Research in Ecology
https://journals.bilpubgroup.com/index.php/re

ARTICLE

Bridging Ecosystem Value and Decision-Making: GEP Accounting in Nanhua County, China, and Pathways for Green Policy

Yongfei You [1], *Youwei Zuo* [2], *Yaxin Jiang* [3], *Lu Xu* [1], *Zhengwen He* [4], *Yihong Tang* [1], *Bo Lei* [5], *Wei Yuan* [1], *Hongping Deng* [2*]

[1] *Chongqing Yike Environmental Protection Engineering Co., Ltd, Chongqing 404100, China*
[2] *School of Life Sciences, Southwest University, Chongqing 404100, China*
[3] *College of Pharmaceutical Sciences, Southwest University, Chongqing 404100, China*
[4] *Chuxiong Yi Autonomous Prefecture Bureau of Ecology and Environment, Chuxiong 675000, China*
[5] *Chongqing Academy of Environmental Sciences, Chongqing 404100, China*

ABSTRACT

Establishing effective mechanisms for recognizing and realizing ecosystem value is a central challenge in linking ecological conservation with sustainable development. Gross Ecosystem Product (GEP) accounting has emerged as an important tool for quantifying ecosystem service contributions, yet its application at the county scale—particularly in mountainous regions—remains limited. Taking Nanhua County in southwestern China as a representative case, this study develops a county-level GEP accounting framework tailored to complex topography and forest-dominated landscapes. By integrating biophysical models (InVEST, RUSLE, and SCS-CN) with market-based and replacement cost valuation methods, provisioning, regulating, and cultural services were systematically assessed for the year 2024. Results show that the total GEP reached 163.25 billion CNY, with regulating services accounting for 93.17%. Provisioning services were mainly supported by forestry and specialty agriculture, while cultural services were driven by ecotourism and landscape-related benefits. Spatial analysis revealed pronounced heterogeneity, with high-value GEP areas concentrated in forested southern mountains and lower values in central basins and urbanized zones. These findings highlight the ecological structure

*CORRESPONDING AUTHOR:
Hongping Deng, School of Life Sciences, Southwest University, Chongqing 404100, China; Email: denghp@swu.edu.cn

ARTICLE INFO
Received: 22 December 2025 | Revised: 26 February 2026 | Accepted: 2 March 2026 | Published Online: 15 June 2026
DOI: https://doi.org/10.30564/re.v8i3.12917

CITATION
You, Y., Zuo, Y., Jiang, Y., et al., 2026. Bridging Ecosystem Value and Decision-Making: GEP Accounting in Nanhua County, China, and Pathways for Green Policy. Research in Ecology. 8(3): 275–293. DOI: https://doi.org/10.30564/re.v8i3.12917

underpinning county-level ecosystem value and demonstrate the potential of GEP accounting to support spatial prioritization and comparative assessment. While subject to uncertainty inherent in ecosystem service valuation, the framework provides an indicative basis for exploring pathways that link ecological protection with green development in similar mountainous regions.

Keywords: GEP; County Region; Territorial Spatial Planning; Ecological Compensation

1. Introduction

Ecosystem service valuation is a core topic in ecological economics and sustainable science, providing an analytical bridge between ecosystem conservation and green development decision-making [1]. Since the pioneering work of Costanza et al. [2], valuation research has expanded from conceptual frameworks to policy-oriented accounting approaches that aim to make nature's contributions visible, measurable, and comparable with conventional economic indicators. Under accelerating biodiversity loss and ecosystem degradation, quantifying natural capital and its contributions to human well-being has become a shared priority for both scholars and policymakers [3]. Within this global shift, Gross Ecosystem Product (GEP) has emerged as a comprehensive indicator that monetizes the supply capacity of ecological products by accounting for provisioning goods, regulating services, and cultural services delivered by ecosystems [4]. In parallel, international initiatives such as the United Nations System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA-EA) and the European Union's Mapping and Assessment of Ecosystems and their Services (MAES) programme have promoted standardized ecosystem accounting and accelerated its transition from research practice toward governance infrastructure [5,6].

Among the most policy-relevant directions, integrating GEP accounting with ecological compensation mechanisms has attracted increasing attention. Ecological compensation aims to internalize environmental externalities and incentivize conservation by transferring resources from beneficiaries to providers of ecosystem services. However, compensation standards derived from opportunity costs, willingness-to-pay, or negotiated transfers can be subjective and weakly linked to actual ecological contributions, which undermines perceived fairness and policy effectiveness—especially where ecosystem services are spatially heterogeneous and spill over administrative boundaries [7]. GEP accounting offers a service-contribution-based alternative by providing a unified monetary measure of ecosystem service flows, enabling compensation design to better reflect "what is provided, where it is provided, and who benefits" [8]. In this sense, the value of GEP is not merely the production of an aggregate number, but the ability to translate ecological functions into decision-ready information for setting standards, targeting funds, and evaluating outcomes.

This integration between GEP and compensation also clarifies why technical progress matters: robust compensation requires credible, spatially explicit quantification of services, particularly regulating services (e.g., climate regulation, water conservation, soil retention) that generate large benefits but are difficult to observe directly. Recent advances in remote sensing provide consistent, high-resolution data for land cover, vegetation productivity, evapotranspiration, and surface characteristics, strengthening the spatial mapping of ecosystem service proxies that underpin compensation calculations [9]. In addition, the refinement and broad adoption of ecosystem service models such as InVEST and ARIES have improved methodological standardization and reproducibility, enabling analysts to convert land-use patterns into key service indicators relevant to compensation, including carbon storage/sequestration, water yield and retention, and erosion control [10,11]. The growing use of machine learning further enhances the capacity to integrate large, heterogeneous datasets, identify non-linear relationships, and improve pattern recognition for service hotspots, thereby supporting more accurate targeting and verification in compensation programs [12]. Rather than representing isolated technical trends, these developments collectively expand the feasibility of linking compensation to measurable service provision across scales and landscapes.

Empirical studies have begun to operationalize the GEP–compensation linkage across different ecosystems and governance contexts. In watershed ecological compensation, quantified water conservation and hydrological regulation services can improve equity by aligning transfers with upstream ecological contributions and downstream benefits [13–15]. In forest ecological compensation, researchers have explored linking GEP-derived values to management inputs and protection costs to improve allocation efficiency in key ecological function zones [16]. Similar approaches have been extended to grassland and marine ecosystems, suggesting that the coupling logic can be adapted to multiple ecological systems and service types [17,18]. Beyond fiscal transfers, market-based instruments are also emerging as complementary pathways. Carbon sink trading and water rights trading translate ecosystem functions into tradable assets, potentially enhancing the efficiency and durability of compensation when supported by transparent service accounting [19,20]. Under carbon neutrality targets, nature-based solutions (NbS) have further stimulated interest in mechanisms that deliver carbon benefits together with co-benefits such as water regulation and soil conservation, reinforcing the role of GEP as a quantitative foundation for performance-oriented compensation and market arrangements [21,22]. Meanwhile, ecological product certification and green finance tools can broaden the institutional toolbox for value realization, offering diversified pathways when integrated with robust accounting results [23].

GEP accounting also has growing relevance for territorial spatial planning, where spatially explicit ecosystem service information can support delineation of ecological conservation redlines, urban development boundaries, and basic farmland protection redlines. By identifying priority areas for protection, ecological corridors, and zones where land-use conversion would cause disproportionate service losses, GEP-based evidence can help optimize landscape patterns and manage trade-offs between conservation and development [24,25]. Applications in urban green space planning and ecological infrastructure layout further illustrate the role of accounting outputs as an evidence layer that can be interpreted by planners and linked to investment priorities [26]. Nevertheless, compensation and spatial planning are highly policy-sensitive domains, and thus require service-specific, spatially interpretable results that can be communicated to stakeholders and audited by institutions.

Despite substantial progress, county-scale GEP studies remain limited, particularly in mountainous ecological functional areas in Southwest China. Existing work often provides a single-year accounting snapshot but offers insufficient evidence on how GEP results can be translated into concrete decision instruments—such as compensation standards, spatial zoning rules, or sectoral development pathways—under conditions of strong topographic heterogeneity and forest-dominated service profiles. To address this gap, we take Nanhua County as a representative mountainous county and develop an integrated GEP accounting framework that combines multi-source datasets with spatially explicit modeling to (i) quantify provisioning, regulating, and cultural services within a unified accounting structure, (ii) characterize the compositional structure and spatial heterogeneity of GEP across land-use and terrain gradients, and (iii) interpret service-specific outputs in relation to practical policy levers, with an emphasis on ecological compensation and territorial spatial planning. By linking county-level GEP accounting to decision-relevant service maps and interpretable policy entry points, this study offers a replicable template for similar mountainous counties and helps move GEP from "valuation results" toward an actionable evidence base for ecological product value realization and regionally grounded green development.

2. Study Area

Nanhua County (24°44′–25°21′ N, 100°44′–101°20′ E) is located in west-central Yunnan Province, China (**Figure 1**). Encompassing a total area of 2,343 km^2, the county exhibits a typical terrain pattern of "mountains as the main body, interspersed with basins." The elevation spans from 1,560 to 2,861 m, with mountainous areas accounting for 93.6% of the total area. The region experiences a low-latitude plateau monsoon climate, characterized by an average annual temperature of 14.9 °C and an average annual precipitation of 843 mm. These hydrothermal conditions foster a land use structure dominated by forests, with a forest coverage rate reaching 71.06%. Other land use types, including cropland (12.11%) and grassland (7.95%), are interwoven, collectively forming a typical ecological transition zone from the Yunnan-Guizhou Plateau to the Hengduan Mountains. These unique physical geographical characteristics make it an important water conservation area at the source of the Red River and provide an ideal sample for studying ecosystem services in the mountainous regions of Southwest China.

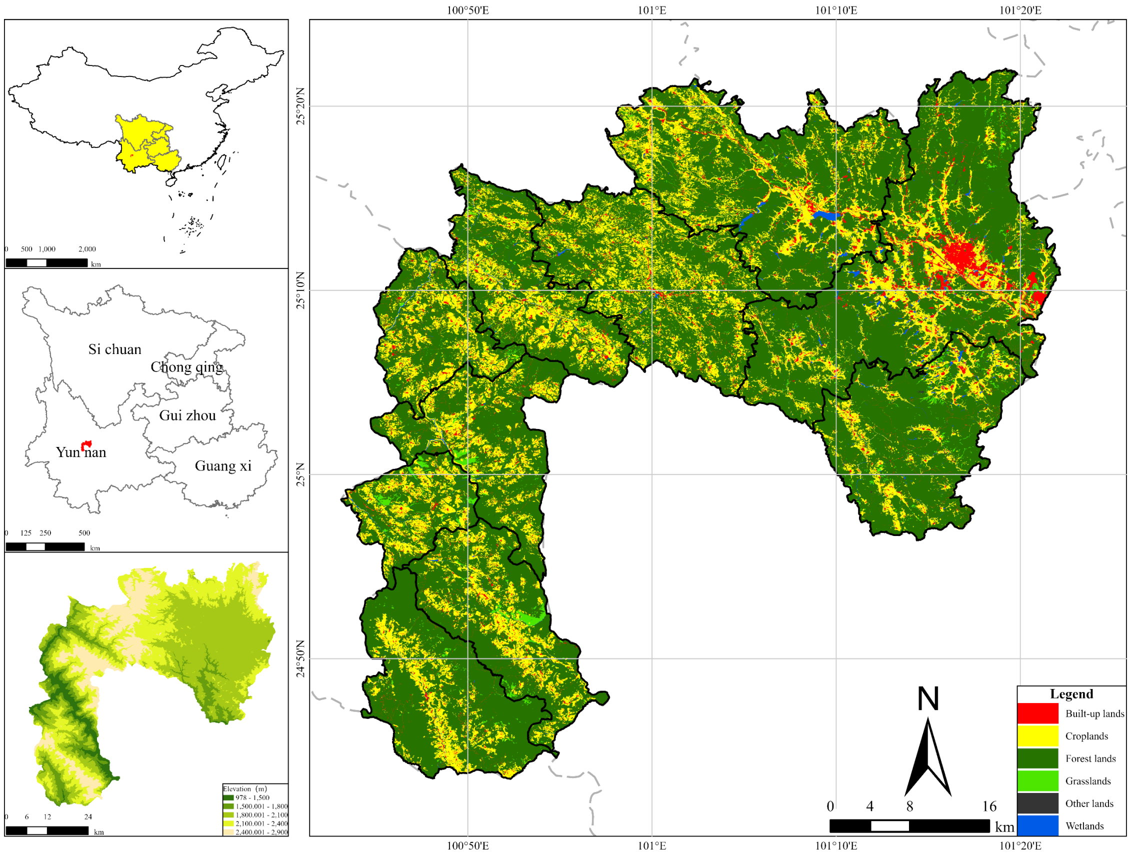

Figure 1. Geographical location and land use type of Nanhua County.

3. Research Methodology

3.1. Indicator System

Integrating the characteristics, structure, and ecological processes of typical county-level ecosystems in the southwestern region, and based on the theory and methods of ecosystem service function value accounting [27], this study established a GEP accounting indicator system tailored to the local context through functional refinement and indicator specification. This system includes three major categories: product provision value, regulating service value, and cultural service value, encompassing 16 functional indicators. The technical framework of this study is detailed in **Figure 2**.

3.2. Accounting Methods

3.2.1. GEP Accounting Method

GEP is defined as the sum of the value of products and services provided by ecosystems to humans. It involves calculating the total economic value of ecosystem products and services based on the quantification of their functional capacity [28]. The formula is as follows:

$$GEP = EPV + ERV + ECV \tag{1}$$

Where: GEP is the Gross Ecosystem Product; EPV is provisioning services value; ERV is regulating services value; ECV is cultural services value.

Provisioning services value is assessed using the market value method. Regulating services include six functions: water conservation, soil retention, flood storage, air purification, water purification, and climate regulation. Each service function has corresponding methods for quantifying its physical quantity and value. The total economic value of regulating services is the sum of the values of each service function, combined with national and local price standards. Cultural services refer to the non-material benefits people obtain from the aesthetic landscape of ecosystems and their ethnic culture, including spiritual feelings, knowledge acquisition, and recreation. The value of cultural services is accounted for from two aspects: leisure tourism and landscape value. Detailed calculation methods are provided in **Appendix A**.

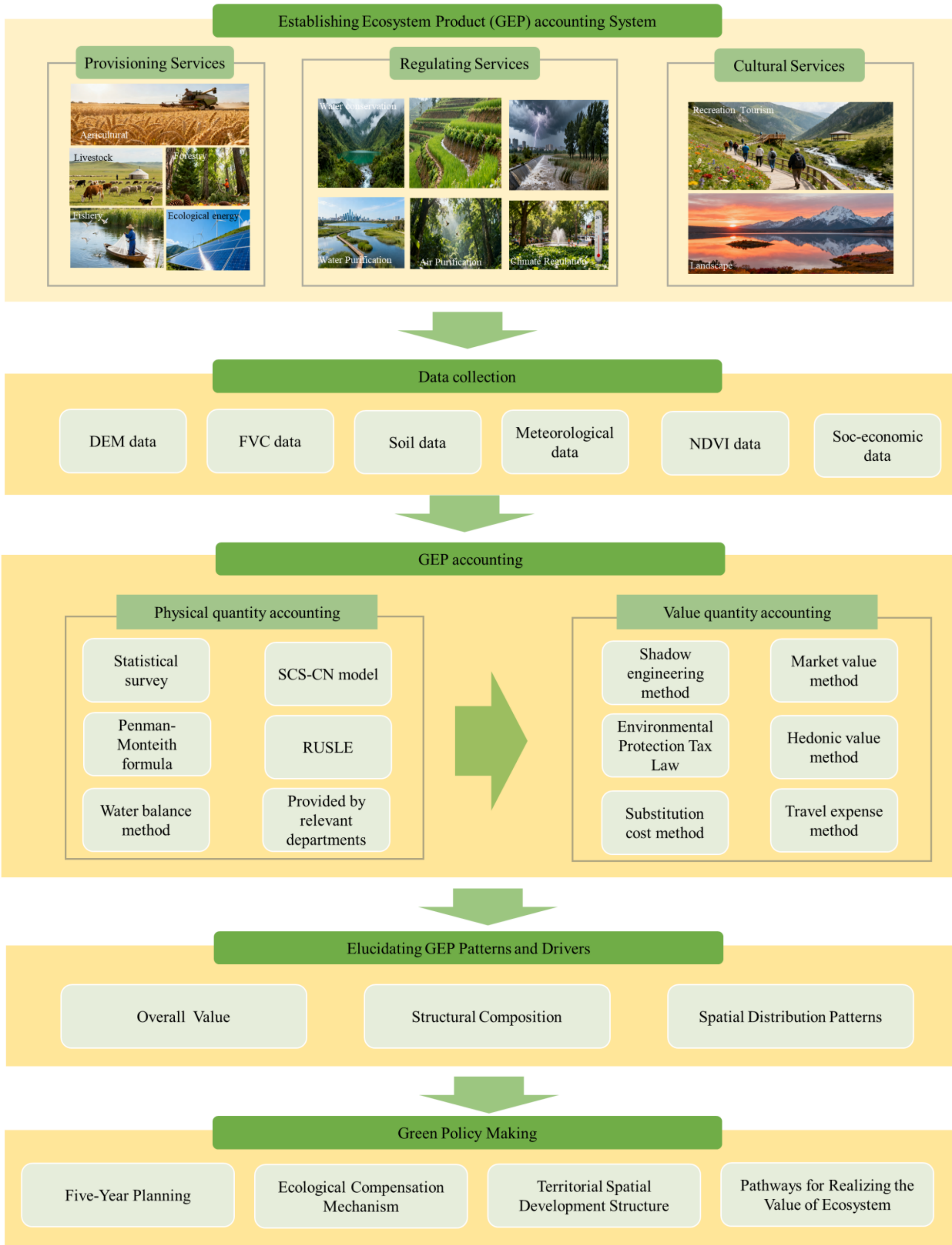

Figure 2. Technical framework of this study.

3.2.2. Methodological Specifications

While the core accounting methodologies applied in this study—such as biophysical modeling using InVEST, and valuation based on market prices and replacement costs—are well established in the ecosystem services literature, and the national technical guideline Ecosystem assessment—Technical guidelines for terrestrial gross ecosystem product accounting (GB/T 46869—2025) has been formally issued, the key contribution of the present GEP framework lies in its systematic integration and localized parameterization, designed to align with the specific ecological and socio-economic context of typical mountainous counties in southwestern China. The specificity and value of this framework are demonstrated through the consistent application and local adaptation of established methods to generate spatially explicit, context-relevant outcomes that can inform spatial planning, ecological compensation, and sustainable management in comparable mountainous socio-ecological systems. This is reflected in three main aspects:

(1) Indicator Selection Focused on Dominant Services

The accounting prioritizes and details regulating services—such as water retention, soil conservation, and climate regulation—that are of critical ecological importance in forested mountainous regions. This approach captures the structural role of these services in sustaining local livelihoods and delivering downstream benefits, moving beyond a generic checklist of ecosystem services.

(2) Localized Calibration of Parameters

Key model parameters and valuation coefficients were calibrated using locally sourced data to enhance representativeness. Examples include:

Deriving regional values for the rainfall erosivity factor R and soil erodibility factor K in the RUSLE model based on county-level meteorological and soil data.

Applying locally surveyed costs of reservoir construction and maintenance as the replacement cost for water-related services, ensuring that valuations reflect local economic conditions.

Valuing provisioning services (e.g., wild mushrooms, characteristic medicinal plants) using local market prices and production statistics to capture region-specific economic profiles.

(3) Pragmatic Integration of Data and Methods

The framework combines remote-sensing data, regional statistical yearbooks, field-based parameters, and established models in a practical manner to address data-availability constraints in complex terrain. This integrated approach seeks to balance scientific rigor with operational feasibility at the county scale.

The spatial visualization and pattern analysis in this study focus specifically on regulating services. This focus is based on the following considerations: (a) The biophysical processes underpinning regulating services (e.g., water retention, soil conservation) exhibit explicit spatial dependencies. Their supply can be modeled as continuous surfaces using spatially explicit tools (e.g., InVEST, RUSLE), making them well-suited for detailed spatial mapping and pattern analysis. (b) Regulating services constitute the dominant component of GEP in the study area. Consequently, their spatial patterns are critical for understanding the regional ecological functional baseline. (c) The valuation of material provisioning services is often more closely linked to administrative units (e.g., townships) in economic statistics, while spatially refined assessment of cultural services relies on higher-resolution data on human activities, which falls beyond the current data foundation. Therefore, to ensure the scientific robustness and reliability of the spatial analysis, this study provides an in-depth exploration of the spatial heterogeneity of regulating services. The results offer core support for identifying key ecological spaces and guiding spatial planning.

3.3. Data Sources

Data for material products primarily came from the Nanhua County Forestry and Grassland Bureau, Agriculture and Rural Affairs Bureau, and Statistics Bureau. Prices for some material products that could not be obtained were sourced from market research and statistical yearbooks. Data related to cultural services, including leisure tourism, came from the Nanhua County Culture and Tourism Bureau statistics. The list and area data of benefiting land and residential areas were provided by the County Housing, Urban-Rural Development Bureau, and Planning and Natural Resources Bureau. Meteorological station data within Nanhua County came from the Meteorological Bureau, with some data from surrounding stations sourced from the National Meteorological Science Data Center (https://data.cma.cn/). DEM data came from the Geospatial Data Cloud website (https://www.gscloud.cn/). Fractional Vegetation Cover (FVC) data used products from the Ministry of Ecology and Environment's Satellite Application Center (https://search.earthdata.nasa.gov/). Soil data came from the ”1:1,000,000 Soil Database of China” by the Nanjing Institute of Soil Science, Chinese Academy of Sciences. Details are provided in **Appendix B**.

4. Results and Analysis

4.1. GEP and Structural Characteristics

According to the accounting results, the total GEP of Nanhua County in 2024 was 163.249 billion yuan (**Table 1**). In terms of value composition, regulating services dominated absolutely, with a value of 152.100 billion yuan, accounting for 93.17% of the total GEP, highlighting the core role of regulatory functions in the county's ecosystem (**Figure 3**). The values of material products and cultural services were relatively small, at 4.796 billion yuan and 6.353 billion yuan, accounting for 2.94% and 3.89%, respectively.

Within regulating services, climate regulation had the highest value (115.297 billion yuan), constituting 75.81% of the total regulating service value and representing the largest contribution to the GEP. Water conservation (23.906 billion yuan) and soil retention (12.809 billion yuan) were also significant, together forming the main body of the county's ecosystem regulating services.

Material product value primarily came from agricultural products (1.820 billion yuan) and forestry products (1.332 billion yuan). Within cultural services, leisure tourism (3.695 billion yuan) and landscape value (2.658 billion yuan) contributed equally.

Table 1. GEP accounting results of Nanhua County in 2024.

Service Category	Accounting Indicator	Physical Quantity		Value (CNY Million)	Service Category Value	
		Unit	Quantity		Total (CNY Billion)	Proportion
Provisioning Services	Agricultural Products	t	266,399	1,819.78	4.80	2.94%
	Livestock Products	t	29,330.27	1,203.48		
	Fishery Products	t	1,400	40.39		
	Forestry Products	t	36,110.68	1,331.62		
	Ecological Energy	10,000 KWH	119,000	401.23		
Regulating Services	Water Conservation	10,000 m^3	44,385.43	23,905.99	152.1	93.17%
	Soil Retention	t	11,887.17	12,808.57		
	Flood Regulation	10,000 m^3	1,537.75	828.23		
	Air Purification	t	24,838.37	86.93		
	Water Purification	t	574.3	1.72		
	Climate Regulation	10,000 KWH	22,172,440.78	115,296.69		
Cultural Services	Recreation & Tourism	10,000 people	356.97	3,695.42	6.35	3.89%
	Landscape Value	10,000 m^2	383.51	2,657.73		
Total					163.25	100%

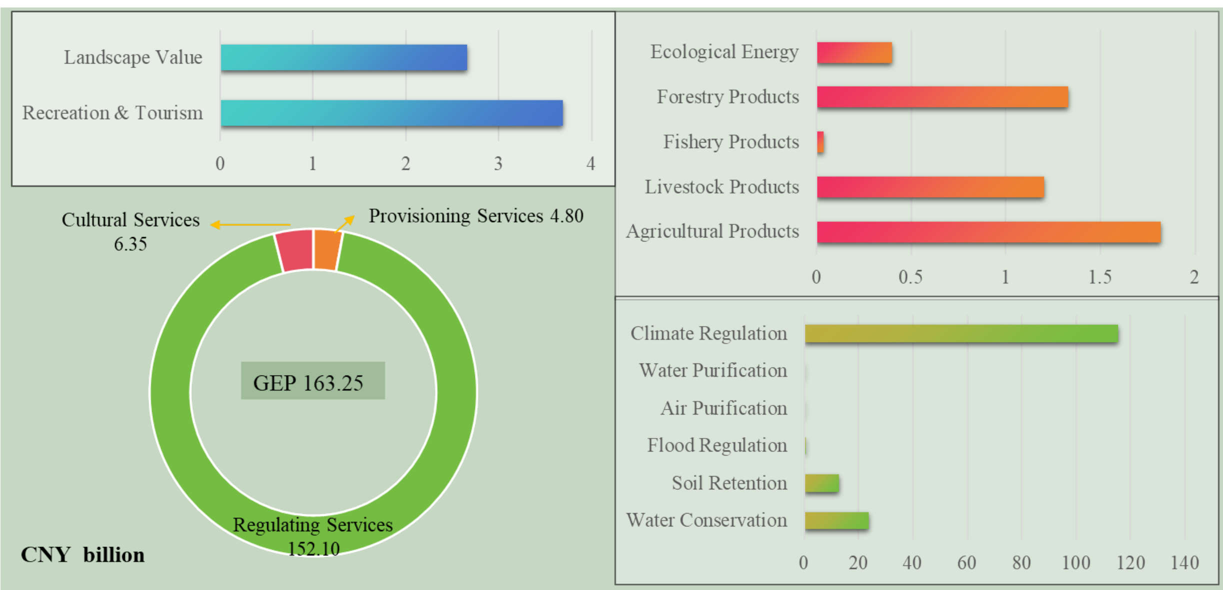

Figure 3. Composition of GEP accounting results of Nanhua County in 2024 (unit: billion yuan).

4.2. Main Characteristics of Provisioning Services

The total value of Provisioning Services was 4.796 billion yuan. The internal structure exhibited a distinct characteristic of "forestry dominance with balanced agriculture and animal husbandry". Forestry products had the highest value, reaching 1.332 billion yuan, accounting for 27.78% of the total value. The values of livestock products and agricultural products were comparable, at 1.220 billion yuan and 1.181 billion yuan, accounting for 25.44% and 24.63%, respectively. The value of ecological energy was 401 million yuan (8.36%), while fishery products had the smallest value, only 8 million yuan (0.17%). Within each category, the product structure was highly concentrated: Forestry Products: Wild mushrooms were prominent, with a value of 1.176 billion yuan, constituting 88.28% of the forestry product value and forming the absolute dominant category. As shown in **Table 2**, Livestock Products: Pork was the main product, valued at 649 million yuan, accounting for 53.20%. Agricultural Products: Vegetables (501 million yuan), medicinal herbs (373 million yuan), and flue-cured tobacco (322 million yuan) were the top three bulk products, collectively accounting for over 90% of the agricultural product value. Ecological Energy: Valued at 401 million yuan.

Table 2. Physical quantity and value of various provisioning services.

Category	Products	Physical Quantity (t)	Value (10,000 Yuan)
Agricultural Products	Wheat	13,287.8	3,454.83
	Barley	5,582.6	1,451.48
	Buckwheat	259.6	389.4
	Sorghum	347	54.13
	Potato	7,458.8	6,712.92
	Sweet Potato	154.8	100.25
	Corn	47,486	12,821.22
	Soybean	1,210.6	1,089.54
	Adzuki Beans	4.2	2.73
	Other Legumes	7,111.3	2,844.52
	Melons	10,753	4,086.21
	Vegetables	98,607	50,075
	Fruits	13,334	7,742.54
	Rice	36,514.3	10,224
	Flowers	2,170	4,089
	Flue-cured Tobacco	10,000	32,231
	Sugarcane	30	21
	Medicinal Herbs	6,792	37,327
	Peanuts	43	66
	Rapeseed	4,770	4,054.5
	Sunflower Seeds	16	15.36
	Tea	467	3,125
Livestock Products	Beef	3,496	27,968
	Mutton	1,421	12,078.50132
	Pork	18,549	64,921.5
	Poultry Meat	4,996	13,988.80352
	Poultry Eggs	772	1,158
	Rabbit Meat	33.23	49.85
	Mule Meat	29.64	50.39
	Donkey Meat	33.24	132.96
	Horse Meat	0.16	0.39
	Honey	61.41	6.14
Forestry Products	Timber	19.87	1,627.52
	Bamboo	65	58.5
	Walnuts	16,328.1	9,682.56
	Chestnuts	372.2	298.13
	Pine Nuts	149.3	464.32
	Prickly Ash	1487	941.271
	Wild Medicinal Herbs	650.9	1,551.75
	Wild Mushrooms	13,833.5	117,584.75
	Edible Wild Vegetables	254.4	482.09
	Edible Wild Fruits	99	52.07
	Various Leaves	2,680	407.36
	Various Barks	110	5.5

Table 2. *Cont.*

Category	Products	Physical Quantity (t)	Value (10,000 Yuan)
Fishery Products	Aquaculture	1,400	4,039
Ecological Energy	Wind & Solar Power	1,190	40,123

Note: Unit of measurement: Flowers: 10,000 stems; Wind & Solar Power: million kWh.

The structure of material products in Nanhua County is highly coupled with its natural endowment as a ”mountainous county” and its traditional agro-forestry industrial base (**Figure 4**), specifically reflected in: (1) Precise Matching of Forestry Advantages and Vertical Climate: The county's high forest coverage rate (71.06%) and its location on the Yunnan-Guizhou Plateau, characterized by significant vertical climate variation, provide unique growing conditions for understory products. The valuable wild mushrooms (1.176 billion yuan) originate precisely from this environment, directly embodying the transformation of ”green waters and green mountains” into ”golden and silver mountains.” Simultaneously, specialty economic forest products like walnuts (97 million yuan) and prickly ash (9 million yuan) also demonstrate the potential for value-added utilization of mountainous forest land resources. (2) Spatial Adaptation of Agricultural and Livestock Structure to Land Resources: Under the constraints of limited arable land in mountainous areas, agricultural products primarily consist of vegetables, medicinal herbs, and flue-cured tobacco, which are highly adaptable and have high economic value. This strategy avoids large-scale competition with plain agriculture while fully leveraging the advantages of specialized mountainous cultivation. The animal husbandry sector is dominated by pork (649 million yuan), aligning with the characteristics of scattered household farming in mountainous areas and forming a courtyard circulation system with agricultural production (providing feed). (3) Green Alignment of Clean Energy with Natural Conditions: The value of ecological energy (wind and solar power), amounting to 401 million yuan, benefits from the county's relatively good wind and solar resources. This not only contributes to the value of material products but also represents an important direction for the county's eco-industrialization, providing a new path for achieving green development.

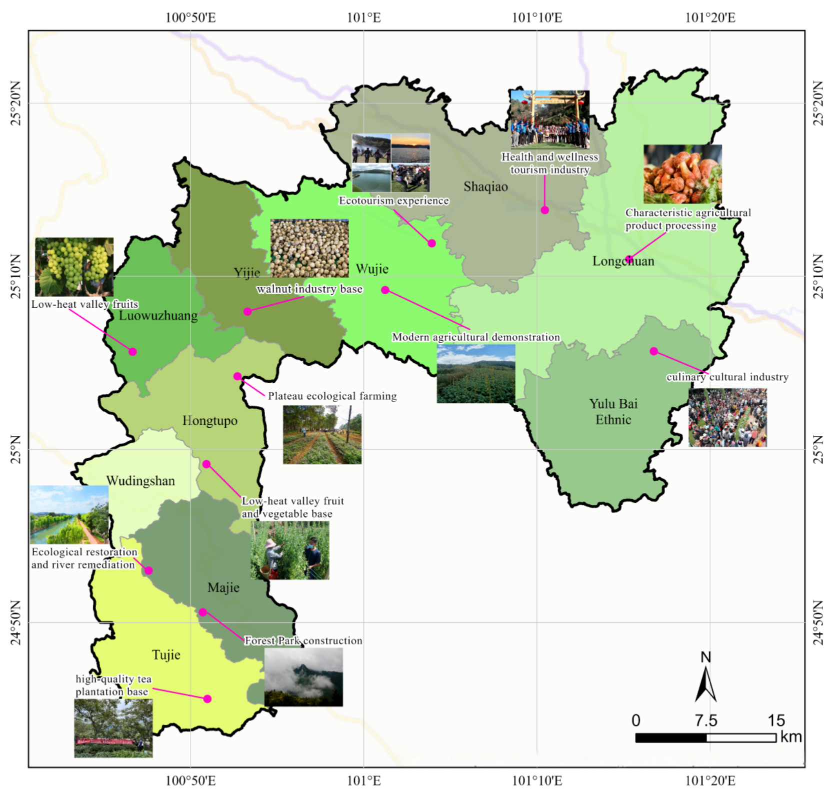

Figure 4. Spatial distribution of key industries in Nanhua County.

Note: All the pictures above are from government publicity materials.

In summary, the material product structure of Nanhua County is the result of long-term interaction and optimal adaptation between its natural endowment and human industrial choices. High-value forestry products (especially wild mushrooms) and specialty agricultural products (medicinal herbs, flue-cured tobacco) highlight the comparative advantages of a mountainous county, while ecological energy represents a future green development direction. This structural characteristic suggests that when formulating ecological economic development policies, priority should be given to consolidating and amplifying the core advantage of forestry, while steadily promoting the upgrading of characteristic agriculture and the development of clean energy.

4.3. Main Characteristics of Regulating Services

In 2024, the total value of ecosystem regulating services in Nanhua County reached 152.100 billion yuan, accounting for an absolute dominant share of 93.17% of the total GEP. This underscores its functional role as a key component of the ecological security barrier in southwestern China.

Internally, the structure exhibited a distinct pattern characterized by ”climate regulation as the core, supported by water conservation and soil retention” (**Figure 3**). The value of climate regulation was the highest, reaching 115.297 billion yuan, contributing 75.81% to the total value of regulating services and representing the primary component. Water conservation and soil retention values were 23.906 billion yuan and 12.809 billion yuan, respectively, together accounting for over 24% of the total. In contrast, the values of flood regulation and storage (828 million yuan), air purification (87 million yuan), and water purification (2 million yuan) were relatively minor. This structure indicates that the regulatory functions of Nanhua County's ecosystems are primarily manifested in three fundamental services: maintaining regional climate stability, ensuring water security, and conserving land resources.

Based on a systematic accounting of the regulating service values of ecosystems in Nanhua County, this study reveals significant functional differentiation among different ecosystem types in the provision of these services (**Table 3**). Forest ecosystems play a central role in maintaining regional ecological stability and dominate the regulating services, with a total value of 116.540 billion yuan (76.61%). Their contributions are particularly prominent in climate regulation (91.383 billion yuan), water conservation (14.511 billion yuan), and soil retention (9.883 billion yuan). Although cropland ecosystems are primarily dedicated to agricultural production, they still contribute 23.652 billion yuan (15.55%) to the total regulating service value, with significant roles in climate regulation (14.777 billion yuan) and water conservation (6.863 billion yuan), reflecting the multifunctionality of agricultural ecosystems. Furthermore, wetlands possess the crucial ecological function of acting as ”natural purifiers”. While the total value of wetland ecosystems is relatively low (238 million yuan, 0.16%), their specialized function in water purification (1 million yuan) is irreplaceable. Notably, land-use changes driven by human activities impact ecosystem service functions. The extremely low regulating service values of barren land (5 million yuan) and impervious surfaces (85 million yuan) indicate severe degradation of ecological functions in these land-use types. These accounting results clearly demonstrate the complementarity and differences among ecosystems in providing regulating services, offering a scientific basis for delineating regional ecological conservation priorities and optimizing land use.

Table 3. Regulation service value of different ecosystems.

Items	Cropland	Forest	Shrub	Grassland	Wetland	Barren	Impervious	Total Value
Flood regulation and storage	0.93	6.95	0.27	0.14	0	0	0	8.29
Air purification	0.13	0.68	0.03	0.03	0	0	0	0.87
Climate regulation	147.77	913.83	44.28	44.81	2.01	0.04	0.33	1,153.07
Water conservation	68.63	145.11	8.71	15.78	0.34	0.01	0.51	239.08
Water Quality Purification	0	0	0	0	0.01	0	0	0.02
Soil conservation	19.06	98.83	6.97	3.21	0.02	0	0.01	128.11
Total	236.52	1,165.4	60.26	63.98	2.38	0.05	0.85	1,521.14
Proportion(%)	15.55%	76.61%	3.96%	4.21%	0.16%	0.00%	0.06%	/

Note: The ”vegetation-flood regulation”: component in flood regulation has already been accounted for in the water conservation function, thus this item requires deduction during the aggregation process.

4.4. Spatial Distribution Characteristics of Regulating Services

Spatial distribution analysis reveals a highly uneven pattern of regulating service values in Nanhua County, strongly correlated with topography and land use types. As shown in **Figure 5**, high-value areas are highly concentrated: These areas, particularly for climate regulation and water conservation, form contiguous zones in the southern and southwestern mountainous regions of the county. This area represents the core distribution zone of Nanhua's forest resources, characterized by high vegetation coverage and intact ecosystems, which provide extremely powerful carbon sequestration, oxygen release, water conservation, and soil retention functions. Low-value areas show a point-axis distribution: These are primarily located in the central basin, along major transportation routes, and in urban built-up areas. Intensive human activity and relatively low surface vegetation coverage in these zones result in weaker ecosystem regulating functions. Critically, the spatial distributions of individual regulating services show high consistency. Areas with high climate regulation value typically also exhibit high values for water conservation and soil retention. This reveals the synergy of forest ecosystems in providing multiple regulating services simultaneously. It also implies that protecting the forested southern mountains can yield multiple benefits for climate, water, and soil concurrently.

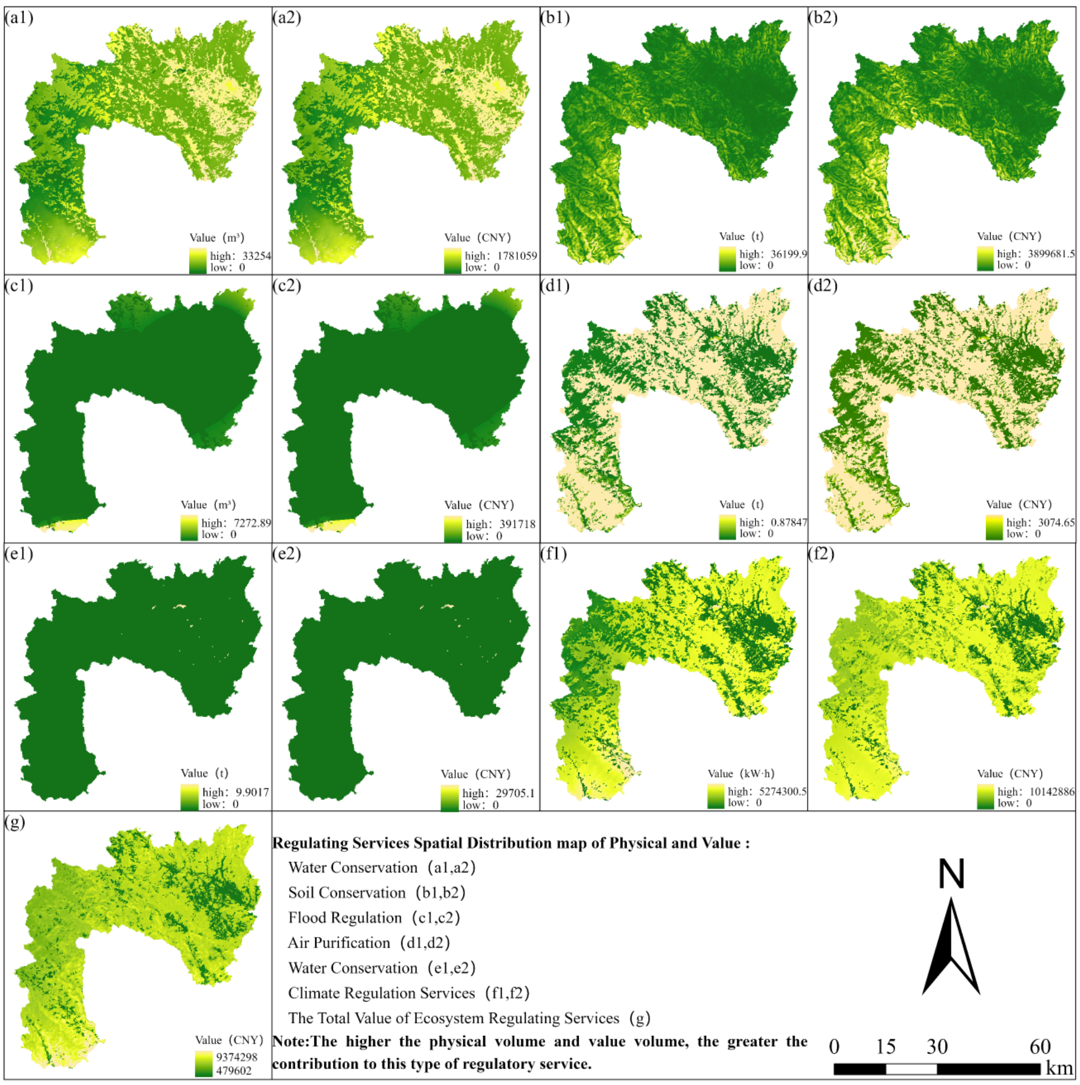

Figure 5. Regulating services spatial distribution map of physical and value.

Note: The higher the physical volume and value volume, the greater the contribution to this type of regulatory service.

4.5. Main Characteristics of Cultural Services

In 2024, the total value of cultural services provided by the ecosystem in Nanhua County reached 6.353 billion yuan, accounting for 3.89% of the county's total GEP. The internal structure exhibits a distinct characteristic of ”tourism dominance supported by landscape value.” The value of recreational tourism was 3.695 billion yuan, constituting 58.17% of the total cultural service value, while the landscape value was 2.658 billion yuan, representing 41.83%. This structure indicates that the cultural service value of Nanhua County has formed a relatively balanced dual-driven model. It generates economic benefits not only through direct tourism receipts but also by enhancing the value of surrounding land and properties via the aesthetic appeal of the natural landscape, collectively forming a crucial pathway for transforming ”green mountains and clear waters” into ”golden and silver mountains.”

Spatial analysis, integrated with the distribution characteristics of Nanhua County's ecosystems, reveals the following patterns in the distribution of cultural service value. High-value areas for recreational tourism are primarily located in regions rich in ecotourism resources, including the highly forested southern mountainous areas and river valleys with unique ecological landscapes. Leveraging their high-quality ecological environment and distinctive natural scenery, these areas attract a significant number of tourists, generating substantial economic value. Conversely, high-value areas for landscape value are mainly found in the peripheral zones of areas with superior ecological environments, particularly residential areas and land parcels that benefit from high-quality ecological views. These areas experience a significant premium effect due to their proximity to an excellent ecological environment.

5. Discussion

5.1. Structural Characteristics of County-Level GEP and Ecological Implications

The GEP accounting results for Nanhua County reveal a highly imbalanced internal structure, dominated by regulating services, which account for over 90%. This structural characteristic reflects the fundamental ecological role of forest-based mountainous ecosystems in providing large-scale, non-material benefits such as climate regulation, water conservation, and soil retention. Similar patterns have been observed in other forest-rich regions, where regulating services substantially exceed provisioning and cultural services in monetary valuation [29–31].

From an ecological perspective, this dominance is closely linked to the county’s natural endowments, including high forest coverage, complex topography, and relatively low intensity of land conversion. Together, these factors enhance regional-scale ecological processes such as evapotranspiration, carbon sequestration, and hydrological regulation. In contrast, provisioning services are constrained by limited arable land and fragmented agricultural landscapes, while cultural services depend on accessibility and market demand.

Importantly, the GEP structure highlights the dependence of local economic activities on underlying ecological functions. Forestry products, specialty agriculture, and ecotourism are indirectly supported by regulating services through stable microclimates, soil fertility, and water availability. This interdependence indicates that maintaining ecosystem integrity is a prerequisite for sustaining existing livelihood systems in mountainous counties, rather than an external constraint on development. This finding also underscores the significant potential of Nature-based Solutions (NbS) hold significant potential for achieving win-win outcomes for ecological conservation and economic development [32]. The development advantages of Nanhua County are deeply rooted in its ecosystem services.

5.2. Spatial Distribution Characteristics for Spatial Prioritization and Planning Support

Spatially explicit outputs provide a diagnostic lens for understanding ecosystem service distribution, informing spatial prioritization when integrated with socio-economic constraints and governance realities. Recent county-level studies in China demonstrate that mapping ecological product values can support spatial planning by identifying hotspots and potential trade-offs, while emphasizing that accounting outputs should be interpreted as indicative signals rather than rigid zoning rules [33]. Furthermore, evidence from broader empirical analyses suggests that GEP-type indicators may correlate with local green transition outcomes, reinforcing the importance of linking ecological accounting with development evaluation while requiring cautious interpretation of causality [34].

In Nanhua County, the concentration of high regulating service values in forested mountainous areas indicates their potential significance in maintaining county-scale ecological functions, such as climate regulation, runoff modulation, and erosion control. The planning value of spatial analysis lies primarily in identifying: (i) areas with synergistic occurrences of multiple regulating services, designated as "ecological conservation core zones" requiring the strictest protection measures; and (ii) areas where development intensity coincides with relatively low regulating service provision, classified as "urban-rural coordinated development zones" permitting moderate urban construction and agricultural activities. This application aligns with ecosystem accounting principles that emphasize using spatially structured information to support policy dialogues and scenario exploration.

5.3. GEP Accounting in Ecological Compensation and Benefit-Sharing

Ecological compensation represents the predominant form of compensatory conservation in China, integrating vertical fiscal transfers, horizontal inter-jurisdictional compensation, and market-based instruments. Its institutional framework has become increasingly well-defined alongside the ongoing refinement of the compensation system [35]. Recent research underscores that a key challenge lies in translating ecosystem service contributions into operational mechanisms that address spillover effects, equity, and feasibility, rather than relying solely on singular valuation metrics [36]. Within this context, GEP can serve as a complementary evidence base for identifying service-providing areas and structuring benefit-sharing discussions, particularly where ecosystem service spillovers generate upstream-downstream externalities [37].

For Nanhua County, the substantial contribution of regulating services suggests that compensation mechanism design could, in principle, consider (i) the spatial distribution of key regulating services yielding cross-administrative benefits (e.g., water retention, soil conservation) and (ii) the alignment between conservation costs and areas delivering high levels of these services. However, recent analytical frameworks emphasize that compensation standards should not be derived mechanistically from monetary valuations alone. Instead, accounting outputs should be integrated with ecological effectiveness indicators, transaction costs, and distributive considerations to avoid oversimplification. Consequently, the most constructive role of GEP in compensation discussions is to enable transparent interregional comparisons and to provide a consistent accounting reference that can be integrated with institutional and stakeholder processes.

5.4. Uncertainty and Sensitivity Analysis in County-Level GEP Accounting

Uncertainties in county-level GEP accounting stem primarily from the integration of multi-source models, heterogeneous datasets, and monetized valuation proxies within the methodological framework [38]. In this study, these uncertainties can be systematically categorized into four types: model structural uncertainty, parameter uncertainty, data uncertainty, and valuation uncertainty. The absolute values of GEP—particularly those of the dominant regulating services—are sensitive to the selection of key parameters. For example, moderate variations in evapotranspiration-related parameters would be expected to shift the magnitude of climate regulation estimates, while changes in rainfall–runoff parameterization would affect water conservation estimates. These uncertainties and sensitivities align with the prevailing understanding in recent ecosystem service assessment literature [39].

The significance of this study lies in the structural and spatial nature of its core findings, rather than in precise numerical quantification. The overarching pattern of "regulating services constituting the dominant share" and the spatially heterogeneous distribution characterized by "high-value areas concentrated in forested mountainous regions" are fundamentally driven by relatively stable geographic factors such as land cover types, topography, and ecosystem integrity. This interpretation resonates with recent academic discourse highlighting that, in ecosystem service assessments, the stability of relative patterns and rankings often outweighs the precision of absolute valuation [40]. Accordingly, the GEP results presented here should be interpreted as indicative and comparative, suitable for spatial prioritization, cross-area comparison, and exploring plausible governance pathways, rather than as exact economic outputs.

5.5. Research Limitations and Future Prospects

This study has certain limitations. Firstly, data based on a single year make it difficult to reveal the dynamic change trends and driving mechanisms of GEP. Future work needs to establish a continuous accounting mechanism to analyze the response relationships between GEP and climate change as well as land use change. Secondly, the assessment of some cultural service values still relies heavily on indirect data; future research should strengthen field surveys and questionnaire surveys to improve the assessment accuracy.

Looking ahead, GEP accounting research should be deepened in the following directions: (1) exploring spatially explicit analyses for provisioning and cultural services to enhance the comprehensiveness of GEP spatial assessment; (2) promoting the deep integration of GEP accounting with systems like territorial spatial planning and ecological-environmental zoning management to test its application effectiveness in actual decision-making. (3) deepening mechanistic research on specific regulating services (e.g., carbon sequestration) and their market-based realization pathways; (4) exploring specific schemes for incorporating GEP into government performance appraisal systems to enhance its policy influence.

6. Conclusion

This study, taking Nanhua County as a typical case, systematically constructed a GEP accounting framework suitable for typical counties in southwestern China and conducted a comprehensive accounting and in-depth analysis of the county's ecological product value in 2024. The main conclusions are as follows:

The ecological asset inventory has been clarified, revealing the fundamental characteristics of value composition. Accounting results indicate that the total GEP of Nanhua County in 2024 reached 163.249 billion yuan, exhibiting a distinct structure dominated overwhelmingly by regulating services. Their value amounted to 152.100 billion yuan (93.17%), far exceeding the values of material products (4.796 billion yuan, 2.94%) and cultural services (6.353 billion yuan, 3.89%). This fully demonstrates that the most core capital of Nanhua County lies in the immense regulating functions provided by its ecosystems, particularly the contributions of forest ecosystems to climate regulation (115.297 billion yuan), water conservation (23.906 billion yuan), and soil retention (12.809 billion yuan), which establish its fundamental role as a key regional ecological security barrier.

Spatial heterogeneity patterns were identified, pinpointing the core areas for ecological protection. Spatial analysis of GEP revealed that high-value areas are highly concentrated in the southern mountainous region, overlapping significantly with areas of high forest coverage, while low-value areas are distributed in the central basin and urban zones. This highly uneven spatial pattern clearly indicates the priorities and core areas for ecological protection, providing irrefutable scientific evidence for implementing ”targeted protection” and ”differentiated management.”

The multiple policy implications of GEP accounting for county-level green development were elucidated. Moving beyond mere accounting, this study focused on exploring the application pathways of GEP results in planning, ecological compensation, and spatial governance. The conclusions demonstrate that deeply integrating GEP into county five-year plans enables the setting of quantitative targets, optimization of spatial layout, and precise siting of projects. Using it as a benchmark for constructing ecological compensation mechanisms allows for the scientification and spatial differentiation of compensation standards. Furthermore, its spatial distribution map serves as a rigid baseline for optimizing territorial spatial patterns and constraining development activities.

Author Contributions

Conceptualization, Y.Y.; data collection, Y.T. and Z.H.; image processing, L.X.; data analysis, B.L. and Y.J.; writing—original draft preparation, Y.Y. and Y.Z.; writing—review and editing, H.D.; project administration, Y.Y.; funding acquisition, W.Y. All authors have read and agreed to the published version of the manuscript.

Funding

This work is supported by the International Science, Technology and Innovation Cooperation Project of Sichuan Province (Project No. 2024YFZ0224).

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data will be made available upon request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AI Use Statement

During the preparation of this work, the authors used ChatGPT and DeepSeek for language refinement and translation. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content, including accuracy, interpretation, and adherence to academic standards.

Appendix A. Detailed Valuation Formulas

1. Provisioning Services Value

$$V_m = \sum_{i=1}^{n} E_i \times P_i \quad (1)$$

Where: V_m is the value of provisioning services provided by the ecosystem; E_i is the yield of the i-th category of material product; P_i is the unit price of the i-th category of material product; i represents agricultural, forestry, animal husbandry, fishery products, and ecological energy, etc.

2. Regulating Service Value Accounting

- **Water Conservation Service**

This refers to the ecosystem's function of intercepting and storing precipitation, enhancing soil infiltration and storage, conserving soil moisture, regulating stormwater runoff, and replenishing groundwater, thereby increasing available water resources. This study uses the water balance method to calculate the water conservation physical quantity. The value of water conservation mainly lies in the economic value of water storage and retention, assessed using the shadow engineering method. This involves simulating the construction of water conservancy facilities with a storage capacity equivalent to the ecosystem's water conservation volume and calculating the value based on the required construction costs.

$$Q_{wr} = \sum_{i=1}^{n} A_i \times (P_i - R_i - ET_i) \times 10^{-3} \quad (2)$$

$$V_{wr} = Q_{wr} \times C_{we} \quad (3)$$

Where: Q_{wr} is the water conservation volume (m^3/a); P_i is the rainfall producing runoff (mm/a); R_i is the surface runoff (mm/a); ET_i is the evapotranspiration (mm/a); A_i is the area of the i-th ecosystem type (m^2); i is the ecosystem type, n is the total number of ecosystem types; V_{wr} is the water conservation value (yuan/a); Q_{wr} is the total water conservation volume of Nanhua County (m^3/a); C_{we} is the construction and maintenance cost of the reservoir project (yuan/m^3).

- **Soil Retention Service**

This is the function of ecosystems (e.g., forests, grasslands) to protect soil through canopy, litter, root systems, etc., reducing rainfall erosivity, increasing soil erosion resistance, and minimizing soil loss. The soil retention physical quantity is calculated primarily based on the Revised Universal Soil Loss Equation (RUSLE)[41]. The soil retention value mainly includes four aspects: topsoil preservation, fertility maintenance, reduction of non-point source pollution, and reduction of sediment deposition.

$$Q_{sr} = R \times K \times L \times S \times (1 - C \times P) \quad (4)$$

$$E_{land} = \sum Q_{sr} V_a / (10,000 h\rho) \quad (5)$$

$$E_{fer} = \sum (Q_{sr} \times Y_i \times H_i \times \alpha_i) / (B_i \times 10,000) \quad (6)$$

$$E_{sd} = (Q_{sr}/\rho) \times \lambda \times c \quad (7)$$

$$V_{sr} = E_{land} + E_{fer} + E_{npp} + E_{sd} \quad (8)$$

Where: Q_{sr} is the soil retention amount (t/a); R is the rainfall erosivity factor, represented by the multi-year average rainfall erosivity index; K is the soil erodibility factor, typically represented by the soil loss caused by unit rainfall erosivity on a standard plot; L is the slope length factor (dimensionless); S is the slope steepness factor (dimensionless);

C is the cover-management factor (dimensionless); P is the support practice factor (dimensionless). E_{land} is the value of conserved topsoil (yuan/a); h is the regional soil thickness (m), obtained from field soil sample data; ρ is the regional soil bulk density (t/m^3 or g/cm^3), obtained from field soil sample data; V_a is the average annual income per unit area for different land types (yuan/hm^2). E_{fer} is the value of soil fertility maintenance (yuan/a); Y_i is the mass content of various nutrients (N, P, K) in the soil (%); α_i is the conversion factor for different nutrients. E_{sd} is the value of reduced sediment deposition (yuan/a); λ is the sediment deposition coefficient, taken as 24%; c is the unit cost of reservoir dredging engineering (yuan/m^3); V_{sr} is the value of ecosystem soil retention (yuan/a).

- **Flood Storage Service**

This refers to the unique ecological structure of natural ecosystems that can absorb large amounts of rainfall and transit water, store flood peak volume, attenuate and lag flood peaks, thereby mitigating threats and losses caused by flood peaks during the flood season. This study uses vegetation-regulated water storage to characterize the ecosystem's flood storage capacity. Using daily precipitation data and the SCS-CN model from the "water conservation" section, the surface runoff under flood conditions (daily rainfall > 50 mm) is calculated (Q_{veg50}). The flood storage volume by vegetation is the remaining portion after subtracting this surface runoff (Q_{veg}) from the rainfall. The replacement cost method (i.e., reservoir construction and maintenance costs) is used to value the flood storage service of natural ecosystems.

$$C_{vc} = \sum_{i=1}^{n} A_i \times (P_i - Q_{vegi50}) \times 10^{-3} \quad (9)$$

$$V_{fm} = C_{fm} \times C_{we} \quad (10)$$

Where: C_{vc} is the vegetation flood storage volume (m^3/a); P_i is the rainfall (mm/a); Q_{vegi50} is the surface runoff from vegetation under flood conditions (daily rainfall > 50 mm) (mm/a); A_i is the area of the i-th vegetation type (m^2); i is the vegetation type, including only natural vegetation like forest, shrubland, and grassland. V_{fm} is the value of ecosystem flood storage (yuan/a); C_{fm} is the ecosystem flood storage volume (m^3/a); C_{we} is the unit construction and maintenance cost of reservoir storage capacity (yuan/m^3).

- **Air Purification Service**

This refers to the ecosystem's function of absorbing, filtering, blocking, and decomposing atmospheric pollutants (e.g., SO_2, NO_x, dust, or particulate matter), purifying air pollutants, and improving atmospheric environment quality (including releasing negative oxygen ions). Air purification is reflected in purifying pollutants, intercepting particulate matter, and improving the atmospheric environment. This study uses actual emissions to quantify the physical amount of various air pollutants purified and converts them into atmospheric pollutant equivalents. The environmental protection tax method is used to value the air purification service.

$$eqa_i = Q_i \div t_i \quad (11)$$

$$V_a = \sum_{i=1}^{n} Q_{api} \times C_{air} \quad (12)$$

Where: eqa_i is the equivalent of a certain atmospheric pollutant (t/a); Q_i is the actual emission of the i-th atmospheric pollutant (t/a); t_i is the equivalent value of the i-th atmospheric pollutant. V_a is the value of atmospheric environmental purification by the ecosystem (yuan/a); Q_{api} is the purification equivalent of the i-th atmospheric pollutant (t/a); i is the category of atmospheric pollutants, i = 1, 2, ..., n, dimensionless; C_{air} is the value per equivalent of atmospheric pollutant (yuan/t).

- **Water Purification Service**

This refers to the function of aquatic wetland ecosystems (lakes, rivers, marshes, etc.) to adsorb, degrade, and transform water pollutants, purifying the water environment. This study uses actual pollutant discharge to quantify the physical amount of water purification and converts it into water pollutant equivalents. The environmental protection tax method is used to value the ecosystem's service of degrading water pollutants and purifying water quality.

$$eqw_j = Q_j \div t_j \quad (13)$$

$$Q_{wpi} = W_i \div t_i \times S_{wet} \quad (14)$$

$$V_w = \sum_{i=1}^{n} Q_{wpi} \times C_{water} \quad (15)$$

Where: eqw_j is the equivalent of a certain water pollutant (t/a); Q_j is the actual discharge of the j-th water pollutant (t/a); t_j is the equivalent value of the j-th water pollutant. Q_{wpi} is the water purification equivalent of the i-th pollutant (t/a); W_i is the purification amount per unit area of the i-th water pollutant (t/km^2·a); t_i is the equivalent value of the i-th water pollutant; S_{wet} is the wetland area (km^2); i is the category of water pollutants, such as TN, TP, COD, dimensionless; V_w is the value of water quality purification by the ecosystem (yuan/a); Q_{wpi} is the purification equivalent of the *i*-th water pollutant (t/a); *i* is the category of the *i*-th water pollutant in the study area, i = 1, 2, ..., n, dimensionless; C_{water} is the value per equivalent of water pollutant (yuan/t).

- **Climate Regulation Service**

This refers to the ecological function of ecosystems, through vegetation transpiration and water surface evaporation, to absorb solar energy, lower air temperature, increase air humidity, and improve human comfort. This study uses the total energy consumed by ecosystem evapotranspiration and the equivalent electricity consumption of air conditioning for cooling under the same conditions as the physical quantity for climate regulation. The replacement cost method (i.e., the electricity cost required for artificial temperature and humidity regulation) is used to value the climate regulation service provided by ecosystems.

$$E_t = \sum\nolimits_{i}^{n} ET_i \times A_i \times q \times 10^6/(3,600 \times r) \tag{16}$$

$$V_{tt} = E_{tt} \times P_e \tag{17}$$

Where: E_t is the total energy consumed by ecosystem evapotranspiration (kW·h/a); ET_i is the evapotranspiration of the *i*-th pixel (mm); A_i is the ecosystem area (km^2); *i* is the ecosystem type (forest, shrubland, grassland, wetland); *q* is the latent heat of vaporization, i.e., the heat required to evaporate 1 g of water (J/g); *r* is the energy efficiency ratio of air conditioning, dimensionless, taken as 3.0 here. V_{tt} is the value of ecosystem climate regulation (yuan/a); E_{tt} is the total energy consumed by the ecosystem for regulating temperature or humidity (kW·h/a); P_e is the local electricity price (yuan/kW·h).

3. **Cultural Service Value Accounting**

The value of cultural services is accounted for from two aspects: leisure tourism and landscape value.

$$N_t = \sum\nolimits_{i=1}^{n} Nt_i \tag{18}$$

$$V_{house} = Q_{house} \times P_a \tag{19}$$

Where: N_t is the total number of tourists; Nt_i is the number of tourists in the *i*-th tourist area; *i* is the number of tourist areas, i = 1, 2, …, n; V_{house} is the landscape aesthetic value (yuan/a); Q_{house} is the total area benefiting from the ecosystem (km^2); P_a is the unit area premium brought by the ecosystem (yuan/km^2·a). The unit area premium is calculated as the difference between the "average sales price" of each property and the average real estate price.

Appendix B. Data Sources Summary

Table 4. Data Period and Sources.

No.	Data Name	Year	Data Source
1	Population	2024	Nanhua County Statistics Bureau
2	Agricultural Products	2024	Nanhua County Agriculture and Rural Affairs Bureau
3	Forestry Products	2024	Nanhua County Forestry and Grassland Bureau
4	Livestock Products	2024	Nanhua County Agriculture and Rural Affairs Bureau
5	Eco-energy	2024	Nanhua County Development and Reform Commission
6	Aquaculture and Fishing Products	2024	Nanhua County Agriculture and Rural Affairs Bureau
7	Fertilizer Price and Application Rate	2024	Nanhua County Agriculture and Rural Affairs Bureau
8	Rainfall for Runoff Generation, Storm Rainfall, Evaporation	2024	Nanhua County Meteorological Bureau
9	Environmental Monitoring Data, Flow Velocity	2024	Nanhua Branch of Chuxiong Prefecture Ecology and Environment Bureau
10	Air Pollutant Emissions	2024	Nanhua Branch of Chuxiong Prefecture Ecology and Environment Bureau
11	Water Pollutant Emissions	2024	Nanhua Branch of Chuxiong Prefecture Ecology and Environment Bureau
12	Unit Storage Capacity Construction and Maintenance Cost for Reservoirs	2024	Nanhua County Water Affairs Bureau
13	Vector Data of Water Systems (Rivers, Lakes, Reservoirs, Ponds, etc.)	2024	Nanhua County Water Affairs Bureau
14	Reservoir Dredging Project Cost	2024	Nanhua County Water Affairs Bureau
15	DEM Data Source	2024	Geospatial Data Cloud Website (https://www.gscloud.cn/)
16	Soil Data	2024	Institute of Soil Science, Chinese Academy of Sciences (*1:1,000,000 Soil Database of China*)
17	Soil Conservation	2024	Nanhua County Water Affairs Bureau
18	Regional Inflow, Outflow, and Inter-basin Water Transfer Volumes	2024	Nanhua County Water Affairs Bureau
19	Meteorological Data	2024	Nanhua County Meteorological Bureau
20	Data from Surrounding Meteorological Stations	2024	National Meteorological Science Data Center (https://data.cma.cn/)
21	Fractional Vegetation Cover (FVC)	2024	Ministry of Ecology and Environment Satellite Center FVC Data (https://search.earthdata.nasa.gov)
22	Vector Boundaries of Individual Buildings	2024	Nanhua County Housing and Urban-Rural Development Bureau
23	Average Commodity Housing Price in the Jurisdiction	2024	Dayao County & Nanhua County Housing and Urban-Rural Development Bureaus
24	Tourist Numbers	2024	Nanhua County Culture and Tourism Bureau
25	Tourism Revenue	2024	Nanhua County Culture and Tourism Bureau

References

[1] Ouyang, Z.Y., Song, C.S., Zheng, H., et al., 2020. Using Gross Ecosystem Product (GEP) to Value Nature in Decision Making. Proceedings of the National Academy of Sciences of the United States of America. 117(25), 14593–14601. DOI: https://doi.org/10.1073/pnas.1911439117

[2] Costanza, R., d'Arge, R., de Groot, R., et al., 1998. The Value of the World's Ecosystem Services and Natural Capital. Ecological Economics. 25(1), 3–15. DOI: https://doi.org/10.1016/S0921-8009(98)00020-2

[3] Hao, C.Z., Wu, S.Y., Zhang, W.T., et al., 2022. A Critical Review of Gross Ecosystem Product Accounting in China: Status Quo, Problems and Future Directions. Journal of Environmental Management. 322, 115995. DOI: https://doi.org/10.1016/j.jenvman.2022.115995

[4] Ouyang, Z.Y., Zhu, C.Q., Yang, G.B., et al., 2013. Gross Ecosystem Product: Concept, Accounting Framework and Case Study. Acta Ecologica Sinica. 33(21), 6747–6761. DOI: https://doi.org/10.5846/stxb201310092428 (in Chinese)

[5] International Monetary Fund, 2025. System of Environmental-Economic Accounting: Ecosystem Accounting. International Monetary Fund: Washington, DC, USA.

[6] Maes, J., Teller, A., Erhard, M., et al., 2020. Mapping and Assessment of Ecosystems and Their Services: An EU Ecosystem Assessment. Publications Office of the European Union: Luxembourg, Luxembourg.

[7] Salzman, J., Bennett, G., Carroll, N., et al., 2018. The Global Status and Trends of Payments for Ecosystem Services. Nature Sustainability. 1, 136–144. DOI: https://doi.org/10.1038/s41893-018-0033-0

[8] Wunder, S., 2015. Revisiting the Concept of Payments for Environmental Services. Ecological Economics. 117, 234–243. DOI: https://doi.org/10.1016/j.ecolecon.2014.08.016

[9] García-Pardo, K.A., Moreno-Rangel, D., Domínguez-Amarillo, S., et al., 2022. Remote Sensing for the Assessment of Ecosystem Services Provided by Urban Vegetation: A Review of the Methods Applied. Urban Forestry and Urban Greening. 74, 127636. DOI: https://doi.org/10.1016/j.ufug.2022.127636

[10] Villa, F., Ceroni, M., Bagstad, K., et al., 2009. ARIES (Artificial Intelligence for Ecosystem Services): A New Tool for Ecosystem Services Assessment, Planning, and Valuation. Available from: http://bioecon-network.org/pages/11th_2009/Villa.pdf (cited 18 September 2025).

[11] Zhang, Q., Ye, B., Shen, X., et al., 2024. Coupling Coordination Evaluation of Ecology and Economy and Development Optimization at Town-Scale. Journal of Cleaner Production. 447, 141581. DOI: https://doi.org/10.1016/j.jclepro.2024.141581

[12] Willcock, S., Martínez-López, J., Hooftman, D.A.P., et al., 2018. Machine Learning for Ecosystem Services. Ecosystem Services. 33, 165–174. DOI: https://doi.org/10.1016/j.ecoser.2018.04.004

[13] Hu, H., Tian, G., Wu, Z., et al., 2023. Cross-Regional Ecological Compensation under the Composite Index of Water Quality and Quantity: A Case Study of the Yellow River Basin. Environmental Research. 238, 117152. DOI: https://doi.org/10.1016/j.envres.2023.117152

[14] Fang, Z., Chen, J., Liu, G., et al., 2020. Framework of Basin Eco-Compensation Standard Valuation for Cross-Regional Water Supply—A Case Study in Northern China. Journal of Cleaner Production. 279, 123630. DOI: https://doi.org/10.1016/j.jclepro.2020.123630

[15] Chen, Y., Wu, Q., Guo, L., 2024. Ecological Compensation Based on the Ecosystem Service Value: A Case Study of the Xin'an River Basin in China. Water. 16(20), 2923. DOI: https://doi.org/10.3390/w16202923

[16] Ding, F., Zhou, C., 2025. Analysis of Ecological Compensation Willingness and Influencing Factors of Public Welfare Forest—Take Yulong County, Lijiang City as an Example. Research in Ecology. 7(2), 19–31. DOI: https://doi.org/10.30564/re.v7i2.8685

[17] Hou, L., Xia, F., Chen, Q., et al., 2021. Grassland Ecological Compensation Policy in China Improves Grassland Quality and Increases Herders' Income. Nature Communications. 12(1), 4683. DOI: https://doi.org/10.1038/s41467-021-24942-8

[18] Jiang, Y., Zhang, J., Chen, K., et al., 2019. Moving towards a Systematic Marine Eco-Compensation Mechanism in China: Policy, Practice and Strategy. Ocean and Coastal Management. 169, 10–19. DOI: https://doi.org/10.1016/j.ocecoaman.2018.12.002

[19] Li, T., Li, J., Wang, Y., 2019. Carbon Sequestration Service Flow in the Guanzhong-Tianshui Economic Region of China: How It Flows, What Drives It, and Where Could Be Optimized? Ecological Indicators. 96, 548–558. DOI: https://doi.org/10.1016/j.ecolind.2018.09.040

[20] Zheng, H., Liu, Y., Zhao, J., 2021. Understanding Water Rights and Water Trading Systems in China: A Systematic Framework. Water Security. 13, 100094. DOI: https://doi.org/10.1016/j.wasec.2021.100094

[21] da Silva Bezerra, D., 2025. Nature-Based Solutions to Climate Change. Scientific Reports. 15, 22095. DOI: https://doi.org/10.1038/s41598-025-05678-7

[22] Chu, C.-C., Ren, X., Luo, D., et al., 2025. Research on the Governance Path of Agricultural Carbon Emissions Based on Ecological Compensation Mechanism and Green Fiscal and Taxation Policies. Research in Ecology. 7(3), 42–59. DOI: https://doi.org/10.30564/re.v7i3.10033

[23] Ranjan, R., 2024. Creating Synergies between Pay-

ments for Ecosystem Services, Green Bonds, and Catastrophe Insurance Markets for Enhanced Environmental Resilience. Land Use Policy. 136, 106970. DOI: https://doi.org/10.1016/j.landusepol.2023.106970

[24] Woodruff, S.C., BenDor, T.K., 2016. Ecosystem Services in Urban Planning: Comparative Paradigms and Guidelines for High Quality Plans. Landscape and Urban Planning. 152, 90–100. DOI: https://doi.org/10.1016/j.landurbplan.2016.04.003

[25] Ren, X., Tan, X., Luo, D., et al., 2025. Coupling and Spatial Disparities of Regional Economy and Ecosystem in High-Quality Town Development. Research in Ecology. 7(1), 15–29. DOI: https://doi.org/10.30564/re.v7i1.8118

[26] Cao, X., Huang, X., Shan, W., et al., 2025. The Construction of Territorial Space System and the Guidance of Planning System for Chinese Path to Modernization. Journal of Natural Resources. 40(10), 2591. DOI: https://doi.org/10.31497/zrzyxb.20251001 (in Chinese)

[27] Bai, Y., Li, H., Wang, X.Y., et al., 2017. Evaluating Natural Resource Assets and Gross Ecosystem Products Using Ecological Accounting System: A Case Study in Yunnan Province. Journal of Natural Resources. 32(7), 1100–1112. DOI: https://doi.org/10.11849/zrzyxb.20160755 (in Chinese)

[28] You, X., He, D.J., Xiao, Y., et al., 2019. Assessment of Ecological Protection Effectiveness in a County Area: Using Eshan County as an Example. Acta Ecologica Sinica. 39(9). DOI: https://doi.org/10.5846/stxb201806021234 (in Chinese)

[29] Shen, Y., Q., Yi, X., Chen, M., et al., 2024. Gross ecosystem product accounting in Miyun County: the supply and use of ecosystem services. Frontiers in Ecology and Evolution. 12, 1367768. DOI: https://doi.org/10.3389/fevo.2024.1367768

[30] Zhou, X., Wang, Q., Zhang, R., et al., 2022. A Spatiotemporal Analysis of Hainan Island's 2010–2020 Gross Ecosystem Product Accounting. Sustainability. 14(23), 15624. DOI: https://doi.org/10.3390/su142315624

[31] Pema, D., Xiao, Y., Ouyang, Z.Y., et al., 2020. Assessment of Ecological Conservation Effect in Xishui County Based on Gross Ecosystem Product. Acta Ecologica Sinica. 40(2), 499–509. DOI: https://doi.org/10.5846/stxb201812202767 (in Chinese)

[32] Cohen-Shacham, E., Andrade, A., Dalton, J., et al., 2019. Core Principles for Successfully Implementing and Upscaling Nature-Based Solutions. Environmental Science and Policy. 98, 20–29. DOI: https://doi.org/10.1016/j.envsci.2019.04.014

[33] Shen, P., Wu, L., Huo, Z., et al., 2023. A Study on the Spatial Pattern of the Ecological Product Value of China's County-Level Regions Based on GEP Evaluation. International Journal of Environmental Research and Public Health. 20(4), 3181. DOI: https://doi.org/10.3390/ijerph20043181

[34] Liu, K.D., Jin, M.H., Cheng, L., 2025. County Green Transformation: How Does Gross Ecosystem Product Assessment Promote Common Prosperity? Humanities and Social Sciences Communications. 12, 20. DOI: https://doi.org/10.1057/s41599-024-04330-5

[35] Shang, W., Gong, Y., Wang, Z., et al., 2018. Eco-Compensation in China: Theory, Practices and Suggestions for the Future. Journal of Environmental Management. 210, 162–170. DOI: https://doi.org/10.1016/j.jenvman.2017.12.077

[36] Chen, M., Xu, X., Tan, Y., et al., 2025. Integrating Ecosystem Service Spillovers and Environmental Justice in Ecological Compensation: A Pathway to Effective Ecological Protection in China. Ecological Indicators. 174, 113455. DOI: https://doi.org/10.1016/j.ecolind.2025.113455

[37] Yang, H., Gou, X., Li, Z., et al., 2025. Assessing Ecosystem Services and Their Spillover Effects to Inform Cost-Benefit Sharing and Horizontal Eco-Compensation Mechanisms in the Qilian Mountains, China. Ecosystem Services. 75, 101764. DOI: https://doi.org/10.1016/j.ecoser.2025.101764

[38] Hamel, P., Bryant, B.P., 2017. Uncertainty Assessment in Ecosystem Services Analyses: Seven Challenges and Practical Responses. Ecosystem Services. 24, 1–15. DOI: https://doi.org/10.1016/j.ecoser.2016.12.008

[39] Venter, Z.S., Czúcz, B., Stange, E., et al., 2024. 'Uncertainty Audit' for Ecosystem Accounting: Satellite-Based Ecosystem Extent Is Biased without Design-Based Area Estimation and Accuracy Assessment. Ecosystem Services. 66, 101599. DOI: https://doi.org/10.1016/j.ecoser.2024.101599

[40] Walther, F., Barton, D.N., Schwaab, J., et al., 2025. Uncertainties in Ecosystem Services Assessments and Their Implications for Decision Support—A Semi-Systematic Literature Review. Ecosystem Services. 73, 101714. DOI: https://doi.org/10.1016/j.ecoser.2025.101714

[41] Liu, L., Wang, J., Li, J., 2025. Evaluation of Ecosystem Service Capacity Using the Integrated Ecosystem Services Index at Optimal Scale in Central Yunnan, China. Ecology and Evolution. 15(4), e71222. DOI: https://doi.org/10.1002/ece3.71222