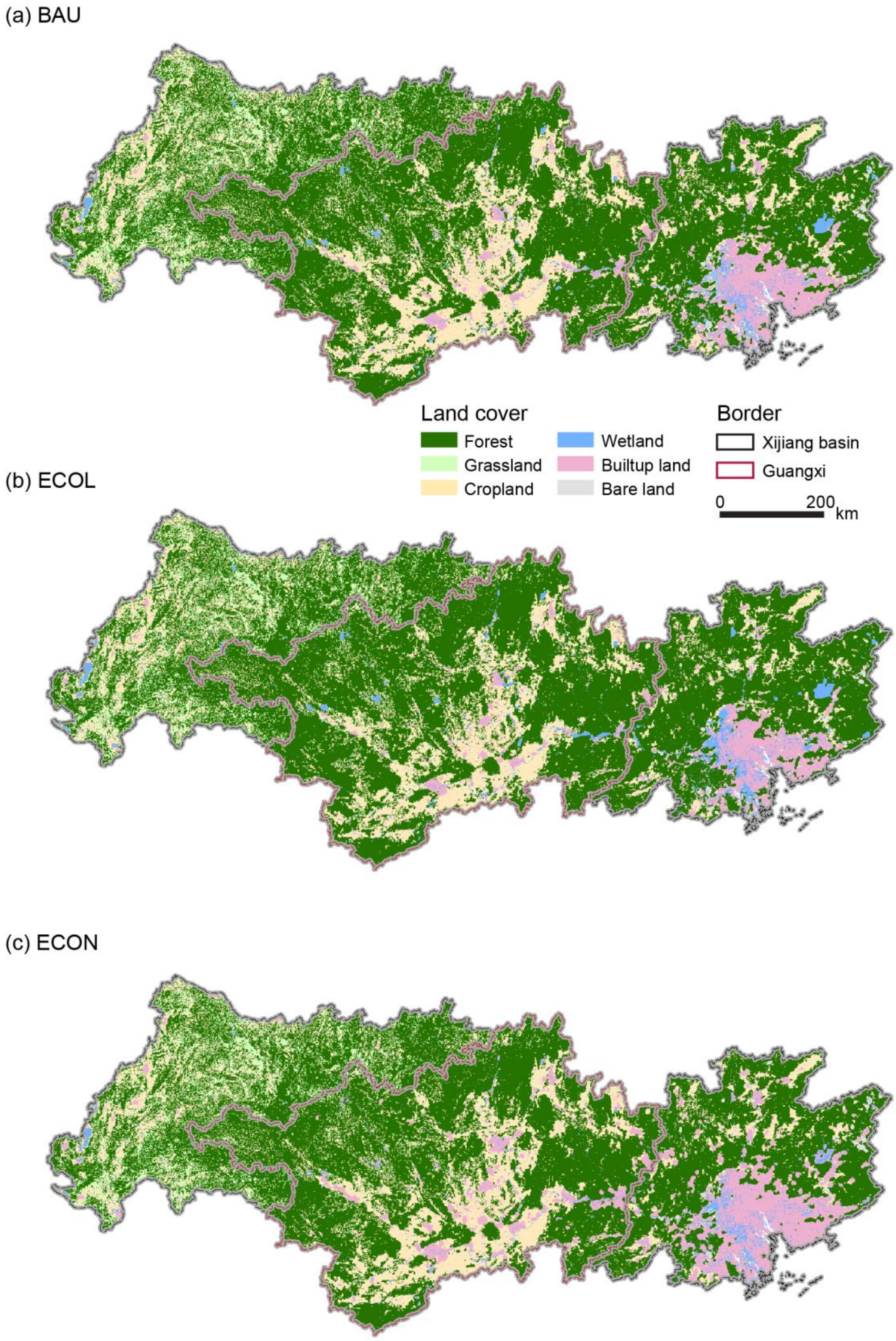

Figure 3.5. Spatial distribution of different land cover types under different scenarios

3.1.4 Limitation and implication of the model performance

Although the model performed well in simulating the land cover patterns in Xijiang basin, several limitations on the model performance exist. While the model had a high accuracy in predicting the quantity and spatial distribution of the land cover in 2015, the model accuracy for future scenarios of land cover patterns was not assessed. Due to data accessibility, validation was carried out only for the historical land cover pattern (i.e., the land cover pattern in 2015 in this study), instead of future datasets of land cover.

On the other hand, the model construction and the prediction of future land cover patterns were processed based on a synthetical analysis on the historical datasets (e.g., environmental factors like elevation, distance to infrastructure, population), without considering the temporal dynamics of the environmental factors, which to a certain extent increase the model uncertainty.

3.2 Historical patterns of biodiversity and ecosystem services

3.2.1 Provision of threatened species habitats

(1) Spatial distribution of important areas

For amphibians, the areas with high level of importance accounted for 19.2% of the total area of the basin (Table 3.5), and these areas mainly distributed in the north and west parts of Guangxi, the south part of

Guizhou (Figure 3.6). The areas with medium level of importance accounted for 71.3% of the basin area and mainly distributed in Qujing of Yunnan. In addition, the important areas also distributed in the Yuxi and Honghe parts of Yunnan province, the Liupanshui and Qianxinan parts of Guizhou province and the Shaoguan and Qingyuan parts of Guangdong province. Generally important areas for the amphibians accounted for 9.5% of the basin area and mainly distributed in the southern and eastern Guangxi and the northeast part of Guangdong.

Table 3.5. Areas and proportion of species habitats with different importance levels

Species	High		Medium		Low	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
Amphibians	85060	19.2	315627	71.3	42171	9.5
Birds	132253	29.9	227356	51.3	83249	18.8
Mammals	177476	40.1	222085	50.2	43297	9.8

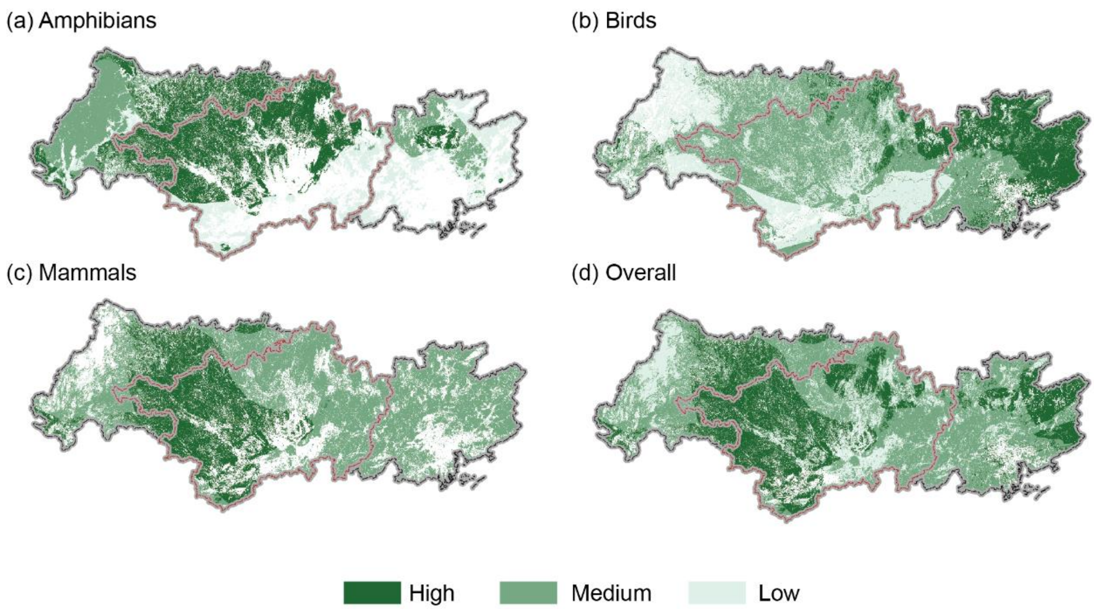

Figure 3.6. Spatial distribution of species habitats with different importance levels

For the birds, the habitat areas categorized as having high and medium level of importance accounted for 29.9% and 51.3% of the total area of the basin, respectively. The highly important areas concentrated in the north and east parts of Guangdong (e.g., Shaoguan, Qingyuan, Meizhou, Heyuan, Huizhou, Shenzhen) and the northeast part of Guangxi (e.g., Laibin, Guilin), while the medium important areas concentrated in the central and north parts of Guangxi, the southeast and south parts of Guizhou, the Honghe part of Yunnan and the central and south parts of Guangdong. Generally important areas for the birds accounted for 18.8% of the total area of the basin and mainly concentrated in the Chongzuo and Wuzhou parts of Guangxi and the Qujing part of Yunnan.

For the mammals, the habitat areas categorized as having high and medium level of importance accounted for 40.1% and 50.2% of the total area of the basin. The highly important areas concentrated in the east and southwest parts of Guangxi (e.g., Baise, Nanning, Chongzuo) and the southwest, south and southeast parts of Guizhou. The medium important areas concentrated in the north and east parts of Guangxi and most parts of Guangdong, while the generally important areas, accounting for approximately 9.8% of the total area of the basin, mainly concentrated in the Honghe, Yuxi, Kunming and Qujing parts of Yunnan, which are located in the upper reaches of the basin.

With an overlay analysis of the spatial distribution of different species.

The habitat areas with different importance levels for the rare and endangered species were identified for the Xijiang basin. The results showed that approximately 40% of the total area of the basin were categorized as having high or medium level of importance, while the rest areas were categorized as having a low level of importance. The highly important areas mainly distributed in the west and southwest parts of Guangxi (e.g., Baise, Hechi, Chongzuo), the Anshun and southwest parts of Guizhou and the east part of Guangdong (e.g., Heyuan, Qingyuan). The medium important areas mainly distributed in the east and north parts of Guangxi, the Wenshan part of Yuannan, the southeast of Guizhou and most parts of Guangdong. The generally important areas mainly distributed in the central and south parts of Guangxi and the Qujing part of Yunnan.

(2) Limitation and implication of model performance

With the data of rare and endangered species, the spatial distribution of species groups covering amphibians, birds and mammals were analyzed, and the areas with varying importance of biodiversity conservation were identified for different species groups, as well as the overall basin. However, there are several limitations on the model performance, which needs improvement during further studies with more datasets.

One of the aims of this study is to evaluate the effects of different ecosystems on the importance of biodiversity conservation. Therefore, ecosystem type was taken as a major factor, while ecosystem conditions like their diversity, rareness and health status were not considered, which is also due to the data availability.

Recognizing that the objective of biodiversity conservation is to protect a wide range of species in order to maintain species diversity, it is also important to protect areas that perhaps have lower overall species richness, but that are important for the conservation of species that do not occur in other ecosystem types. In this study, specific datasets relating to the effects of protected areas and endemic species for certain ecosystem types are not available. Therefore, species richness was taken as an important index, which might lead to underestimates of the areas of potential habitats with high importance for conservation.

3.2.2 Spatial-temporal distribution of the biophysical supply of ecosystem services

(1) Provisioning service

a) Model calibration and validation

Based on the daily flow data from the Yongwei hydrology station, the model was calibrated using both automatic and manual debugging methods. After 1000 iterations, the model fitted with a relatively high accuracy as indicated by a determination coefficient (R^2) of 0.52 and a Nash efficiency coefficient (NS) of 0.57. The calibrated parameter values were rewritten into ArcSWAT and used to update the input databases, so as to obtain the corrected flows. The variation of the simulated flow was basically consistent with the monitored flow (Figure 3.7).

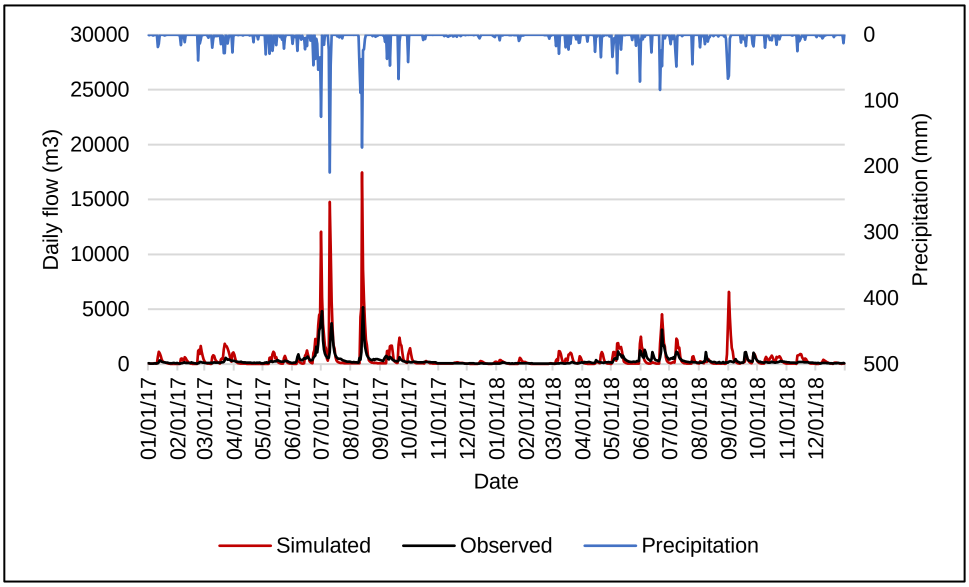

Figure 3.7. Changes of the rainfall and the simulated and observed flow during 2017 – 2018

Generally, the surface flow fluctuated with declining peaks during 2017 – 2018. Considering the high capacity of forests in evapotranspiration, the overall decreasing amount of water flows indicated losses of forest ecosystems in the study area. During the study period, a seasonal trend, with relatively high values from July to September but relatively low values from October to December, was found for the surface flows at the hydrology station investigated. With the calibrated parameters, the model performance was validated using the data of 2018. The result indicated that changes in the predicted flow were overall consistent with the observed flow and the relative error, calculated as the percent change of the simulated water flow relative to the observations, was 14%, suggesting that the model performance had a relatively high accuracy.

b) Comparison between the SWAT and InVEST modelled water yield

Considering the inconsistency in the scale of the model outputs, aggregation in the water yield was carried out for both the SWAT and InVEST model outputs, and comparison in the total amount of water yield from the two models was carried out at a subwatershed scale. The amount of water yield estimated by the SWAT model and the InVEST model had a similarity in the spatial distribution, with high values observed in the central and north parts of Guangxi and in the north part of Guangdong, but low values observed in parts of Yunnan and Guizhou provinces (Figure 3.8). Compared to SWAT model, the InVEST model produced a spatially specific map of water yield with more distribution patches. The total amount of water yield was estimated to be 7.9×10^{11} m^3 and 8.8×10^{11} m^3 by the SWAT and InVEST models, respectively. Compared to the SWAT model, the InVEST model produced relatively lower estimates of water yield and the rooted mean squared error (RMSE) decreased by 32.7% compared to the observations for different sub-watersheds, indicating that the InVEST model could better describe the variation of water yield in the Xijiang river basin.

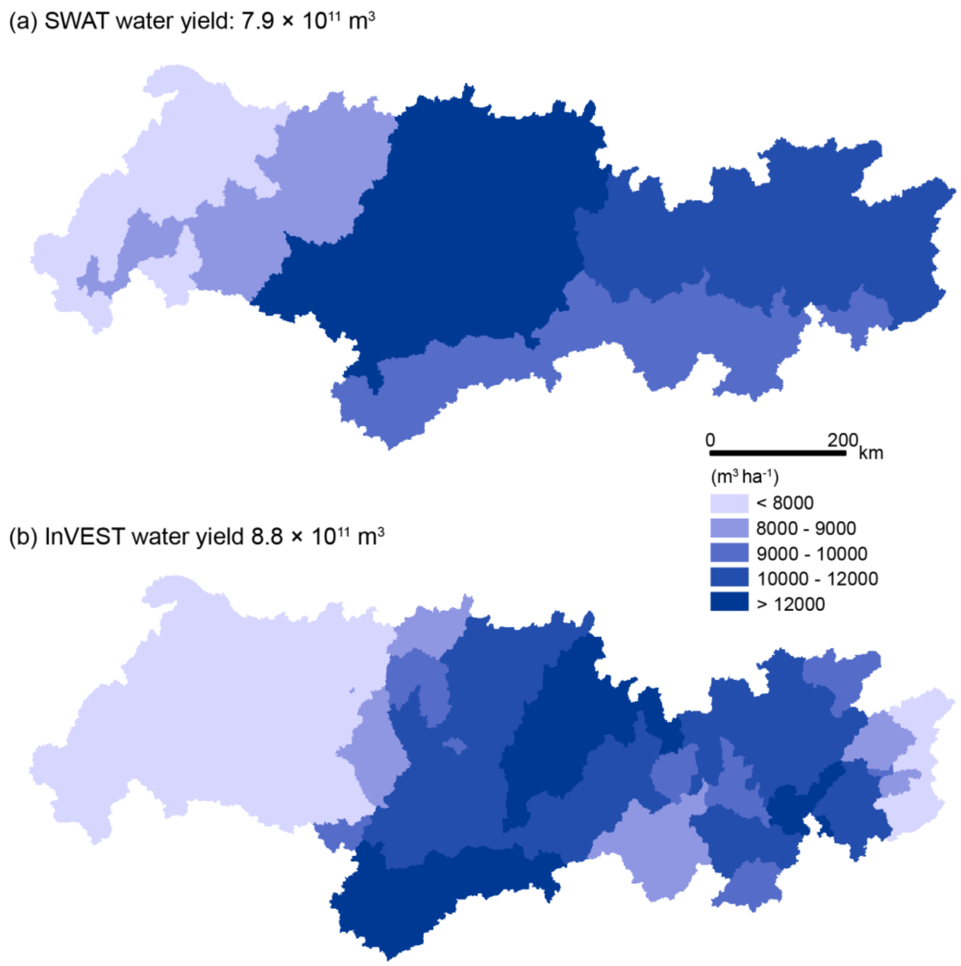

Figure 3.8. Spatial distribution of water yield from InVEST and SWAT models

During modelling processes, the InVEST model considers several hydrological processes like precipitation, evapotranspiration, surface flow and base flow, while the SWAT model considers more explicit hydrological processes like infiltration, lateral flows and percolation to shallow aquifer, etc. Compared to the InVEST model, which mainly captures the annual fluctuations in water flows, the SWAT model gives a more explicit timing changes of flows (e.g., daily or monthly changes). Application of the model in different study areas with varying characteristics of geology, climate, land patterns and soils may result in different outputs. One of the reasons for the relatively lower accuracy of the SWAT model performance may be the insufficiency of training processes, and the neglection of consideration on other hydrological and mass flows due to the lack of input data.

c) Historical changes of water yield

The water yield of Xijiang basin increased from 7.3×10^{11} m^3 to 8.8×10^{11} m^3 during 1995 – 2015. Among the provinces covered by the basin, Guangxi and the central parts of Guangdong were characterized by relatively higher increases in water yield (Figure. 3.9). The total amount of water yield of Guangxi was 2.8×10^{11} m^3 in 2015, which increased by 2.5% compared to that in 1995.

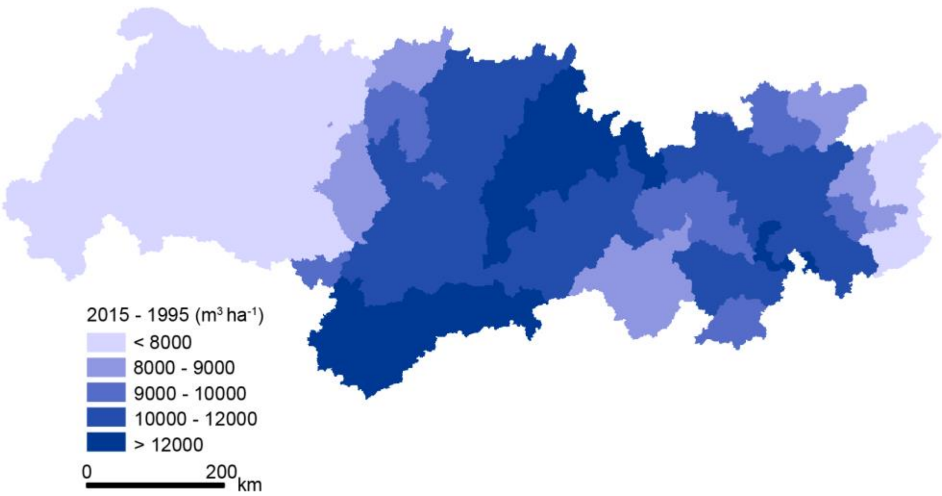

Figure 3.9. Changes of water yield during 1995 - 2015

(2) Regulating services

During 1995 – 2015, an overall increase in the biophysical supply was found for water purification and soil retention (Table 3.6), with the most increase found for the supply of water purification service. In 2015, the regulating services in Guangxi contributed to 46.9 – 78.6% of the total supply of the basin, of which the proportion of carbon storage was 1.1 – 2.1 times higher than those of other regulating services investigated.

Table 3.6. Biophysical supply account of ecosystem services for Xijiang basin in 1995 and 2015.

		Ecosystem types				
		Forest	Grassland	Cropland	Wetland	**Total**
	Unit	T1.1	T2.1	T3.1	T4.1	
Year 1995						
Provisioning service						
Water supply	10^8 m^3	76.42	715.16	6465.05	65.58	**7322.22**
Regulating services						
Water retention	10^8 m^3	768.23	206.94	3.95	108.47	**1087.59**
Flood mitigation	10^8 m^3	3434.30	668.81	19.75	258.53	**4381.39**
Water purification	10^8 tons	3575.68	236.33	37.58	9.38	**3858.97**
Soil retention	10^8 tons	3749.26	348.92	56.39	29.17	**4183.73**
Year 2015						
Provisioning service						
Water supply	10^8 m^3	225.14	608.65	7675.84	316.18	**8825.81**
Regulating services						
Water retention	10^8 m^3	662.77	204.46	5.88	77.02	**950.13**
Flood mitigation	10^8 m^3	739.00	270.48	16.27	70.36	**1096.11**
Water purification	10^8 tons	5472.56	288.10	89.37	19.75	**5869.78**
Soil retention	10^8 tons	5330.58	326.63	75.78	49.67	**5782.66**
Carbon sequestration	10^8 tons	359.33	8.43	1.22	0.17	**369.15**

Note: Carbon sequestration for 2015 was calculated as the variation in the amount of carbon storage during 1995 - 2015.

During 1995 – 2015, the most significant improvement in the biophysical supply of ecosystem services was found for water purification. In 2015, the areas categorized as having high biophysical supply of water purification accounted for approximate one third of the total area of the basin, which was 13.45% higher than that in 1995. In addition, the areas categorized as having high biophysical supply were found to be approximate one third for the regulating services of water retention, soil retention and carbon storage, which had little changes in the areas with high biophysical supply during 1995 – 2015. Although the areas with high biophysical supply of flood mitigation accounted for the largest proportion (44.5%) of the total basin area, little changes were found during the study period.

The areas categorized as having high biophysical supply of flood mitigation, soil retention and carbon storage services mainly concentrated in the north and northwest parts of Guangxi (Figure 3.10). In addition, the areas with high supply of flood mitigation and carbon storage services were found in the central and north parts of Guangdong. The areas categorized as having high supply of water retention service concentrated in the upper reaches of the basin, as well as the north part of Guangdong, and the areas categorized as having high supply of water purification service concentrated in the east part of Guangxi and the north part of Guangdong. During 1995 – 2015, an overall migration to the northwest part of the basin was found for the areas with high supply of flood mitigation, water purification, soil retention and carbon storage services, with concentration observed in Guangxi and the southeast part of Guizhou. In 2015, over half of the total area of the basin were characterized by high supply of the regulating services, with additional concentration observed in the central and north parts of Guangdong, except water retention, which was only found to be with high supply in Guangxi.

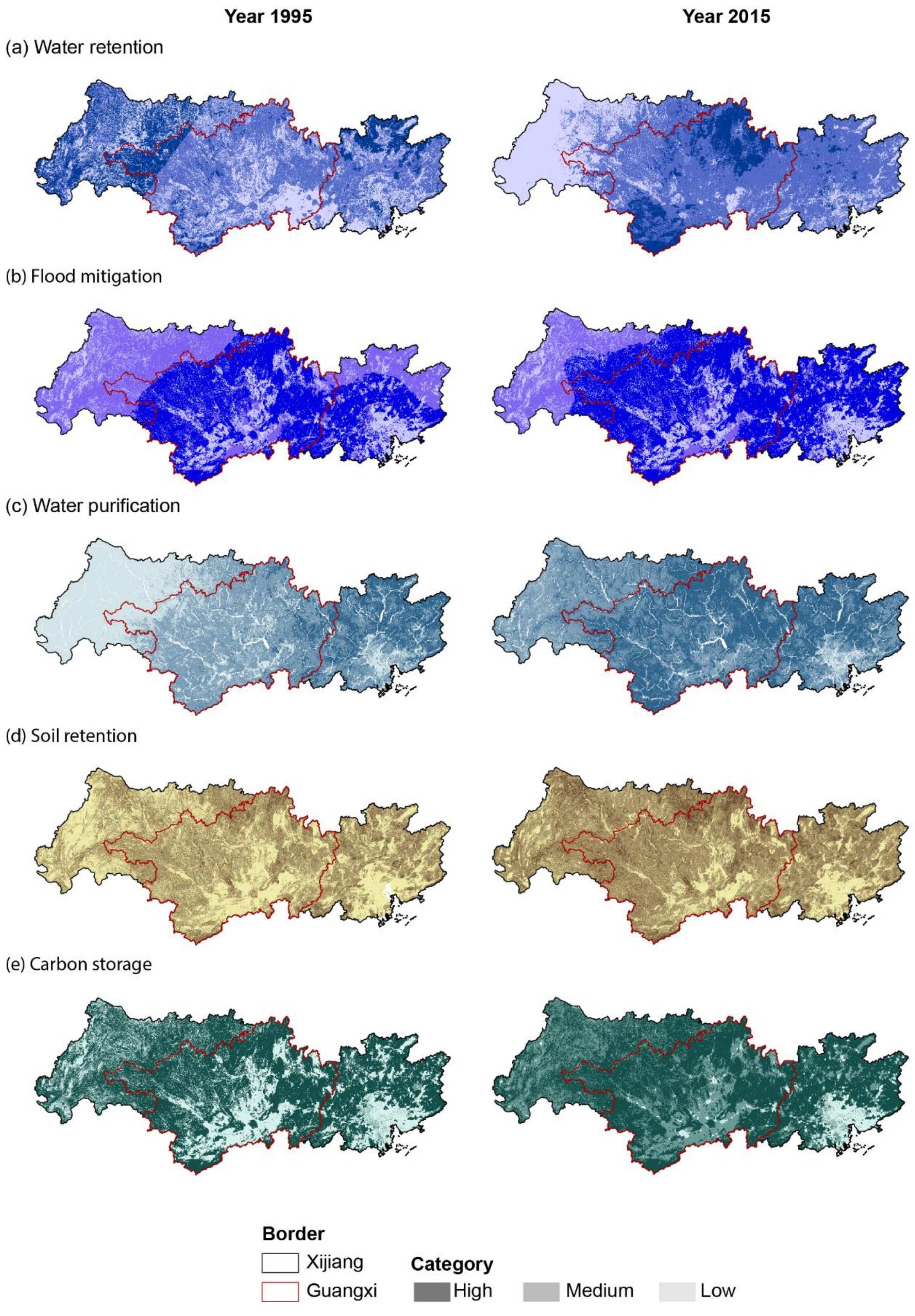

Figure 3.10. Spatial distribution of the biophysical supply of ecosystem services in 1995 and 2015

Variation in the contribution of different ecosystems to the biophysical supply of regulating services had a similarity at both regional and watershed scales, with the greatest contribution found for the forest ecosystem (67.4 – 97.3%) in 2015 (Figure 3.11). The areal supply of water retention, flood mitigation, water purification, soil retention and carbon storage services by the forest ecosystem were 2 – 13 and 2 – 11 times higher than those by the grassland and wetland ecosystems, respectively. The grassland ecosystem contributed 2.3 – 24.7% of the total biophysical supply of regulating services. Cropland and wetland, with contributions of less than 10%, had relatively lower supply than other ecosystem types. Compared to Guizhou and Yunnan, Guangxi had greater contribution to the total biophysical supply of the regulated services, among which forest contributed most to the total biophysical supply of ecosystem services.

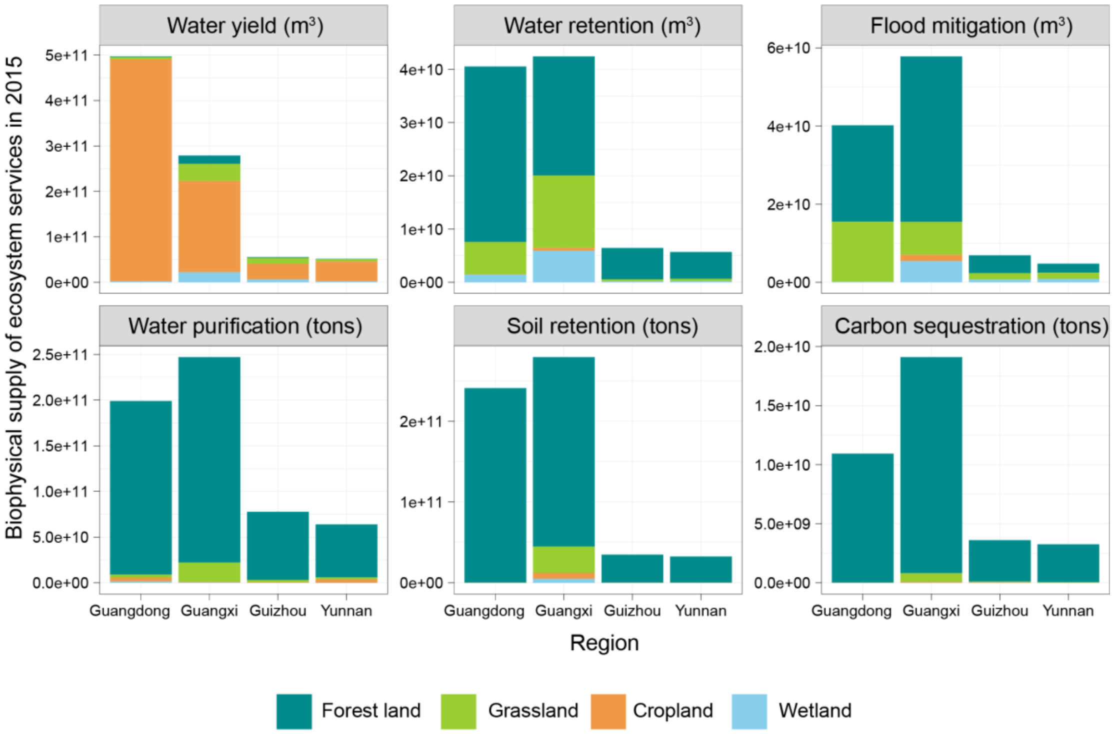

Figure 3.11. Contribution of different ecosystems to the total biophysical supply of ecosystem services for different regions of the Xijiang basin in 2015.

3.2.3 Spatial-temporal distribution of ecosystem service values

The total value of ecosystem services was 13,748 billion CNY for the Xijiang river basin in 2015. During 1995 – 2015, the value of water purification increased from 3859 billion to 5870 billion CNY, which was higher than other types of ecosystem services (Table 3.7). The value of soil retention service was comparable to that of carbon sequestration service, both of which were relatively higher than the values of water retention and flood mitigation services.

The total value of ecosystem services was 5748 billion CNY for Guangxi in 2015, accounting approximately 41.8 of the total ecosystem service value of the whole basin. The most increase was found in the value of water purification service, which was 2 – 3 times higher than those of other ecosystem services during 1995 – 2015. The relatively greater increase in the value of water purification service compared to other ecosystem services could result from the coupling impacts of external human efforts on the improvement of water environment and internal operating mechanism of aquatic ecosystems. During the studied period, a series of ecological protection and restoration measures have been applied to improve the ecological environment in the basin. These measures, such as water pollution disposal, water and soil conservation, forest construction, contribute directly to the improvement of water environment. On the other hand, the biophysiochemical conditions in aquatic ecosystems are more sensitive and could respond more quickly to external disturbances compared to other ecosystems during a certain period (Vander Laan et al., 2013).

Table 3.7. Ecosystem service value account for Xijiang basin in 1995 and 2015 (Unit, 10^8 CNY)

	Ecosystem types				Total
	Forest	Grassland	Cropland	Wetland	
	T1.1	T2.1	T3.1	T4.1	
Year 1995					
Provisioning service					
Water supply	309.48	2896.42	26183.46	265.62	**29654.98**
Regulating services					
Water retention	3111.32	838.10	16.02	439.30	**4404.74**
Flood mitigation	13908.93	2708.67	79.98	1047.06	**17744.64**
Water purification	35756.82	2363.26	375.76	93.84	**38589.67**
Soil retention	8659.94	805.92	130.24	67.38	**9663.48**
Year 2015					
Provisioning service					
Water supply	911.81	2465.04	31087.14	1280.55	**35744.54**
Regulating services					
Water retention	2684.24	828.07	23.82	311.91	**3848.04**
Flood mitigation	2992.94	1095.43	65.91	284.97	**4439.25**
Water purification	54725.59	2880.96	893.72	197.51	**58697.78**
Soil retention	12543.43	754.44	175.04	114.73	**13587.64**
Carbon sequestration	20616.52	483.71	69.90	9.96	**21180.08**

Note: Carbon sequestration for 2015 was calculated as the variation in the amount of carbon storage during 1995 - 2015.

The value of ecosystem services per unit area was found to be 29126 CNY ha^{-1} for forest in 2015, which was higher than other ecosystem types. During 1995 – 2015, difference was found in the changes of ecosystem service value among different ecosystems, with the greatest increase found in the value of ecosystem services provided by forests, which increased by 44.1 – 95.7% of the total value per unit area (Figure 3.12). The value of water purification service and soil retention service per unit area was found to be higher for grassland as compared to other ecosystem types, except forest. A relatively greater increase was found in the values of water yield, water retention and flood mitigation services per unit area of wetland during 1995 – 2015, while a little decrease was found in the values of water purification and soil retention services per unit area of cropland, which had a reverse trend for the values of other types of ecosystem services.

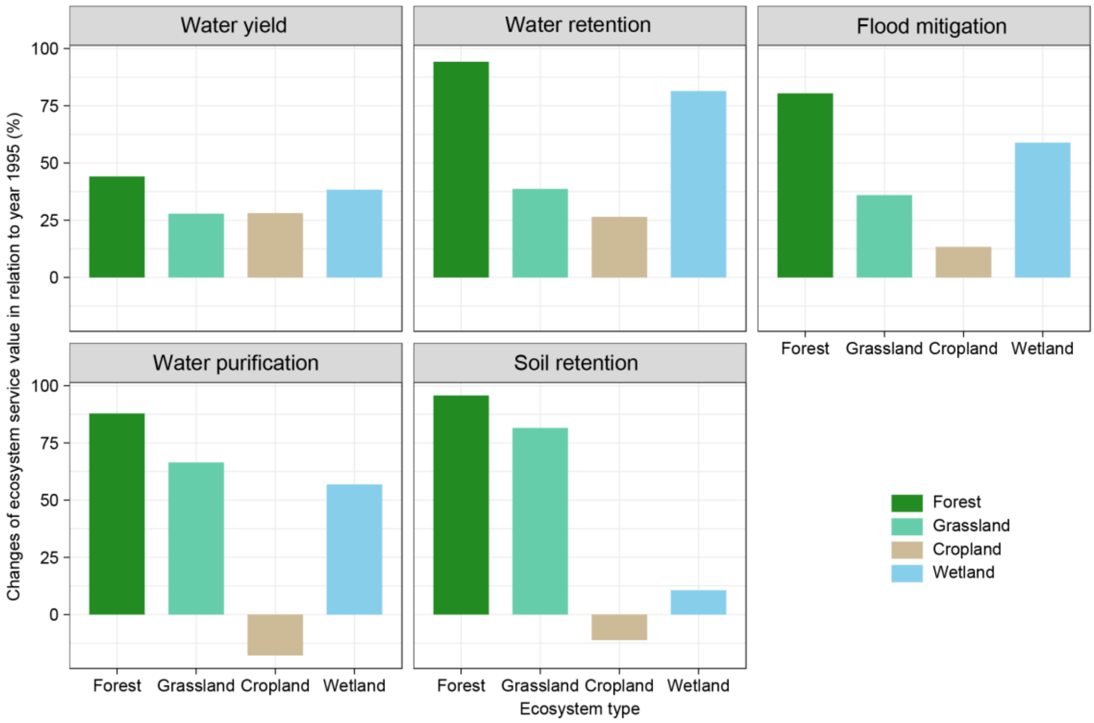

Figure 3.12. Changes in the values of ecosystem services per unit area of different ecosystems during 1995 – 2015.

During 1995 – 2015, the values of ecosystem services per unit area increased for all provinces covered by the basin. During this period, the values of water retention, flood mitigation, water purification and soil retention services per unit area increased by 67.6%, 71.0%, 83.4% and 74.3%

in Guangxi, respectively, which were higher than the increase of corresponding ecosystem service per unit area in other provinces (Figure 3.13). The values of water retention and flood mitigation services per unit area had increased by over one third in both Guizhou and Yunnan since 1995, while the values of water purification and soil retention services per unit area of these two provinces were lower than those of other provinces.

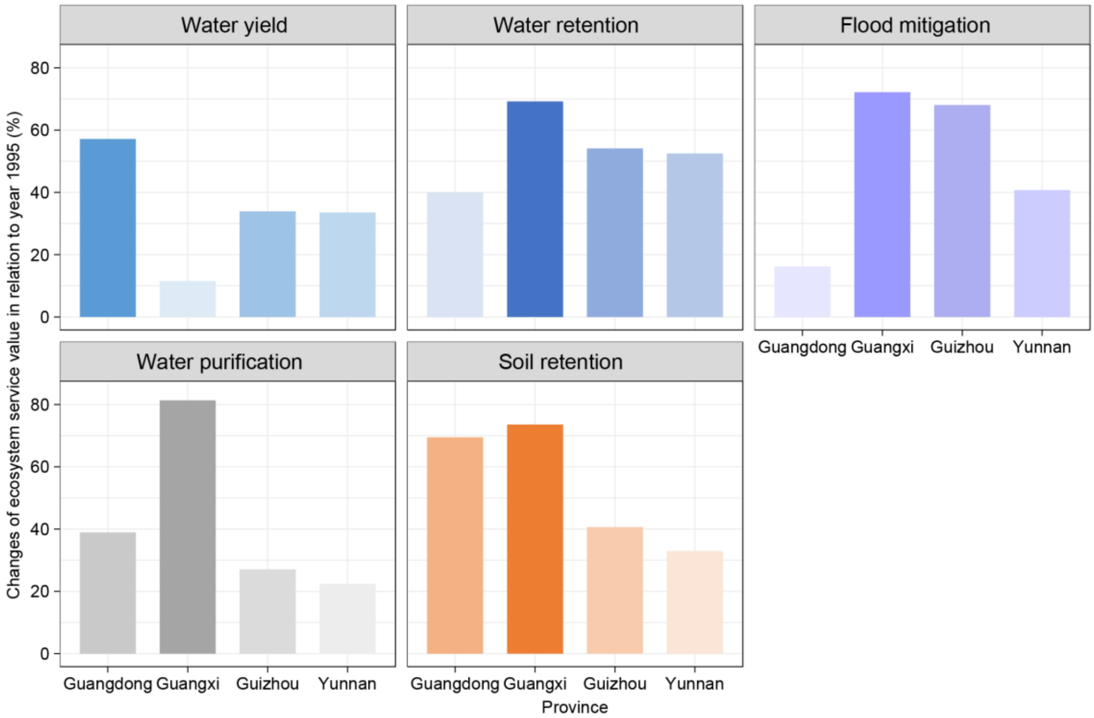

Figure 3.13. Changes in the values of ecosystem services per unit area of different provinces during 1995 – 2015

3.2.4 Limitation and implication of the model performance

With different ecosystem service models, the biophysical supply of critical provisioning service, water yield, and regulating services including water retention, flood mitigation, water purification, soil retention and carbon sequestration has been quantitatively assessed. However, several limitations on the application of the assessment models exist due to data availability and the assumptions and constructions of different models.

For water yield, the amount of water supply by the upstream was quantified for different years, while the water supply service flows between the upstream and downstream regions, as well as the demand of freshwater in the basin, were not quantified due to the lack of hydrology data for model requirements. With hydrologic datasets of a short time period (3 years in this study), the SWAT model was calibrated, which increases the uncertainty of the modeling performance. In addition, the model performance was calibrated to a specific sub-watershed and scaled up to the overall basin due to the lack of hydrology data made available for critical flow stations along the streams. Therefore, more critical datasets relating to the regional characteristics including hydrology and water quality with a longer time scale (e.g., 5 – 10 years) are needed for more accurate application.

Ecological processes and environmental factors relating to biotic and abiotic conditions of the basin fluctuate with different temporal dimensions. For example, streamflow varies with a seasonal characteristic as indicated by different flows at dry and wet seasons, and flood usually occurs with the increasing water depth during raining seasons, while topography features like elevation and slope vary among different years or with a much longer time scale. In this study, ecosystem services like flood mitigation and water retention were assessed with a single time node (i.e., one year), which might lead to the losses of seasonal or other detailed time-reduced characteristics within a year.

In modeling the water purification service, only surface NDR, representing the nutrient transported by surface flow, was considered due to data availability. However, the transportation processes in the subsurface layers, as well as the transformation characteristics among different biological and physiochemical processes of the nutrient, were not assessed, which might result in an overestimation on the water purification capacity. For the soil retention service, the USLE model, which has been widely used but only considers rill/inter-rill erosion processes, was used to estimate the biophysical supply of soil retention service. The neglection other erosion processes like gully or streambank erosion might lead to an underestimation of the amount of eroded soils that export from one pixel to the stream, which in turn results in an overestimation of the biophysical supply of soil retention service.

Although other ecosystem services play an important role in providing benefits for human beings, only 6 ecosystem services including water yield, water retention, flood mitigation, water purification, soil retention and carbon sequestration, were considered in this study as these ecosystem services play much more significant roles in the ecological security of the study area, compared to other ecosystem services. In this case, the current study may present the lower bound of the ecosystem service value.

3.3 Changes of biodiversity and ecosystem services under climate and land cover scenarios

3.3.1 Changes of biodiversity under different scenarios

Compared to the baseline, the habitat importance index under the ECOL scenario increased by 21.8%, which was approximately 1.2 times higher than that under the BAU scenario (Figure 3.14). In comparison, the habitat importance index under the ECON scenario decreased by 6.4% as compared the baseline. A similar trend of the variation in the habitat importance index was found for Guangxi, where the habitat importance index increased by 7.8% and 12.3% under the BAU and ECOL scenarios, respectively, but decreased by 4.8% under the ECON scenario.

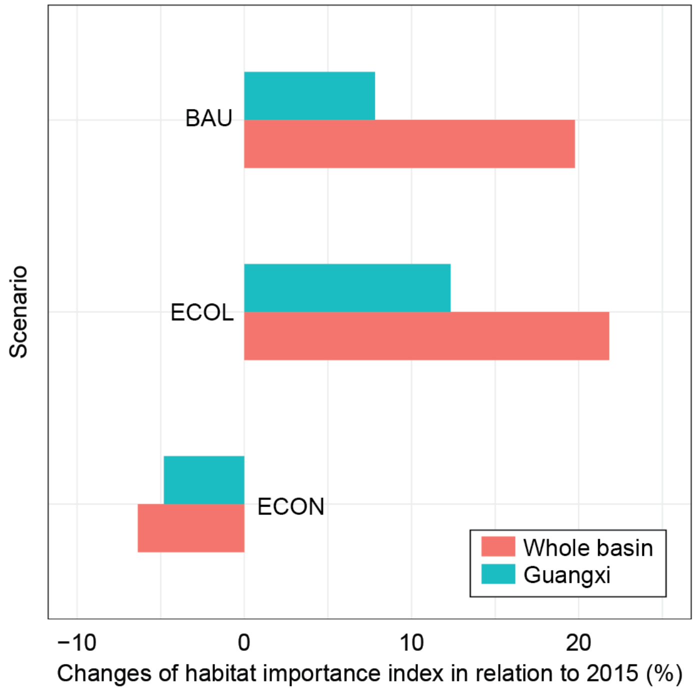

Figure 3.14. Changes of habitat importance index under different scenarios

The proportional areas of different levels of habitat importance for biodiversity conservation changed with varying land cover scenarios. The habitat areas categorized as having high and medium levels of importance under the ECOL scenario accounted for 40.5% and 34.6% of the total area of the basin, respectively, which were higher than those under the ECON scenario (Table 3.7). The proportional areas of high and medium levels of habitat importance under the ECOL scenario increased by 90.2% and 27.3%, respectively, while the proportional areas of general habitat importance decreased by almost 50% as compared to the baseline of 2015 (Figure 3.15). In contrast, a reverse trend was found for the proportional areas under the ECON scenario. Although the habitat areas of high importance increased under the BAU scenario, the proportional increase in relation to the baseline was less than 30% of that under the ECOL scenario, while the habitat areas of medium and low levels of importance decreased as compared to the baseline.

Table 3.7. Areas and proportion of habitats with different importance for biophysical conservation under future scenarios in 2035.

Scenario	**Area (km^2)**			**Proportion in the basin (%)**		
	High	Medium	Low	High	Medium	Low
BAU	122245	117047	192453	28.3	27.1	44.6
ECOL	175017	149275	107453	40.5	34.6	24.9
ECON	91104	99135	241506	21.1	23.0	56.0

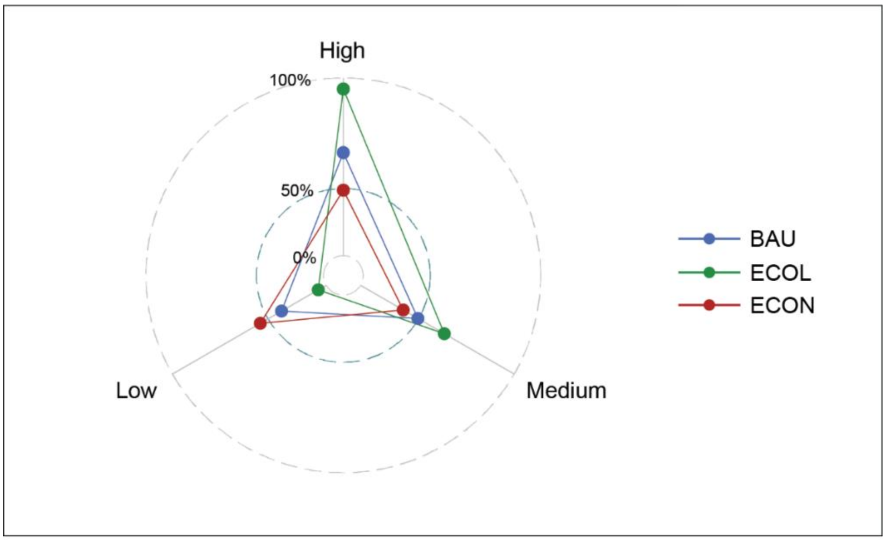

Figure 3.15. Changes of habitat areas with different levels of importance for biodiversity conservation compared to 2015.

The increases of habitat importance index concentrated in Guangxi, the southeast part of Guizhou and the west part of Guangdong (Figure 3.16), while the decreases of the habitat importance index concentrated in the Qujing part of Yunnan and the Pearl river delta region.

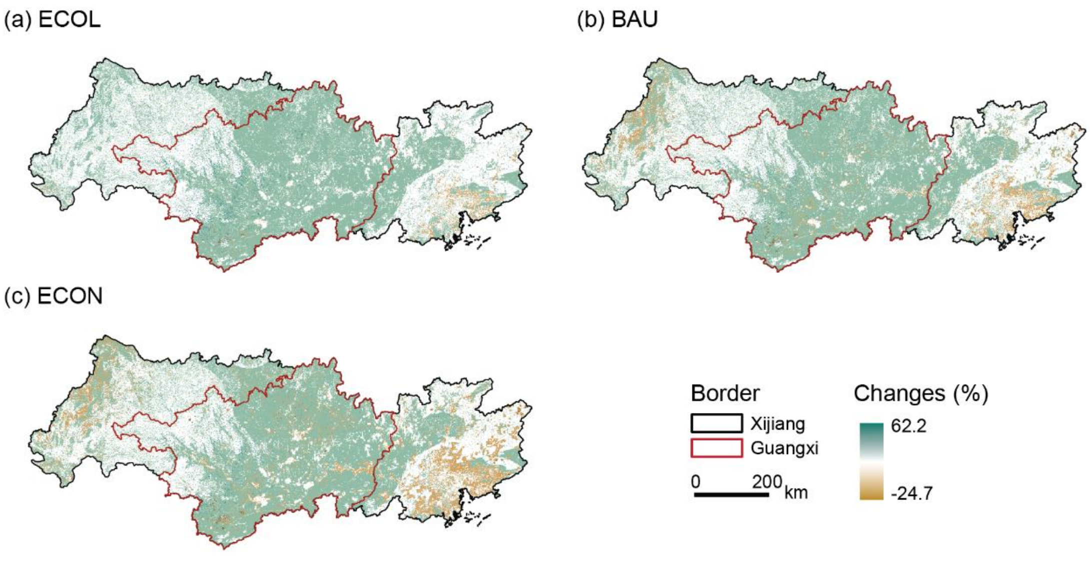

Figure 3.16. Changes of habitat importance index under different scenarios of 2035 compared to 2015.

3.3.2 Changes in the biophysical supply of ecosystem services under different scenarios

Significant effects on the biophysical supply of ecosystem services were found for the future climate change and land cover changes. With the same representative concentration path, comparison of different land cover scenarios indicated a relatively higher amount of water yield under the ECON scenario than the ECOL scenario (Table 3.8). The ECON scenario seemed to be more conducive to the formation of surface runoff. Compared to the BAU scenarios, the amount of water yield rose 32.7 – 57.8% under the ECON scenario, while the amount of water yield under the ECOL scenario decreased by 87.8 – 94.2%. With the same land cover pattern, the amount of water yield under the RCP4.5 scenario was relatively higher than the RCP8.5 scenario, except the ECON scenario, where the RCP8.5 climate change scenario produced a relatively higher amount of water yield.

Table 3.8. Biophysical supply account of ecosystem services for Xijiang basin under different climate and land cover scenarios in 2035.

		Scenario					
		BAU		ECOL		ECON	
	Unit	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Provisioning service							
Water yield	10^8 m^3	79948	31587	4676	3852	106081	47632
Regulating service							
Water retention	10^8 m^3	484	577	9993	1302	366	202
Flood mitigation	10^8 m^3	732	843	14233	1895	515	482
Water purification	10^8 tons	12711	8882	15326	16335	2996	1870
Soil retention	10^8 tons	10490	9240	11902	12534	2730	1972
Carbon sequestration	10^8 tons	1513	961	3980	2852	242	228

Compared to other scenarios, the biophysical supply of regulating services had greater increases under the ECOL-RCP4.5 scenario (Figure 3.17), where increase in the biophysical supply of carbon sequestration service was comparable to that of the water retention and flood mitigation services, which were relatively higher than those of the water purification and soil retention services. Under the ECON scenario, the amount of water yield increases significantly. With the same land cover pattern, the biophysical supply of ecosystem services had relatively higher increase under the RCP4.5 scenario than under the RCP8.5 scenario.

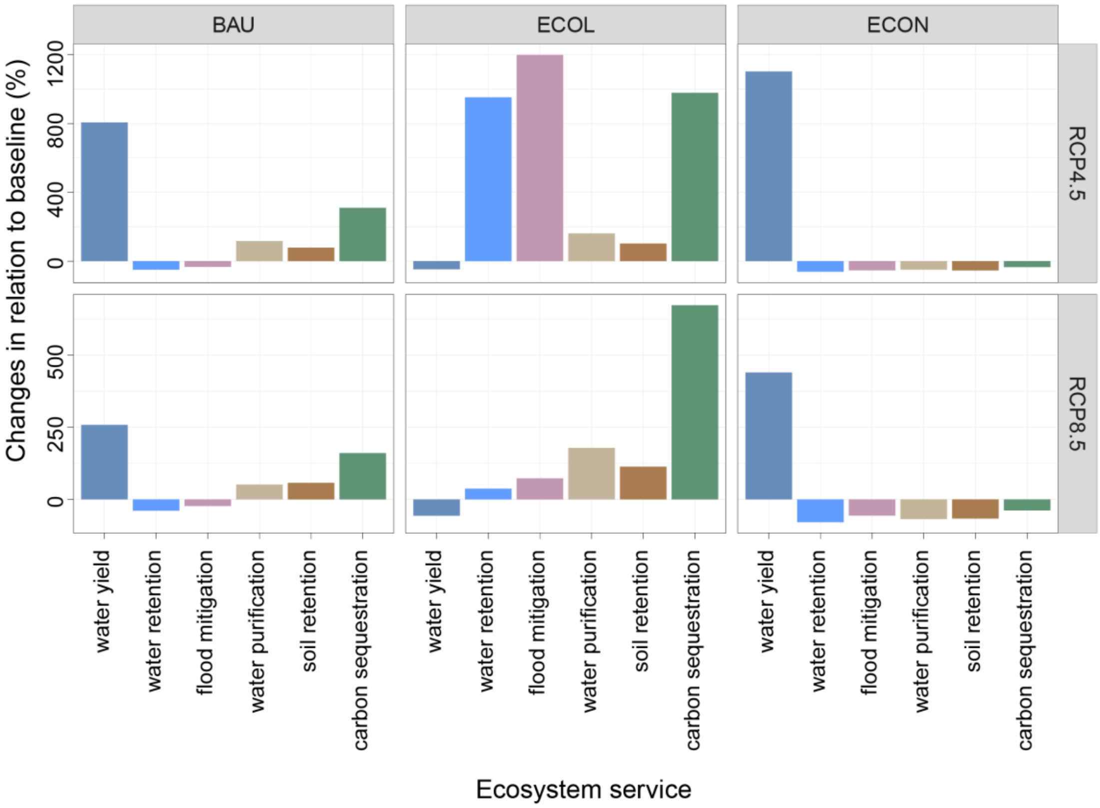

Figure 3.17. Changes in the biophysical supply of ecosystem services for Xijiang under different climate and land cover scenarios in 2035 in relation to the baseline.

Changes in the climatic and land cover patterns have great impacts on the tradeoffs among different ecosystem services. The biophysical supply of ecosystem services was affected by the climate change more than by the land cover change, which showed relatively greater impacts on the types of ecosystem services. Under the ECOL and ECON scenarios, the increases in the biophysical supply of different ecosystem services were slow down with an increased radiation intensity. With the same representative path, the biophysical supply of regulating services increased under the ECOL scenario but decreased under the ECON scenario which was characterized by relatively high levels of water yield. These results indicated that, the ECON scenario with a priority on economic development, is conducive to the formation of surface runoff at the cost of reduction of the biophysical supply of regulating services. In contrast, increases in the strength of ecological protection under the ECOL scenario is conducive to the reduction of water disasters caused by excessive surface runoff, and simultaneously helpful in improving the ecological benefits through increasing the biophysical supply of ecosystem services such as soil retention, water purification and water retention.

Spatial difference was found in the variation of the biophysical supply of ecosystem services under different scenarios. The impacts of land cover changes on the spatial distribution of different ecosystem services were found to be affected by the variation in future climatic conditions. Under the RCP4.5 scenario, comparison analysis of different land cover scenarios indicated that the variations in the biophysical supply of water yield, flood mitigation, water purification, soil retention and carbon sequestration services mainly concentrated in the west and south parts of Guangxi and parts of Guizhou and Yunnan provinces (Figure 3.18), while the variation in the biophysical supply of water retention service mainly concentrated in the west and north parts of Guangxi and the south part of Guizhou. Under the RCP8.5 scenario, the variation in the biophysical supply of water retention service due to the changes of land cover pattern concentrated in the north and northeast parts of Guangxi, while spatial concentrations were found in the central and south parts of Guangdong for other types of regulating services. Additional spatial concentrations under the RCP8.5 scenario could be found in the central and north parts of Guangxi for the biophysical supply of soil retention and carbon sequestration services, respectively.

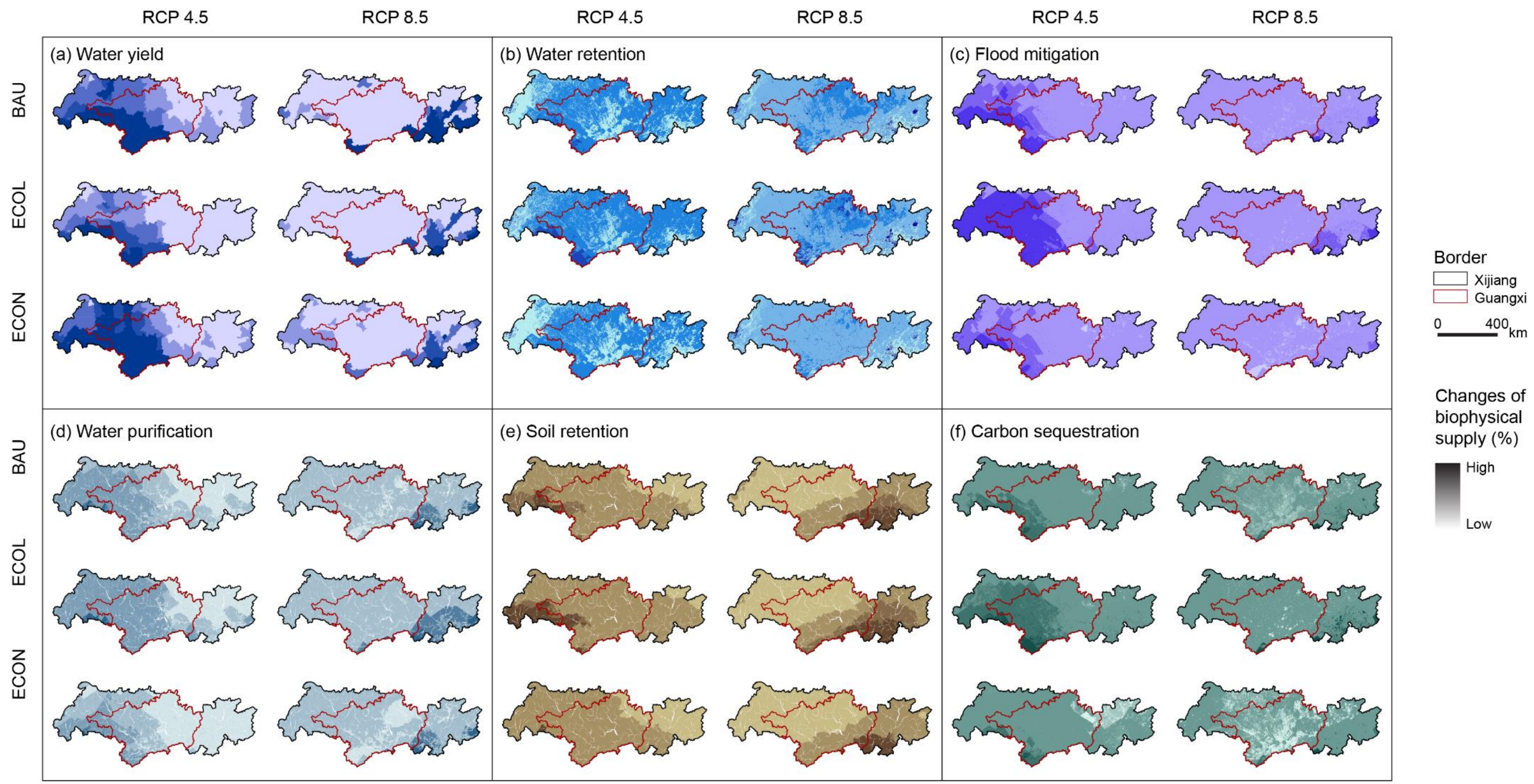

Figure 3.18. Changes in the spatial distribution of the biophysical supply of ecosystem services for 2035 under different climate and land cover scenarios

3.3.3 Changes of ecosystem service values under different scenarios

The total value of water yield service in 2035 varied from 1560 billion CNY under the ECOL-RCP8.5 scenario to 42963 billion CNY under the ECON-RCP4.5 scenario (Table 3.9). The most increase in the water yield value was found for Guangdong province, where the water yield value under the ECON-RCP4.5 reached the plateau and increased by 38.1 – 57.8% compared to that under the BAU scenarios (Figure 3.19). The regulating service values in 2035 show a significant variation among different scenarios, with overall higher estimate found for the ECOL-RCP4.5 and ECOL-RCP8.5 scenarios compared to those under other projected scenarios. The total values of the regulating services were estimated to be 50724 billion and 36891 billion CNY under the ECOL-RCP4.5 and ECOL-RCP8.5 scenarios, respectively. Compared to other provinces covered by the basin, Guangxi was characterized by the most increase in the total regulating service value, which was mainly attributed by the increase in the water retention service value. The total values of regulating services for Guangxi were estimated to vary from 1630 billion CNY under the ECON-RCP8.5 scenario to 32028 billion CNY under the ECOL-RCP4.5 scenario.

Table 3.9. Ecosystem service value account for Xijiang basin under different climati and land cover scenarios in 2035 (Unit, 10^8 CNY).

	Scenario					
	BAU		ECOL		ECON	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Provisioning service						
Water yield	323788	127926	18937	15599	429628	192909
Regulating service						
Water retention	1961	2337	40473	5275	1483	818
Flood mitigation	2964	3416	57646	7675	2085	1953
Water purification	127106	88822	153258	163354	29960	18697
Soil retention	24230	21343	27491	28950	6306	4555
Carbon sequestration	86830	55149	228374	163652	13891	13086

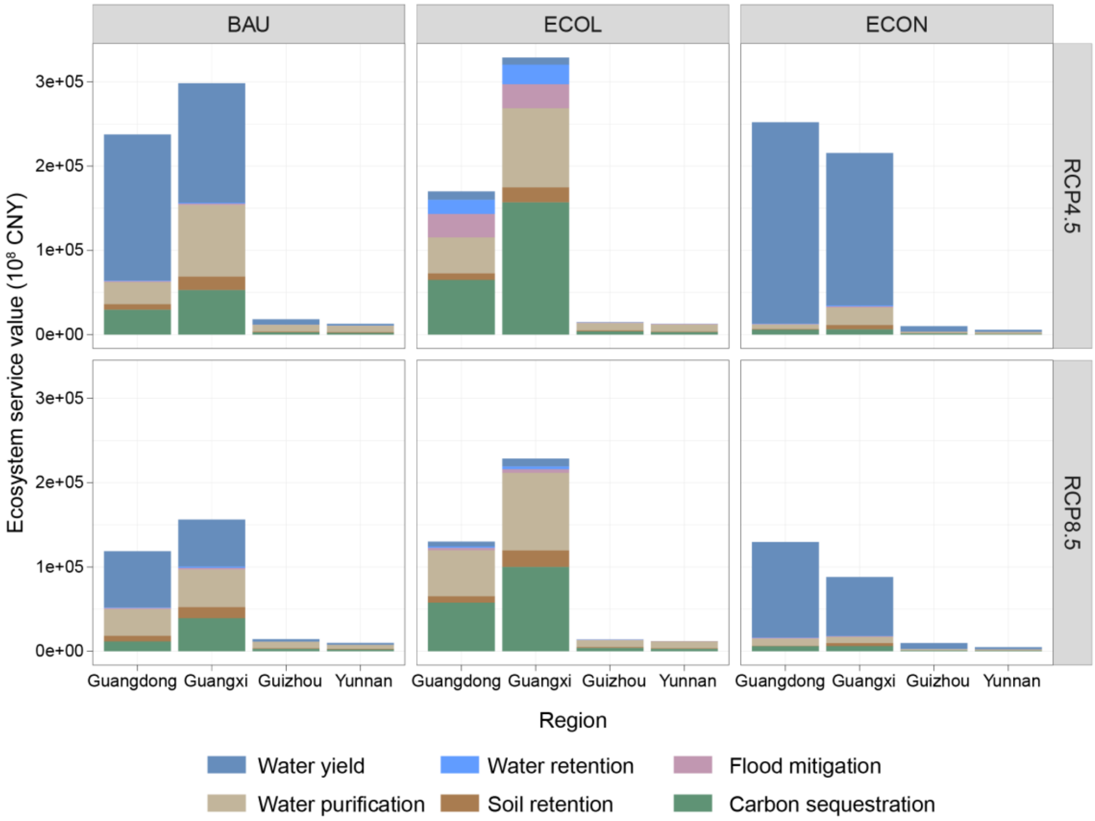

Figure 3.19. Ecosystem service values for different regions of Xijiang basin under different climate and land cover scenarios in 2035.

3.4 Ecosystem service – based ecological compensation standards

3.4.1 Costs and benefits of ecological protection

(1) Ecological protection cost

The total cost of ecological protection in the upper reaches of the Xijiang river basin was 53.11 billion CNY in 2015 (Table 3.10), of which the cost of water pollution prevention and control was 25.43 billion CNY, accounting for almost half of the total cost. The costs of comprehensive treatment of water and soil conservation and forestry construction were 11.60 billion CNY and 16.08 billion CNY, respectively, accounting for 21.9% and 30.3% of the total cost of ecological protection, respectively. Among the provinces covered by the basin, the cost of ecological protection in Guangxi was 37.64 billion CNY, which was higher than that in Guizhou (8.90 billion CNY) and Yunnan (6.57 billion CNY). The cost of water pollution prevention and control accounted for 49.5% and 46.0% of the total cost of ecological protection in Guangxi and Yunnan, respectively, which were higher than the costs of other types (Figure 3.20).

From the perspective of provincial investment, the cost of water pollution prevention and control was found to be comparable to that of comprehensive treatment of water and soil conservation in Guizhou. The costs of these two types accounted for 42.3% and 43.5% of the total cost of ecological protection, respectively, which were higher than that of forestry construction. However, the cost of forestry construction in

Guangxi was almost 3 times higher than that of the comprehensive treatment of water and soil conservation, which was found an opposite trend of these two cost types in Guizhou and Yunnan.

Table 3.10. Ecological protection costs for different regions of Xijiang basin in the year 2015 (Unit: 10^8 CNY).

	Province			**total**
Ecological protection engineering	Guangxi	Guizhou	Yunnan	
Water pollution disposal	186.42	37.65	30.21	**254.28**
Water and soil conservation	52.21	38.71	25.14	**116.06**
Forestry construction	137.77	12.68	10.33	**160.78**
total	**376.4**	**89.04**	**65.68**	**531.12**

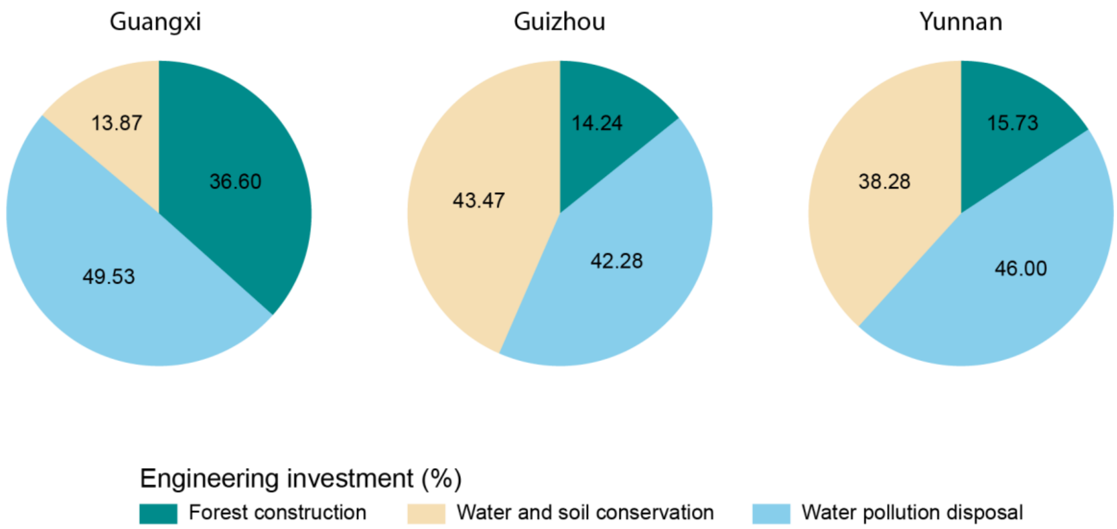

Figure 3.20. Costs of ecological protection in the upstream regions

(2) Ecological benefits

The total ecological benefits for the upstream region were estimated as 785 billion CNY in 2015, with relatively higher contribution by Guangxi province compared to other regions covered by the basin (Figure 3.21). In 2015, Guangxi produced total benefits of 554 billion CNY, which was 4 –

5 times higher than other regions. With the coupling effects of climate and social-economic development strategies, the ecological benefits for the upstream region were estimated to vary from 173 billion CNY under the ECON-RCP8.5 scenario to 4986 billion CYN under the ECOL-RCP4.5 scenario. The variation in the ecological benefits under future climate and land-cover scenarios indicated that, the ecological benefits for both an individual province and the whole upstream region decreased significantly with an extensive development intensity as indicated by the increase of impervious areas under the ECON scenarios, while an overall increase in the ecological benefits were observed with enhanced protection and restoration of the ecological environment in the basin.

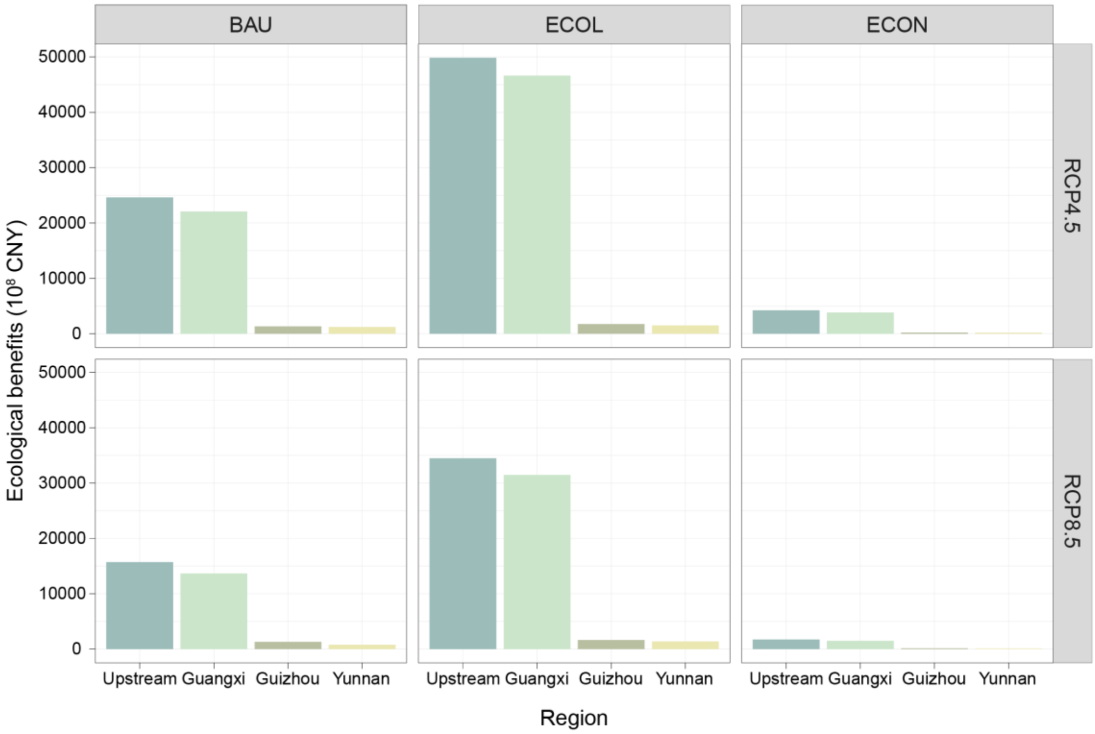

Figure 3.21. Total value of ecosystem services for different ecosystems and regions in the upper reaches of Xijiang river basin in the year 2015.

3.4.2 Ecological compensation standards under different scenarios

With the sharing subjects of the upstream and downstream regions of the basin, ecological compensation that the upstream regions should obtain were calculated based on the benefits obtained and socio-economic characteristics of different regions. The results showed that the total ecological compensation to be obtained by the upstream regions was 48.5 – 693.5 billion CNY in 2015, with relatively larger compensation for Guangxi (34.3 – 490.4 billion CNY) compared to Guizhou (7.8 – 112.1 billion CNY) and Yunnan (6.4 – 90.9 billion CNY). With the coupling effects of climate change and land management strategies, the upper limits of the compensation standards were estimated to increase in 2035 under different scenarios projected, except the ECON scenario, where relative decreases in the compensation standards were observed in relation to the baseline (Table 3.11). With an enhanced protection and restoration strategy for local ecological environments, the compensation standards (ECOL scenario) to be obtained in 2035 were estimated to increase by 75 – 89% compared to those with a historical development trend (BAU scenario).

Table 3.11. Ecological compensation thresholds for Xijiang basin under different climate and land cover scenarios in 2035 (Unit, 10^8 CNY).

	Scenarios											
	BAU				ECOL				ECON			
	RCP4.5		RCP8.5		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Upstream												
Guangxi	441.36	18849.66	421.26	11629.46	403.70	34515.09	390.31	23192.78	506.02	4123.19	414.34	1631.16
Guizhou	26.75	1142.32	39.99	1103.91	15.05	1286.37	20.25	1203.26	27.06	220.49	37.61	148.07
Yunnan	24.13	1030.41	23.53	649.59	12.90	1102.51	17.07	1014.13	24.72	201.43	28.34	111.58
Total	492.23	21022.40	484.77	13382.97	431.64	36903.97	427.62	25410.16	557.80	4545.12	480.29	1890.81

Note: BAU, ECOL and ECON represent the land development scenarios of business as usual, ecological protection priority and economic development priority, respectively.

Significant difference in the upper limits of ecological compensation was found for different ecosystem services under different scenarios of future climate and land cover changes. In 2035, an overall increase in the compensation standards for the upstream region was found for the ECON scenarios in relation to the baseline (Figure 3.22), while a reverse trend was found for the ECOL scenarios, without any dependency on the spatial scales. Compared to the BAU scenarios, the upper limits of compensation standards under the ECON scenarios increased by 16.7 – 24.1% for the upstream region, while the upper limits of compensation standards under the ECOL scenarios decreased by 75.1 – 84.6%. Changes in the compensation standards for the studied regulating services were associated with the service type and the geographical location. Generally, with the same representative concentration path, the proportional increases in the upper limits of ecological compensation for the upstream regulating services in 2035 were found to be higher under the ECOL scenario in relation to the baseline, as compared to those under other land cover scenarios, while an opposite trend was found for the ECON scenarios. Compared to the BAU scenarios, the upper limits of ecological compensation under the ECOL scenarios increased by over 90% for the water retention, flood mitigation and carbon sequestration services, which were relatively higher than the proportional increases for water purification and soil retention services. In addition, with a same land cover pattern, the proportional increases in the upper limits of ecological compensation for the regulating services were found to be 2 – 7 times higher for the RCP4.5 scenario compared to the RCP8.5 scenario. The changing magnitude in the compensation thresholds in 2035 was estimated to vary from region to region, with relatively higher proportional increases in the upper limits found for Guangxi compared to Guizhou and Yunnan. Specifically, Guangxi was projected to obtain higher compensation upper limits on the water retention, flood mitigation and carbon sequestration services, and Guizhou and Yunnan were projected to obtain higher compensation upper limits on the flood mitigation and soil retention services. The results above indicated that the ECOL-RCP4.5 scenario was more reducible to reducing water disasters caused by excessive water yield and improving the benefits of regulating services including water retention, flood mitigation, water purification, soil retention and carbon sequestration. In addition, with a same development scenario, the ecosystems in the upstream region have variable sensitivity to the climate and land cover changes and respond to external disturbances with great spatial heterogeneity, thereby making different contributions to the ecological benefits of the upstream region, which result in fluctuations in the upper limits of compensation standards among different regions.

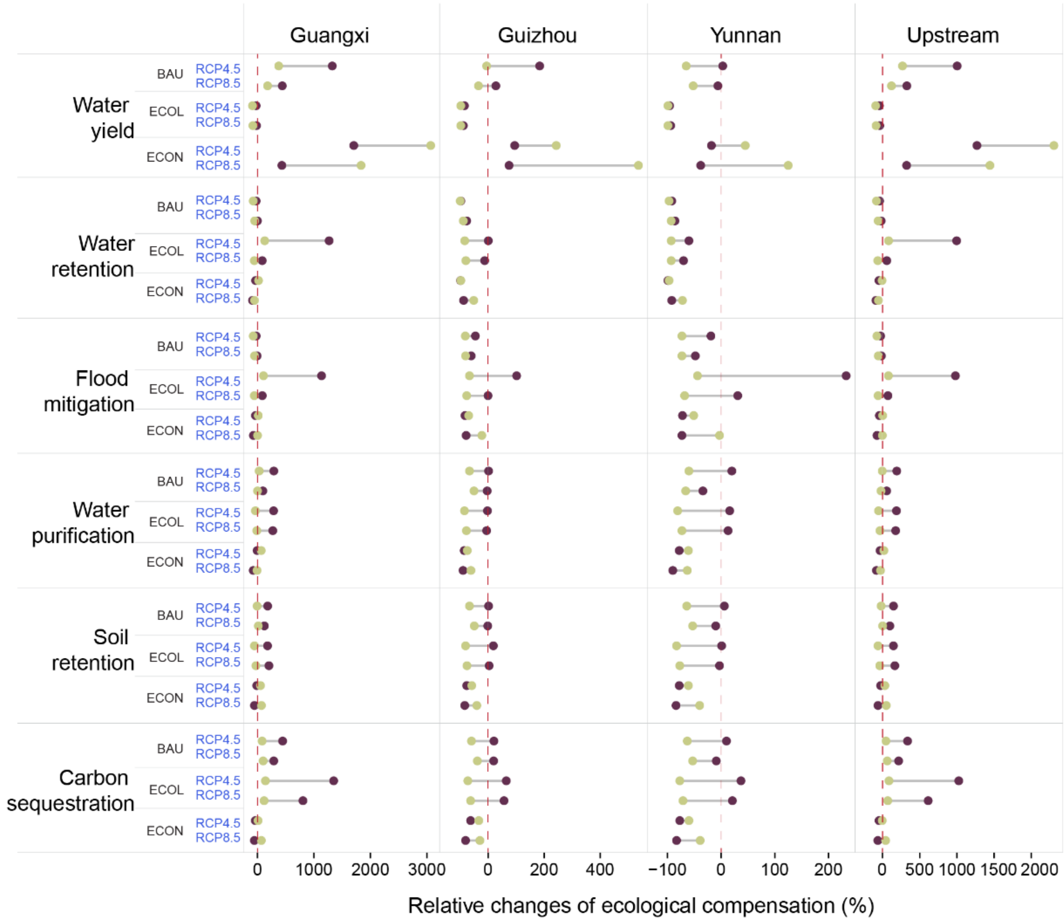

Figure 3.22. Changes of eco-compensation thresholds for upstream regions under different climatic and land cover scenarios.

3.4.3 Priority sequence of ecological compensation

Nearly half of the upstream counties were categorized as having a high level of ecological compensation priority, among which approximately 59.7%, 24.7% and 15.6% of the upstream counties were identified for Guangxi, Guizhou and Yunnan, respectively. Compared to other counties, these counties had relatively higher demand for ecological compensation. The counties categorized as having medium or low priority accounted for approximate one quarter of the upstream counties.

Almost half of the counties in Guangxi were categorized as having high priority, and these counties mainly distributed in the cities of Hechi, Baise, Chongzuo and Hezhou (Figure 3.23). Additonally, several counties (e.g., Rong'an, Rongshui, Pingle, Xing'an, Jinxiu) which distributed in the cities of Liuzhou, Guilin and Laibin, also had high priority. Approximately 27.1% of the counties in Guangxi, which mainly distributed in the cities of Guilin, Liuzhou, Laibin and Guigang, were categorized as having a medium level of ecological compensation priority, while the rest of counties were categorized as having a relatively low priority.

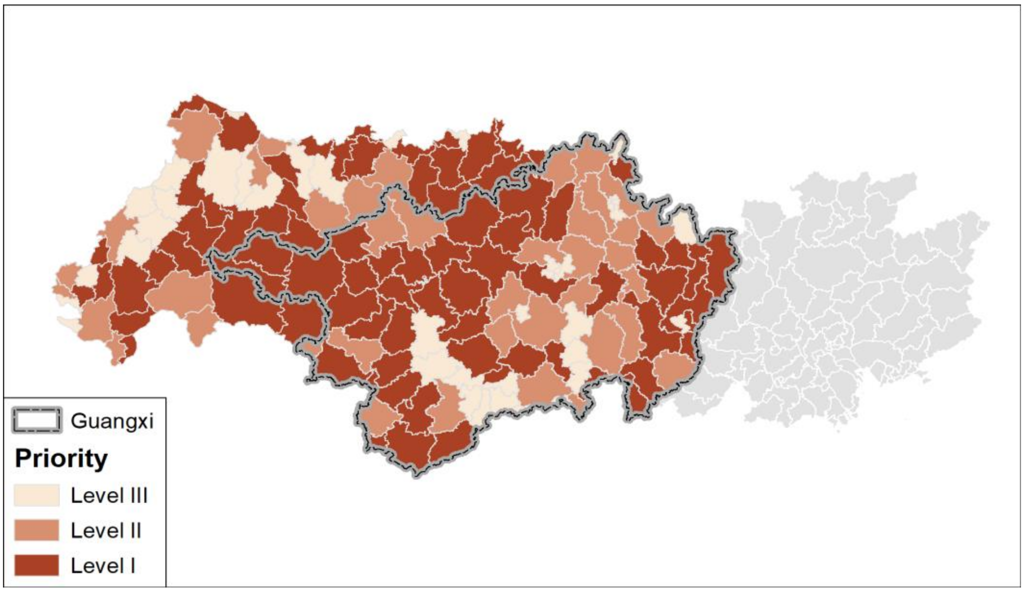

Figure 3.23. County-level distribution of ecological compensation priority revealing the sequences of obtaining ecological compensation among different counties in Xijiang basin. The priority was categorized into high (level I, upper 25%), medium (level II, central 50%) and low (level III, lower 25%) classes based on the distribution of index values.

4 Preliminary recommendations for policy

The results of this study contribute to policymaking through: 1) quantifying the spatial and temporal changes in the biophysical supply and value of different ecosystem services with different climate and land cover conditions, 2) identifying the relative importance of different areas in the basin in biodiversity conservation and providing benefits of ecosystem services, and 3) determining the relative changes of the ecological compensation schemes applied for different ecosystem services under future climate and land cover scenarios. With the SEEA approach, the characteristics in the status and potential variation of different ecosystem contents and ecosystem services under the coupling impacts of climate change and land-urbanization have been revealed. However, more efforts could be given from the following aspects to improve the assessment and modeling performance, which provide more support for policy.

4.1 Strengthening of ecosystem service flow accounting

Ecosystems generate diverse services which can provide a wide range of benefits to human-beings. The valuation of ecosystem services which interact with each other, as well as the social-economic conditions, provides an important data basis for calculating the standards of ecological compensation. An overall consideration on more ecosystem services contributes to the maximum of the balance of benefits between the upstream and downstream regions. On the other hand, while the natural capital accounts provide a quantitative view on the status of ecosystem and ecosystem service stocks, further efforts should be given to the accounting of service flows, since loss of ecosystem services occurs during the transmission between the body of supply and demand, which could lead to underestimation on ecological compensation standards.

4.2 Establishing a standardized methodology framework

The diversity of index and methods used for monitoring and assessing the status of ecosystems, ecological processes and ecosystem services in different studies or regions reduces the comparability of the study results, which increases the uncertainty of monitoring-assessment-based calculation of ecological compensation standards. A standardized methodology framework with an orderly integration of environmental monitoring, natural capital accounting, ecosystem service assessment and ecological compensation determination, is needed for future studies. An in-depth research on the index system of monitoring and assessment containing important indicators relating to the biophysical and social-economic features need to be strengthened.

4.3 Constructing intelligent monitoring and assessment network

To better delineate the dynamics of ecosystems and improve the accuracy of ecosystem service assessments, more location-specific data and information (e.g., water flow, water and soil quality, ecological protection and restoration costs, natural reserve areas and policy) are needed to better support the determination and evidence-based monitoring of ecological compensation. Further efforts should be given in strengthening the long-term dynamic monitoring and assessment of ecological environment and improving coordinated inter-regional prevention and control capacity of the whole basin. Coupling with the method of natural capital accounting, regular assessments on the biophysical supply and value of ecosystem services related to ecological security at multiple scales are needed. By exploring information publishing and sharing system, the unified collection and release of monitoring and assessment information, as well as the data integration and sharing system for fields including the quality of watershed ecological environment, key sources of water and soil pollution and the ecological function zones are expected to be realized with the support of the SEEA-EEA approach. A system integrating real-time responses, feedbacks and warnings for the status of ecological environment is supposed to be constructed with the development and implementation of an intelligent network of ecological monitoring and assessment between the upstream and downstream regions, as well as other systematic units of the basin.

4.4 Promoting ecological compensation demonstration zones

Based on the concept of "co-construction and sharing" and the principle of "who benefits, who compensates", efforts should be given in promoting the construction of ecological compensation demonstration zones, especially in areas where the ecology is fragile or the capacity of providing ecosystem services is high, such as the north part of Guangxi (e.g., Hechi, Baise, Liuzhou), the south part of Guizhou and the northwest part of Yunnan. Combined with the plan of ecological functional zones and the integration of regional sources advantages, a series of ecological projects, including ecological protection and restoration, ecological agriculture, ecological industry, ecological culture and tourism, and the construction of ecologically livable urban and rural areas, are promoted. Cooperation and exchanges on ecological practices are supposed to promote joint development and diversified cooperation.

4.5 Reinforcing the cooperation of different institutes

Further efforts should be given to improve the administrative responsibility mechanism that combines rights, responsibilities and interests. Close cooperation among local institutes, which play critical roles in different fields, could benefit information sharing and exchange, which contributes to the long-term efficiency of ecological protection and restoration through the collaborative development of different institutes. Moreover, an evaluation system is needed to guide and supervise the implementation of ecological compensation policies.

4.6 Exploring diversified ecological compensation financing channels

Currently, the ecological compensation funds in the Xijiang river basin is mainly sourced from fiscal transfer payments, which could not meet the needs of increasing ecological compensation funds in the long run.

Therefore, on the one hand, efforts could be given in striving for central financial funds and gradually increasing the financial transfer payments to different regions of the basin, especially the ecological functional zones and ecologically sensitive and fragile areas (e.g., areas with Karst geomorphology). On the other hand, efforts could be given to the exploration of diversified financing channels, encouragement and boosting of social investment and the enthusiasm of ecological protection to put in place a diversified investment and financing mechanism for ecological protection, which is supported by the central and local governments and operates with a model of government guidance, social investment and market regulation.

4.7 Expansion of watershed ecological compensation models

The main purpose of ecological compensation is to realize the social equity of different regions, protect ecological environment and promote the sustainable and coordinated development of regional society and economy. Usually, a single model of financing compensation is difficult to meet the demands of ecological protectors due to the difference in the financial mechanisms among different regions. Therefore, the implementation of eco-compensation policies can choose a more flexible way, such as accelerating the construction of support policies for industries related to ecological compensation in the upstream region, adjusting the industrial structure in the upstream region, coordinating the development of the whole basin and promoting the formation of a long-term efficient mechanism of ecological compensation in the Xijiang river basin. Compared to Guangdong which is located in the downstream region of the basin, the upstream region is less developed in economy and faces dual tasks of developing economy and improving ecological environment quality, while the downstream region is more developed in economy and has advantages in manpower and financial resources. therefore, it is supposed to actively guide the downstream region to carry out counterpart assistance and exchanges with the upstream region and promote the economic development of upstream region through technical exchanges, personnel training and the development of ecological products in other places.

5 References

Abbaspour, K.C., Rouholahnejad, E., Vaghefi, S., Srinivasan, R., Yang, H., Klove, B., 2015. A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. J. Hydrol. 524, 733-752.

Ayivi, F., Jha, M.K., 2018. Estimation of water balance and water yield in the Reedy Fork-Buffalo Creek Watershed in North Carolina using SWAT. Int. Soil Water Conserv. Res. 6, 203-213.

Birhanu, L., Hailu, B.T., Bekele, T., Demissew, S., 2019. Land use/land cover change along elevation and slope gradient in highlands of Ethiopia. Remote Sensing Applications: Society and Environment 16, 100260.

Chen, H.P., 2013. Projected change in extreme rainfall events in China by the end of the 21st century using CMIP5 models. Chinese Sci. Bull. 58, 1462-1472.

Chen, M.P., Lin, E.D., 2010. Global greenhouse gas emission mitigation under representative concentration pathways scenarios and challenges to China. Adv. Clim. Change Res. 6, 436-

442.

Chesworth, W., Arbestain, M.C., Macias, F., Spaargaren, O., Mualem, Y., Morel-Seytoux, H.J., Horwath, W.R., Almendros, G., Grossl, P.R., Sparks, D.L., Fairbridge, R.W., Singer, A., Eswaran, H., Micheli, E., 2008. Classification of soils: Food and Agriculture Organization of the United Nations (FAO). In: Chesworth W. Encyclopedia of Earth Sciences Series. Springer. Dordrecht.

Duan, Y.C., Meng, F.H., Liu, T., Huang, Y., Luo, M., Xing, W., De Maeyer, P., 2019. Sub-daily simulation of mountain flood processes based on the modified Soil Water Assessment Tool (SWAT) Model. Int. J. Environ. Res. Public Health 16, 3118.

Eastman, J.R., 2012. Idrisi selva tutorial. Idrisi Production, Clark Labs-Clark University.

EPA, 2006. U.S. Environmental Protection Agency. Ecological benefits assessment strategic plan. Washington, D.C.

Feng, Y., Liu, Y., Batty, M., 2016. Modelling urban growth with GIS based cellular automate and least squares SVM rules: a case study in Qingpu-Songjiang area of Shanghai, China. Sto. Environ. Res. Risk Ass. 30, 1387-1400.

Fu, X., Wang, X.H., Yang, Y.J., 2018. Deriving sustability factors for CA-Markov land use simulation model based on local historical data. J. Environ. Manag. 206, 10-19.

Gan, H., Liu, Y.S., Wang, D.W., 2004. Simulation and analysis of the human driving factors of land use type conversion. Resource Sci. 26, 88-93.

Gao, X., Shen, J.Q., He, W.J., Sun, F.H., Zhang, Z.F., Zhang, X., Zhang, C.C., Kong, Y., An, M., Yuan, L., xU, x.c., 2019. Changes in ecosystem services value and establishment of watershed ecological compensation standards. Int. J. Environ. Res. Public Health 16, 2951.

Islam, K., Rahman, M.F., Jashimuddin, M., 2018. Modeling land use change using Cellular Automata and Artificial Neural Network: The case of Chunati Wildlife Sanctuary, Bangladesh. Ecol. Indic. 88, 439-453.

Kareiva, P., Tallis, H.T., Ricketts, T., Daily, G.C., Polasky, S., 2011. Natural Capital: Teory and practice of mapping ecosystem services. Oxford University Press, New York.

Koo, H., Chen, M., Jakeman, A.J., Zhang, F.Y., 2020. A global sensitivity analysis approach for identifying critical sources of uncertainty in non-identifiable, spatially distributed environmental models: A holistic analysis applied to SWAT for input datasets and model parameters. Environ. Modelling Software 127, 104676.

Kumar, N., Singh, S.K., Srivastava, P.K., Narsimlu, B., 2017. SWAT model calibration and uncertainty analysis for streamflow prediction of the Tons River Basin, India, using Sequential Uncertainty Fitting (SUFI-2) algorithm. Model. Earth Syst. Environ. 3, 30.

Lambin, E.F., Meyfroidt, P., 2010. Land use transitions: socio-ecologicl feedback versus socio-economic change. Land Use Pol. 27, 101-118.

Li, C., Zhao, J., Xu, Y., 2017. Examining spatialtemporally varying effects of urban expansion and the underlying driving factors. Sustainable Cities and Society 28, 307-320.

Li, D.J., Xu, E., Zhang, H.Q., 2020. Influence of ecological land change on wind erosion prevention service in arid area of northwest China from 1990 to 2015. Ecol. Indic. 117, 106686.

Li, X., Wu, P., Cao, W., 2016. Practice, problems and countermeasures of ecological compensation standard of watersheds in China. J. Econ. Water Resour. 34, 34-37.

Liu, B., Liu, S., Zheng, S., 1999. Soil conservation and coefficient of soil conservation of crops.

Res. Soil Water Conserv. 6, 32-36.
Liu, B.Y., Nearing, M.A., Risse, L.M., 1994. Slope gradient effects on soil loss for steep slopes. Trans. Am. Soc. Agric. Engin. 37, 1835-1840.
Liu, L., Feng, Q., 2015. A review of advances in payment of ecological services research in relation to a catchment. J. Desert Res. 35, 808-813.
Liu, Y.M., Zhang, J., Zhou, D.M., Gong, H.L., Li, X.J., 2011. The establishment of SWAT database in Guishui River Basin, Beijing, China. International Symposium on Water Resource and Environmental Protection 4, 2721-2724.
Long, H., Li, A., 2015. A study of local legislation of ecological compensation in river basin in China. J. Cent. South Univ. For. Technol. Soc. Sci. 9, 63-67.
Lu, F., Hu, H.F., Sun, W.J., Zhu, J.J., Liu, J.G., Zhou, W.M., Zhang, Q.F., Shi, P.L., Liu, X.P., Wu, X., Zhang, L., Wei, X.H., Dai, L.M., Zhang, K.R., Sun, Y.R., Xue, S., Zhang, W.j., Xiong, D.P., Deng, L., Liu, B.J., Zhou, L., Zhang, C., Zheng, X., Cao, J.S., Huang, Y., He, N.p., Zhou, G.Y., Bai, Y.F., Xie, Z.Q., Tang, Z.Y., Wu, B.F., Fang, J.Y., Liu, G.H., Yu, G.R., 2018. Effects of national ecological restoration projects on carbon sequestration in China from 2001 to 2010. Proc. Natl. Acad. Sci. U.S.A. 115, 4039-4044.
Lu, L., Guo, L., Zhao, S.T., 2014. Land use and land cover change on slope in Qiandongnan prefecture of Sourthwest China. J. Mt. Sci. 11, 762.
MOF, NDRC, MEP, MWR, 2016. Ministry of Finance (MOF), National Development and Reform Commission (NDRC), Ministry of Environment Protection (MEP), Ministry of Water Resource (MWR). The Guidelines for Facilitating Lateral Mechanism of Ecological Compensation between Upper and Down Streams of Cross Province River. http://jjs.mof.gov.cn/zhengwuxinxi/tongzhigonggao/201612/t20161227_2505642.html.
Mondal, M.S., Sharma, N., Kappas, M., Garg, P.K., 2020. Cellular automata (CA) contiguity filters impacts on CA Markov modeling of land use land cover change predictions results. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLIII-B3-2020, 1585-1591.
Navarro-Racines, C., Tarapues, J., Thornton, P., Jarvis, A., Ramirez-Villegas, J., 2020. High-resolution and bias-corrected CMIP5 projections for climate change impact assessments. Sci. Data 7, 7.
Osman, T., Divigalpitiya, P., Arima, T., 2016. Driving factors of urban sprawl in Giza governorate of the Greater Cairo Metropolitan Region using a logistic regression model. Int. J. Urban Sci. 20, 206-225.
Ouyang, Z.Y., Zheng, H., Xiao, Y., Polasky, S., Liu, J.G., Xu, W.H., Wang, Q., Zhang, L., Xiao, Y., Rao, E.M., Jiang, L., Lu, F., Wang, X.K., Yang, G.B., Gong, S.H., Wu, B.F., Zeng, Y., Yang, W., Daily, G.C., 2016. Improvements in ecosystem services from investments in natural capital. Science 352, 1455-1459.
Pi, H., Huggins, D.R., Sharratt, B., 2020. Influence of clay amendment on soil physical properties and threshold friction velocity within a disturbed crust cover in the inland pacific Northwest. Soil and Tillage Research 202, 104659.
Piao, S., Fang, J., Ciais, P., Peylin, P., Huang, Y., Sitch, S., Wang, T., 2009. The carbon balance of terrestrial ecosystems in China. Nature 458, 1009-1013.
Pontius, J.R.G., Malanson, J., 2005. Comparison of the structure and accuracy of two land change models. International Journal of Geographical Information Science 19, 243-265.
Pontius, R.G., Parmentier, B., 2014. Recommendations for using the relative operating

characteristics (ROC). Landscape Ecol. 29, 367-382.
Rao, E.M., Ouyang, Z.Y., Yu, X., Xiao, Y., 2014a. Spatial patterns and impacts of soil conservation service in China. Geomorphology 207, 64-70.
Rao, E.M., Xiao, Y., Ouyang, Z.Y., 2014b. Assessment of flood regulation service of lakes and reservoirs in China. J. Nat. Resour. 29, 1356-1365.
Rao, E.M., Xiao, Y., Ouyang, Z.Y., Jiang, B., Yan, D.H., 2014c. Status and dynamics of China's lake water regulation. Acta Ecol. Sin. 34, 6225-6231.
Renard, K., Freimund, J., 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. J. Hydrol. 157, 287-306.
Rodrigue, J.P., Comtois, C., Slack, B., 2017. The geography of transport systems (4th ed.). Routledge, New York.
Sarma, K., Barik, S.K., 2010. Geomorphological risk and conservation imperatives in nokrek. Biosphere reserve, Meghalaya using geoinformatics. NeBIO 1, 14-24.
Saxton, K.E., Rawls, W.J., 2006. Soil water characteristics estimates by texture and organic matter for hydrologic solutions. Soil Science Society of America Journal 70, 1569-1578.
Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M., Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., D., D., Douglass, J., 2016. InVEST+VERSION+User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund. http://data.naturalcapitalproject.org/invest-releases/3.5.0/userguide.
Sun, J., Dang, Z., Zheng, S., 2017. Development of payment standards for ecosystem services in the largest interbasin water transfer projects in the world. Agric. Water Manage. 182, 158-164.
Tao, S., Zhang, Q., Zhang, S., 1998. The great floods in the Changjiang river valley in 1998. Clim. Environ. Res. 3, 3-12.
Tian, Y.C., Bai, X.Y., Huang, Y.L., Zhang, Q., Zhang, Y.L., 2019. Ecological compensation standard accounting of Chishui River Basin based on ecosystem service value. Trans. Chinese Soc. Agr. Mac. 50, 312-322.
USDA, 1999. United States Department of Agriculture. Soil Survey Staff. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys (2nd ed.). Natural Resources Conservation Service. U.S. Department of Agriculture Handbook.
Valiantzas, J.D., 2018. Temperature-and humidity-based simplified Penman’s ET0 formulae. Comparisons with temperature-based Hargreaves-Samani and other methodologies. Agr. Water Manag. 208, 326-334.
Vander Laan, J.J., Hawkins, C.P., Olson, J.R., Hill, R.A., 2013. Linking land use, in-stream stressors, and biological condition to infer causes of regional ecological impairment in streams. Freshw. Sci. 32, 801-820.
Wang, S.M., Dou, H.S., 1998. Records for Chinese Lakes. Science Press, Beijing.
Wei, H.B., Li, R., Yang, Q.K., 2002. Research advances of vegetation effect on soil and water conservation in China. Acta Phytoecol. Sin. 26, 489-496.

Williams, J.R., 1990. The Erosion-Productivity Impact Calculator (EPIC) model: A case history. Philosophical Transactions Biological Sciences 329, 421-428.

Williams, J.R., Renard, K., Dyke, P.T., 1983. EPIC - A new method for assessing erosions effect on soil productivity. J. Soil Water Conserv. 38, 381-383.

Xu, L., He, N.P., Yu, G.R., 2018. Li Xu, Nianpeng He, Guirui Yu. Datasets of carbon density for China terrestrial ecosystems. 2010. Science Data Bank.

Xu, W.H., Xiao, Y., Zhang, J.J., Yang, W., Zhang, L., Hull, V., Wang, Z., Zheng, H., Liu, J.G., Polasky, S., Jiang, L., Xiao, Y., Shi, X.W., Rao, E.M., Lu, F., Wang, X.K., Daily, G.C., Ouyang, Z.Y., 2017. Strengthening protected areas for biodiversity and ecosystem services in China. Proc. Natl. Acad. Sci. U.S.A. 114, 1601-1606.

Yang, W., Liu, W., Vina, A., Luo, J., He, G., Ouyang, Z.Y., Zhang, H.M., Liu, J.G., 2013. Performance and prospects of payments for ecosystem services programs: Evidence from China. J. Environ. Manag. 127, 86-95.

Yin, R., Liu, C., Zhao, M., Yao, S., Liu, H., 2014. The implementation and impacts of China's largest payment for ecosystem services program as revealed by longitudinal household data. Land Use Pol. 40, 45-55.

Yin, R., Liu, T., Yao, S., Zhao, M., 2013. Designing and implementing payments for ecosystem services programs: lessons learned from China’s cropland restoration experience. For. Policy Econ. 35, 66-72.

Zhang, K.L., Shu, A.P., Xu, X.L., Yang, Q.K., Yu, B., 2008. Soil erodibility and its estimation for agricultural soils in China. J. Arid Environ. 72, 1002-1011.

Zong, Y., Chen, X., 2000. The 1998 flood on the Yangtze, China. Nat. Hazards 22, 165-184.