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Review

A Review of Research Progress on the Value of Ecological Products from Soil and Water Conservation Measures

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Abstract

Against the backdrop of global climate change and sustainable development, research on the value of ecological products derived from soil and water conservation measures has attracted increasing attention. Addressing the issue of value realization for ecological products derived from soil and water conservation measures, this study used VOSviewer software to perform a visual analysis of 2,935 literature entries from the Web of Science Core Collection, covering the fields of "ecological product value" and "ecosystem services" from 2020 to 2024. The research traced two temporal trajectories: the evolution of soil and water conservation technologies and the formation of the theoretical framework for ecological product value. By integrating methods such as multi-source remote sensing, dynamic correction, and model coupling, the study refined the equivalent factor method to establish a value realization mechanism centered on ecological product value and supplemented by ecological compensation. The results demonstrate that the ecological benefits of soil and water conservation measures can be effectively converted into economic benefits, thus providing a crucial reference for promoting regional sustainable development.

Keywords: soil and water conservation measures, ecological product value, value accounting, market mechanisms, value realization

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Introduction

The accounting of the value of ecological products derived from soil and water conservation measures represents a prominent research frontier receiving great attention in contemporary fields such as ecology and hydrology. As the core carrier for maintaining the stability of regional ecosystems and human well-being, the scientific understanding and accurate quantification of the value of ecological products serve as the foundation for subsequent research and applications [1]. Thoroughly examining the developmental trajectory of soil and water conservation measures and the ecological product value system is not only a core requirement for objectively assessing the contribution of ecological products to human beings but also constitutes the fundamental starting point and ultimate aim of this research.

From the perspective of the international academic context, the exploration of ecosystem service functions can be traced back to the 1970s, when the concept of ecosystem service functions was first introduced in "The Report on Human Impact on the Global Environment" [2]. Entering the 1990s, research in this field achieved breakthrough progress. In 1997, Daily [3] provided a systematic elaboration on ecosystem services, which established a theoretical cornerstone for the market-oriented transformation of ecological values. In the same year, the study on the valuation of ecosystem services published by Costanza [4, 5] in the journal Nature greatly stimulated a global academic fervor for this field [6, 7]. Against this backdrop, the United Nations successively launched the Millennium Ecosystem Assessment (MA) project [8] and officially released the Experimental System of Environmental-Economic Accounting for Ecosystems (SEEA-EEA) in 2012. The SEEA-EEA framework, which classifies ecosystem services into three major categories – provisioning, regulating, and cultural [9-11], provides a standardized and normative structure for countries worldwide to conduct ecosystem value accounting.

In parallel with advancements in the international academic community, Chinese scholars have achieved pivotal breakthroughs in research on the value of ecological products. In 1999, Zhiyun Ouyang [12, 13] proposed the first classification framework for ecosystem service evaluation, which laid a solid theoretical foundation for subsequent research [14, 15]. In 2001, Gaodi Xie posited ecosystem service functions as products and services obtained directly or indirectly; he pioneered the equivalent factor method that links the value of ecological services to the output value of grain. Through a series of efforts, including revising the equivalent table by introducing an expert knowledge base and constructing a dynamic assessment model by integrating biophysical parameters, he gradually developed it into a dynamic value assessment system [16-19]. In 2013, drawing on the concept of GDP (Gross Domestic Product) in macroeconomics, Zhiyun Ouyang [1] defined GEP (Gross Ecosystem Product) as "the total value of products and services provided by ecosystems for human well-being". Due to its scientific rigor and operability, the GEP theory was quickly incorporated into China's policy system and widely applied and promoted nationwide. In 2021, GEP accounting was formally integrated as a comprehensive indicator within the latest SEEA-EA framework [20]. The lack of a consistent framework has led to considerable confusion in the terminology used for the value of ecosystem products [21]. In empirical literature, ecological product value accounting is also referred to as ecosystem service value accounting or gross ecosystem product accounting, among other names. Despite the differences in terminology, most of these practices involve assessing the value of the final services of ecosystems and quantifying the benefits that ecosystems provide to humanity [1].

In recent years, China has made significant strides in the valuation of ecological products, yet the academic community still lacks a systematic literature review on the advancement of its implementation mechanisms [22]. Existing research gaps are primarily manifested in the following aspects: despite continuous improvements in accounting standards, research logic often exhibits a fragmented tendency [23], resulting in a severe disconnect across the entire chain between the technical implementation of soil and water conservation measures and the realization of their value. Particularly as soil and water conservation evolves from traditional early-stage engineering interventions toward modern smart governance, the long-term undervaluation of non-market values has created an imbalance between the internalization of protection costs and the externalization of benefits. Therefore, dissecting the mechanisms for deeply integrating soil and water conservation measures with ecological product value accounting holds significant theoretical implications for refining the national ecological compensation system. Moreover, it directly addresses the urgent practical need to achieve the 2035 goal of fully establishing a mechanism for realizing the value of ecological products.

This study develops a comprehensive analytical framework to assess the value realization of soil and water conservation ecological products, based on a quantitative analysis of 2,935 relevant domestic and international publications from 2020 to 2024. Its innovation lies in systematically tracing the independent developmental trajectories of soil and water conservation measure technologies and ecological product value theoretical frameworks for the first time, filling a gap in interdisciplinary theory. Furthermore, it proactively identifies synergistic evolution trends across the three dimensions of "technology, accounting, and management", driving the transformation of soil and water conservation from qualitative benefit description to quantitative value accounting and market-oriented governance. Although this study focuses primarily on typical ecologically fragile regions like the Loess Plateau, the proposed theoretical framework possesses universality and transferability. It is hoped that this research will provide a theoretical reference for subsequent academic exploration and contribute "Chinese wisdom" and "Chinese solutions" to global sustainable development.

Results and Discussion

The Phased Evolution and Technological Development of Soil and Water Conservation Measures

Since the founding of the People's Republic of China, the country's water and soil conservation efforts have transformed, evolving from a focus on single measures to systematic restoration, and from extensive management to intelligent governance. This evolution aligns closely with the development of the ecological product value accounting system. In the 1950s, the initial stage was dominated by engineering measures. By the 1980s, a combination of engineering and biological measures had been implemented for integrated small-watershed management. The 1990s witnessed a shift toward legal standardization following the enactment of the Soil and Water Conservation Law. Entering the 21st century, soil and water conservation has advanced toward high-quality development, emphasizing equal importance on ecosystem quality and ecological productivity. This fully demonstrates the value-realization mechanism for transforming "lucid waters and lush mountains" into "mountains of gold and silver".

As a core practice in ecosystem management, soil and water conservation, which includes both engineering and biological measures, serves not only as a defensive means to prevent soil erosion but also as a process to restore ecosystems into consumable products [24]. Therefore, based on the characteristics of soil and water conservation measures across different periods, the research progress can be divided into four distinct phases: initial exploration stage, technology formation stage, ecological practice stage, and intelligent development stage (Fig. 1).

Initial Exploration Stage

From the 1950s to the 1970s, China's soil and water conservation efforts were in an initial exploration stage, with the governance focus on controlling the widely distributed eroded gullies on the Loess Plateau [25]. The core strategy, known as "protecting the tablelands and stabilizing the gullies", was implemented through localized management practices. This stage was characterized by engineering measures such as the manual construction of fish-scale pits [26], simple silt-trap dams [27], and traditional gully checks. Guided by the concept of using silt-trap dams to control gullies [28], the engineering objectives of "blocking" and "retaining" sediment were achieved. By the 1970s, the philosophy of soil and water conservation gradually expanded from a focus on specific points to a broader areal approach, which laid the groundwork for integrated small watershed management [29]. Pilot projects implementing the "slope-gully integrated management" model were conducted in areas such as the Nanxiao River

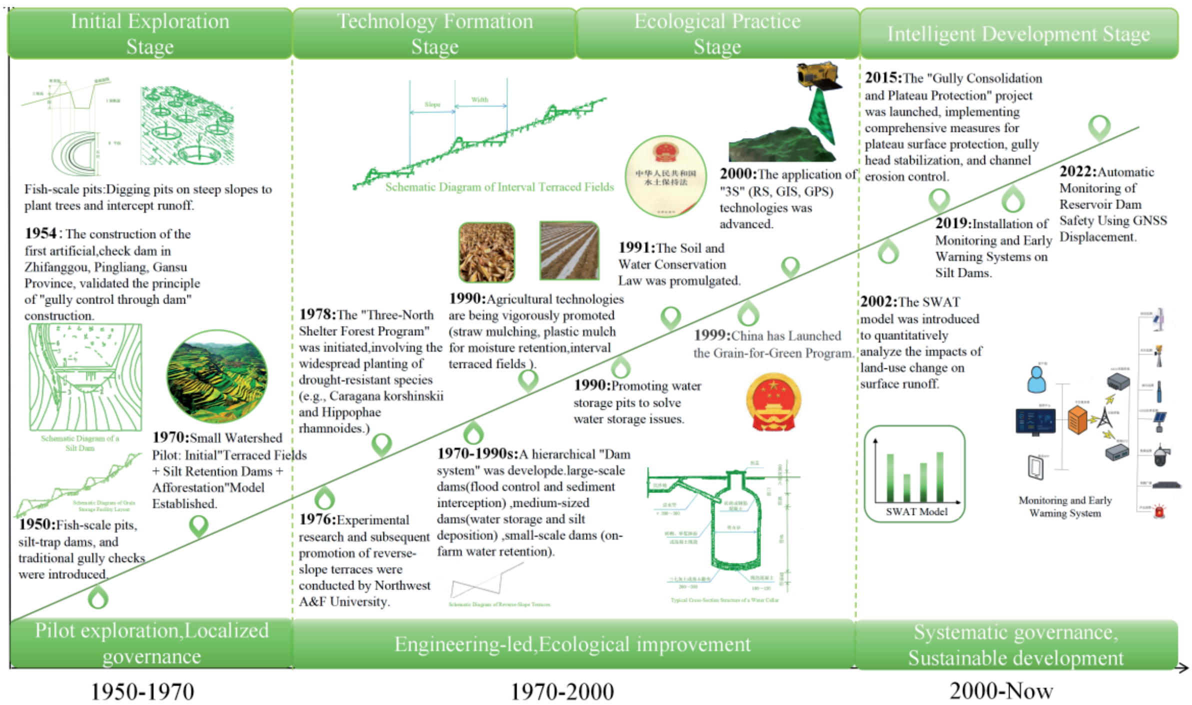

Fig. 1. Timeline of soil and water conservation measures implementation.

basin in Qingyang, Gansu, and Wangjiagou in Lishi, Shanxi. These projects involved the comprehensive implementation of diverse management measures, including terraced field construction, sediment retention through silt dams, and vegetation restoration. Although the concept of "ecological products" had not yet been explicitly proposed during this period, the ecological functions that were established, such as climate regulation, had already begun to demonstrate the externality characteristics of ecosystem service values.

Technology Formation Stage

Building upon the initial exploration stage, soil and water conservation measures entered a stage of technological formation beginning in the 1970s. During this period, a diversified technical system for soil and water conservation was progressively established and validated. In terms of slope engineering, practices such as reverse-slope terraces [30] and interval-slope terraces [31] convert destructive runoff into a usable soil water resource by remodeling the slope surface. At the watershed management level, dam systems featuring backbone dams, medium-sized dams, and small dams working in concert with complementary functions have matured [32]. By establishing an efficient sediment and water regulation network within the gullies, this dam system not only effectively curbed channel downcutting and headward erosion but also significantly enhanced the land's agricultural carrying capacity by trapping silt to create farmland. Meanwhile, large-scale forest and grass measures, such as the planting of drought-tolerant plants (e.g., *Caragana korshinskii* and *Hippophae rhamnoides*), played a pivotal role in soil fixation, windbreaks, and sand fixation. Furthermore, the promotion of agricultural water-saving techniques, including straw mulching [33] and plastic film mulching for moisture conservation [34], maintained the exchange of materials and energy between the soil and the atmosphere. These practices effectively regulated surface runoff and suppressed soil evaporation, continuously optimizing slope hydrological and ecological processes.

Ecological Practice Stage

With the increasing maturity of technical systems, soil and water conservation efforts entered the ecological practice stage in the 1990s, gradually shifting from an engineering-centric approach to integrated management and sustainable development. In terms of engineering techniques, structural improvements were made to water cellars [35] and similar facilities, enhancing their sealing properties and durability. This effectively guaranteed the water supply for agricultural production and the daily life of farmers in arid areas and improved the resilience of ecosystems to drought stress. At the policy level, the formal promulgation of the Law of the People's Republic of China on Water and Soil Conservation provided a legal framework for standardized soil and water loss prevention and control. Building upon this legal foundation, large-scale ecological restoration projects in national land space have been implemented, such as the orderly conversion of steep-sloping farmland to forest and grassland in ecologically fragile regions of the Loess Plateau [36]. On the technological front, advancements in information technology have facilitated precision management in soil and water conservation [37, 38]. Represented by remote sensing (RS) technology, continuous and macro-level monitoring of managed areas at medium-to-high resolutions can be achieved by analyzing and calculating potential canopy fluxes and vegetation indices such as NDVI under different land cover types [39]. The widespread adoption of Geographic Information Systems (GIS) and high-precision Global Positioning Systems (GPS) serves as a crucial technological means for spatially evaluating ecosystem service functions and conducting quantitative accounting.

Intelligent Development Stage

Since the beginning of the 21st century, China's soil and water conservation efforts have advanced into an intelligent development stage. By integrating digital technologies with systematic governance, this approach has propelled the realization of its value, achieving a leap from experience-based management to intelligent governance. Starting with the introduction of distributed hydrological models such as SWAT [40], quantitative simulations of land-use change impacts on runoff were achieved for the first time. Concurrently, economic quantification models were employed to establish a scientific framework for assessing the value of water resource regulation services. Overall, soil and water conservation research has transitioned from single-point interventions to the comprehensive management of landform units. The implementation of the "protecting the tablelands and stabilizing the gullies" project [41], through measures such as constructing detention ponds and retaining ditch embankments, has proven effective in reducing rainstorm erosion on the tableland surface. Meanwhile, the advancement of modern monitoring technologies is profoundly transforming the operation and maintenance models of traditional soil and water conservation measures. By upgrading silt-trapping dam safety monitoring systems [42] and introducing GNSS displacement monitoring technology [43], we have established a dual-monitoring system that balances "engineering safety" and "ecological services". This system provides real-time data support for assessing the value of ecological products derived from soil and water conservation and enables the visualization of the resulting ecological benefits.

Theoretical Framework for Ecosystem Service Value Accounting: A Historical Perspective

In recent years, research on ecological product value assessment has focused on its theoretical methods and practical applications. The aim is to scientifically quantify its multidimensional values, including functional benefits, and establish a comprehensive ecological assessment system. This provides decision-making support for preserving and enhancing the value of ecological assets and promoting regional sustainable development. The development of ecological product value accounting is a process that integrates long-term and short-term objectives. It should be conducted similarly to GDP accounting, with both GEP and GDP advancing in tandem [44] .

Literature retrieval results, keyword co-occurrence network analysis, and top 20 statistics obtained from searching the Web of Science Core Collection (WoSCC) database with the theme of “ecological product value” (a: Literature retrieval results; b: Number of articles published and their citation counts from 2020 to 2024; c: Keyword co-occurrence analysis (The size of nodes intuitively reflects the research popularity of each keyword during 2020-2024, while the lines between nodes reveal the strength of academic connections formed by different research topics due to their co-citation in literature.); d: Frequency and link strength of the top 20 keywords)

First, in terms of publication trends (Fig. 2a) and b)), the number of relevant articles has grown consistently from 2020 to 2024, primarily in the form of Articles and Review Articles, reflecting the increasing academic activity in this field. Second, regarding research content (Fig. 2c) and d)), the keywords “management”, “model”, and “sustainability” form a highly concentrated cluster within the keyword network. This cluster clearly maps a core research pathway: academia is dedicated to integrating the “models” of value accounting with the “practices” of ecological management, ultimately serving the overarching goal of “sustainable development”. This emerging research trend points the way toward establishing market-based ecological compensation grounded in scientific principles.

The development of ecological product value accounting marks a deepening evolution from theoretical exploration to policy practice. Its theoretical origins can be traced back to the pioneering assessment of global ecosystem service values conducted by Costanza et al. in 1997. Entering the 21st century, Chinese scholars have achieved critical breakthroughs in localized practice. Among them, the “equivalent factor method for ecosystem services” proposed by Gaodi Xie’s team and the concept of GEP put forward by Zhiyun Ouyang’s team marked significant milestones. These advancements marked a leap from evaluating individual services to quantifying the total ecological value. Based on a review of previous studies on ecological product value and their developmental characteristics, the research evolution can be divided into four distinct phases: theoretical foundation stage, system building stage, conceptual innovation stage, and application deepening stage, as illustrated in Fig. 3.

Theoretical Foundation Stage

From the late 1990s to the early 21st century, the value of ecological products was characterized by its theoretical foundation stage. During this period, applications were primarily centered on the initial exploration of theoretical frameworks, with assessment

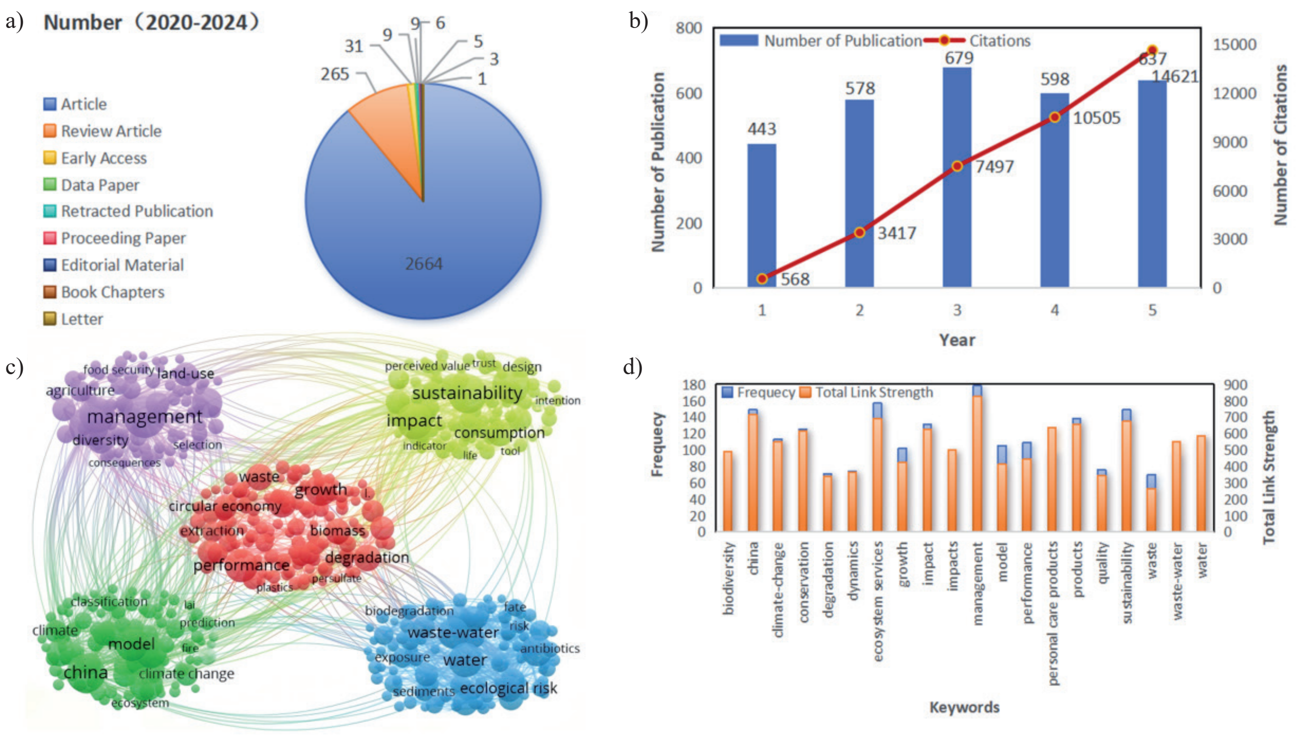

Fig. 2. Literature search diagram.

methods in their embryonic stage. In 1997, Daily [3] first proposed the integration of ecosystem services into decision-making systems in Nature's Services. In the same year, Costanza [4] developed a structured framework to quantify and manage the contributions of natural capital to human well-being, categorizing service functions into 17 major groups (Fig. 4) based on the interdependencies between ecosystem functions and services. The proposal of this classification marked a milestone in ecological economics and serves as a link to promote the connection between natural ecosystems and socio-economic systems [45, 46]. It conducted the first global quantitative valuation of ecosystem services, with the introduction of an equivalent factor valued at 54$/hm^2. In 1999, Zhiyun Ouyang [12], building upon Daily's framework and adapting it to the Chinese context, preliminarily defined the connotation of ecosystem service functions and explored methods for classifying and evaluating their eco-economic values. This work helped improve assessment accuracy and addressed the challenge of quantifying non-market services.

System Building Stage

The pioneering research by Costanza et al. attracted global attention to ecosystem services, stimulated extensive academic exploration, and propelled this field into the system-building stage. In 2001, the United Nations launched the MA project [8], which conducted surveys on a global and regional scale and revealed that 60% of global ecosystem service functions were still degraded.

Based on the direct contribution of ecosystem services to human well-being, the MA classified ecosystem services into four major categories: provisioning services, regulating services, cultural services, and supporting services. This classification framework has been widely adopted worldwide. Shidong Zhao [47] argued that the MA comprehensively illuminated the interrelationships among ecosystems, ecosystem services, and human well-being, propelling ecological science into a new era.

To effectively integrate ecological service value with China's context, scholars such as Gaodi Xie [17, 18] conducted extensive experimental research. Through questionnaire surveys of hundreds of professionals with an ecological background and based on the classification of ecosystem service types and land use categories, they developed an equivalent factor table for the ecological service value of China's ecosystems. This established that the economic value of one ecosystem service equivalent factor equals 1/7 of the national average grain yield per unit area market value for that year. Meanwhile, Gaodi Xie recognized that there is a close correlation between the magnitude of ecosystem service functions and biomass. Therefore, Equation (1) (Table 1) was introduced to dynamically adjust the unit price of ecological services, which provides a new perspective for subsequent assessments of ecosystem service value.

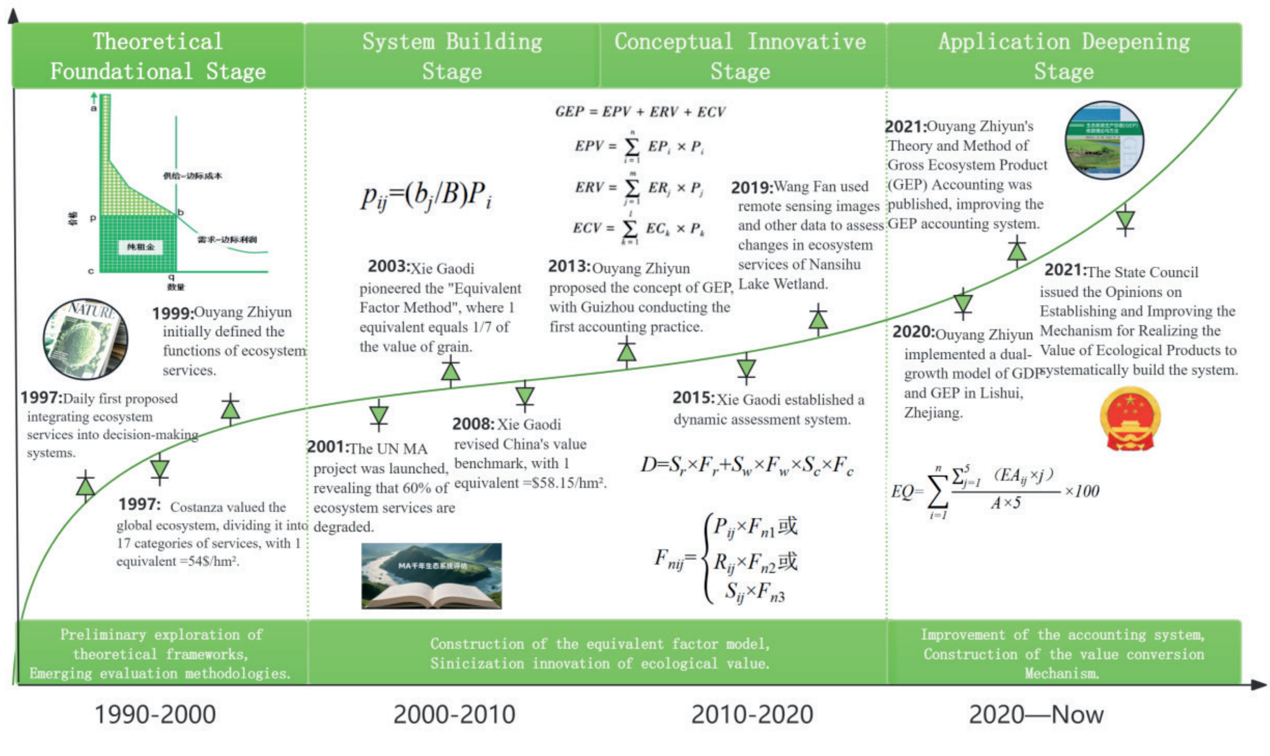

Fig. 3. Research progress diagram on the value of ecological products.

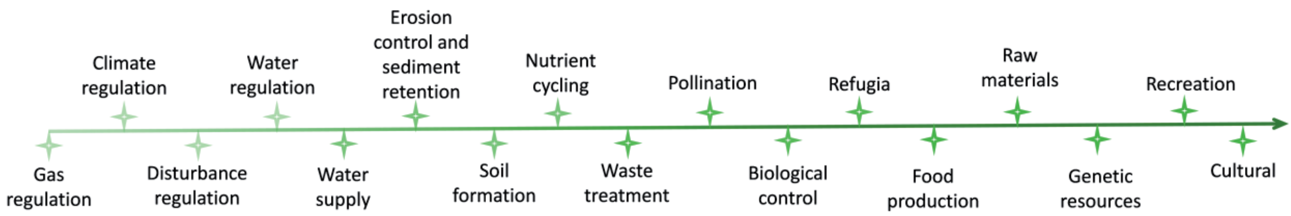

Fig. 4. Costanza's classification of ecosystem services.

Conceptual Innovation Stage

To advance a theoretical system with local characteristics, Zhiyun Ouyang [1] formally introduced the concept of GEP in 2013, defining it as the total value of final products and services provided by ecosystems for humanity. Based on the functional types of ecosystem services, GEP is categorized into three major groups: ecosystem provision value, ecological regulation services value, and ecological cultural services value. Drawing on the concept of GDP, this concept utilizes pricing [48] to achieve synergy between ecology and economy. For calculating the GEP of a region or country, Equation (2) (Table 1) can be applied. In 2015, Gaodi Xie's team [17, 19], building upon their 2003 research, established the net profit from grain production per unit area of farmland ecosystems as a standard equivalent factor for ecosystem service valuation. The value of grain output in farmland ecosystems, calculated using three major grain crops (rice, wheat, and maize as the primary basis), is determined with Equation (3) (Table 1). Additionally, Equation (4) (Table 1) is employed to construct a value equivalent factor table for the spatiotemporal dynamic changes of ecological services. The new equivalence factor table addresses the static nature and spatial homogeneity issues of traditional methods [49], providing more scientific support for ecosystem assessments.

Based on the aforementioned theoretical frameworks and methodologies, a large number of empirical studies have been conducted. For instance, some scholars have employed the equivalent factor method to accurately calculate the spatiotemporal evolution characteristics of ecosystem service value in specific regions [50, 51]; other studies have focused on evaluating the service functions of particular terrestrial ecosystems, such as

Table 1. Formula Collection.

Number	Name	Formula	Source
1	Revision of the Unit Price of Ecosystem Services	$p_{ij}=(b_j/B)P_i$	Xie et al. (2003) [17]
2	Gross Ecosystem Product	$EPV=\sum_{i=1}^{n} EP_i \times P_i$ $ERV=\sum_{j=1}^{m} ER_j \times P_j$ $ECV=\sum_{k=1}^{i} EC_k \times P_k$	O Y et al. (2013) [1]
3	Value of Grain Yield in the Farmland Ecosystem	$D=S_r \times F_r + S_w \times F_w + S_c \times F_c$	Xie et al. (2015) [19]
4	Value Equivalent Table for Spatiotemporal Dynamic Changes of Ecosystem Services	$F_{nij}=\begin{cases} P_{ij} \times F_{n1} \\ R_{ij} \times F_{n2} \\ S_{ij} \times F_{n3} \end{cases}$	Xie et al. (2015) [19]
5	The Ecological Asset Composite Index	$EQ=\sum_{i=1}^{n} \frac{\sum_{j=1}^{5} (EA_{ij} \times j)}{A \times 5} \times 100$	O Y et al (2020) [58]

surface water bodies, forests, and grasslands [52-54]. Concurrently, research methodologies have become increasingly diversified, with the emergence of new approaches that integrate value assessment with land use change analysis, multi-objective optimization models, and ecological compensation, which has greatly enriched the connotation of this scope [55-57].

Application Deepening Stage

With the further refinement of ecological products, Zhiyun Ouyang [58, 59] has successively employed the Ecological Asset Composite Index (Equation (5), Table 1) and single monetization indicators to quantify the total value of ecosystem services, which holds significant importance for achieving harmonious coexistence between humanity and nature. In 2021, Ouyang Zhiyun's [60] work "Theory and Methodology of Gross Ecosystem Product (GEP) Accounting" was published, systematically elaborating on the concept of GEP, its accounting framework, accounting methods, and application cases across different spatial scales. This research not only innovatively proposes a GEP accounting framework covering three major categories: ecosystem provision value, ecological regulation services value, and ecological cultural services value, but also conducts an in-depth exploration of the application pathways of GEP in fields such as ecological assessment and government performance evaluation. Notably, the GEP accounting method proposed in this monograph has been adopted by the SEEA-EA, gaining international recognition. China's work on ecological product value realization has entered a new phase of institutionalized and systematic advancement. The Opinions [61, 62], successively issued by the State Council and the Ministry of Water Resources, provide a scientific theoretical basis for ecological product value assessment.

Research on the Ecological Product Value of Soil and Water Conservation Measures

Throughout historical development, China's soil and water conservation efforts and the theory of ecological product value have presented two development threads that are both independent and ultimately converging. On one hand, decades of exploration in soil and water conservation have evolved the field from early single-project interventions into a comprehensive prevention and control system encompassing engineering, afforestation, and grassland restoration measures. Its core objective remains curbing soil erosion while restoring and enhancing ecological environments. On the other hand, with the deepening of human understanding of natural well-being, the concept of ecological products has gradually evolved from the vague notion of "ecological benefits" to a clear and substantive concept, providing theoretical support for its scientific quantification and value assessment. This chapter is based on this interdisciplinary field, systematically sorts out and reviews the current accounting methods and practical challenges of ecological product value under soil and water conservation measures, and constructs an analytical framework ranging from the "technology" of ecological products to their "accounting" and further to "management". This framework will effectively promote the transformation pathway of the ecological service functions of soil and water conservation in the economic market.

Theoretical Integration: from Soil and Water Conservation Measures to Ecological Product Value

The cognitive evolution of the value of soil and water conservation measures has evolved from a single-function perspective to one emphasizing multiple services and from direct economic benefits to the comprehensive value of ecological products. In the early stage, value accounting centered on the direct use value and indirect economic benefits of these measures [63]. For example, the primary factor determining the ecological function of urban lakes and wetlands in Wuhan is their role in regulating indirect use values [64]; the market value method was used to assess the grain output value of newly added cropland resulting from engineering measures such as terraces and check dams [65, 66]; the shadow engineering method was applied to calculate the cost savings from reduced sedimentation in reservoirs or waterways [67]; and the replacement cost method was utilized to account for the water conservation value in specific regions [68]. The accounting methods in this stage were intuitive and easy to understand, providing crucial evidence for justifying the rationality of soil and water conservation measures. However, their limitations were equally prominent: the single-dimensional nature of value assessment severely underestimated the non-market values of these measures in aspects such as carbon sequestration and biodiversity conservation, leading to an incomplete evaluation of ecosystem services [69].

With the deepening exploration of the ecosystem services theoretical framework, the valuation of soil and water conservation measures has witnessed a major methodological innovation. Researchers have analyzed the phased evolution of biological, engineering, and agricultural measures [70] under soil and water conservation classifications, driving the development of ecological product accounting toward spatiotemporal dynamics. The core of this paradigm shift lies in evaluating soil and water conservation measures within a three-category framework: product value, regulatory services, and cultural services. By employing various accounting methods to convert the physical quantities of ecosystem services into comparable value metrics [71], researchers have achieved the comparability of heterogeneous services. This approach establishes a comprehensive value chain for the ecological products derived from soil and water conservation measures.

Spatial Evolution: from Single Projects to Regional Coordination

The evolution of ecological product value accounting for soil and water conservation measures exhibits distinct hierarchical characteristics in the spatial dimension, progressing from the micro-level of individual projects to the macro-level of regional scales. This shift reflects not only advancements in accounting techniques but also a deepening understanding of the cascading effects of ecosystem services.

In the practice of calculating the ecological product value of soil and water conservation measures, the project scale represents the earliest applied and most methodologically mature research level. This scale primarily focuses on engineering entities or land parcel units. Terraced fields, as a typical example of slope micro-landform modification, have a relatively well-established value calculation system, primarily accounting for two indicators: soil retention and crop yield increase. For soil conservation, the "spatial substitution method" is commonly employed to establish control groups, comparing erosion responses between terraced slopes and undisturbed slopes. Studies extensively utilize the Revised Universal Soil Loss Equation (RUSLE) [72], employing refined parameter inputs to simulate and quantify the soil erosion reduction achieved by terraced measures. Subsequently, based on the conversion logic between functional value and monetary value [73], the replacement cost method is predominantly used for monetization: First, the fertilizer retention value is calculated using the equivalent value of nutrients like N and K lost in soil, combined with fertilizer market prices. Second, the avoided losses from land productivity degradation due to reduced soil erosion are assessed. For crop yield increases, the assessment logic is relatively straightforward: comparing the yield per unit area difference between terraced fields and sloping farmland, then determining the marginal economic contribution based on the market price mechanism of the corresponding agricultural products.

As research into ecosystem structure and function deepens, isolated assessments of individual projects no longer adequately meet decision-making needs for watershed governance. Consequently, the regional scale has become the mainstream level for calculating the value of ecological products in soil and water conservation. Taking the Loess Plateau Ecological Restoration Project as an example, the focus of assessment at this scale has shifted from localized physical protection to broader regulatory services such as carbon sequestration, oxygen release, and water conservation. In carbon sequestration services, the net primary productivity (NPP) of vegetation is regarded as a key indicator for measuring ecosystem carbon sink capacity [74]. Technologically, this relies primarily on multi-source remote sensing data. This approach can either directly utilize long-term NPP standard products from satellites like MODIS or employ light use efficiency models such as CASA (Carnegie-Ames-Stanford Approach) [75], combined with meteorological interpolation data, to achieve high-precision spatiotemporal dynamic simulations. The accounting logic unfolds as follows: First, calculate the increment in vegetation NPP before and after ecological restoration, then convert this into physical carbon sequestration quantities using carbon conversion coefficients specific to different vegetation functional groups. Subsequently, based on different value realization pathways, regional-scale soil and water conservation measures' carbon sink services are monetarily evaluated by referencing real-time prices in international/domestic carbon markets or employing shadow price models like the afforestation cost method [76], thereby achieving a holistic quantification of the watershed's ecological security barrier function.

At the empirical research level, the Loess Plateau, as a prototypical example of an ecologically fragile region, further demonstrates the complexity of scale evolution in the pathways for realizing the value of ecological products, exhibiting significant spatial heterogeneity. First, in the Mao [77] and Liang [78] zones of the hilly gully areas, engineering measures at the project scale constitute the initial pillar of ecological product value output. Empirical data indicate that during the initial remediation phase, structures like sediment retention dams and silt-trapping dams typically contributed over 60% to the value of regulation services, with value increments primarily stemming from soil conservation and downstream flood mitigation. Second, in the plateau Yuan areas [79], the accounting scale shifted from individual projects to regional coordination focused on gully stabilization and plateau conservation. Through micro-topography reshaping, the focus of ecological value realization shifted from windbreak and sand fixation to water conservation and groundwater recharge, yielding significantly higher value growth rates than single slope management areas. Furthermore, empirical results for large-scale vegetation restoration and other biological measures indicate a threshold effect in ecological benefits [80]. At the regional scale, once vegetation coverage surpasses a specific threshold, ecosystems transition from soil stabilization and water retention functions to multifunctional service clusters encompassing local climate regulation and biodiversity support. Consequently, the marginal value of its ecological products exhibits nonlinear explosive growth. This empirical analysis, grounded in specific geographical contexts, profoundly reveals the intrinsic relationship between engineering biological coupling measures and regional ecological value production, providing a crucial scientific basis for tailored strategies to enhance ecological products on the Loess Plateau.

Advances in Methodology: Value Quantification through Multi-Technology Integration

The selection and application of value accounting methods directly determine the scientific validity

Table 2. GEP Accounting under Soil and Water Conservation [60, 86].

Accounting subject	Functional Quantity		Monetary Value	
	Calculation Method	Formula	Calculation Method	Formula
Water Conservation	Water Balance Method	$Q_{wr}=\sum_{i=1}^{n} A_i \times (RP_i-R_i-ET_i) \times 10^{-3}$	Market Value Method (Alternative Engineering Method)	$V_{wr}=Q_{wr}\times C_{we}$
Soil Conservation	Revised Universal Soil Loss Equation	$Q_{SE}=R\times K\times L\times S\times B\times E\times T$	Substitution Cost Method	$V_{SE}=Q_{SE}\times A_s\div\rho\times P_S$
		$Q_{SA}=R\times K\times L\times S\times B\times E\times T\times R_{sl}\times R_{gu}$	Substitution Cost Method	$V_{SA}=per\times Q_{SA}\times C_{RD}\div\rho$
		$M_N=M_A\times CO_N$ $M_P=M_A\times CO_P$ $M_K=M_A\times CO_K$ $M_{OM}=M_A\times CO_{OM}$	Market Value Method	$V_M=M_A\times P_F$
Flood Regulation and Storage	Multi-Module Coupling Evaluation Method	$Q_{PC}=C_{vc}+C_{rc}+C_{mc}$	Surrogate Market Method	$V_{FL}=Q_{PC}\times P_{EO}$
		$C_{vc}=\sum_{i=1}^{n}(P_h-R_{fi})\times A_{iv}\times 10^{-3}$		
		$C_{rc}=0.35\times C_t$ $C_{rc}=C_i-C_u$		
		$C_{mc}=C_{SWS}+C_{sr}$		
Oxygen Release	Oxygen Equivalent Conversion Method	$Q_{OP}=M_{O_2}/M_{CO_2}\times Q_{CO_2}$	Market Value Method	$V_{OP}=Q_{OP}\times C_{O_2}$
Carbon Sequestration and Sink Enhancement	Carbon Storage Accounting Method	$Q_{CO_2}=FCS+GSCS+WCS+CSCS$	Market Value Method	$V_{cf}=Q_{CO_2}\times C_C$
Species Conservation	Shannon-Wiener Diversity Index	$H' = -\sum(p_i\times \ln p_i)$	Surrogate Market Method	$V_{sw}=\sum(C_{SWi}\times A_{SWi})$
Climate Regulation	Vegetation Transpiration Energy Consumption Model	$E_p=\frac{\sum(EPP_i\times A_i)\times D}{ER\times 3600}$	Substitution Cost Method	$V_{EP}=E_P\times P_e$
Non-Point Source Pollution Reduction	Environmental Governance Cost Substitution Method	$Q_{dpd}=\sum_{i=1}^{n} Q_{sr}\times c_i$	Environmental Governance Cost Substitution Method	$V_{dpd}=\sum_{i=1}^{n} Q_{dpdi}\times q_i$

and reliability of assessment results. Research in this field shows an obvious trend of shifting from single-methodology applications to the integration of multiple technologies. The primary step in valuation is the precise quantification of the physical quantities of ecological products generated by soil and water conservation measures. Researchers extensively employ RS and GIS for long-term change monitoring of soil and water conservation measures [81]; GPS is utilized for precise surveys and verification in complex environments. More importantly, distributed hydrological models such as SWAT [82], soil erosion models such as RUSLE [83], and ecosystem models like InVEST [84] have been extensively applied to analyze the dynamic changes of key ecological services before and after the implementation of soil and water conservation measures.

Based on the theory of ecological product value, the benefits generated by soil and water conservation measures are defined as identifiable and measurable "ecological products". According to the mainstream approach currently recognized in China, the concept of ecological product value (GEP) proposed by Zhiyun Ouyang [1, 2] remains the primary framework used for valuation and is widely recognized nationwide. GEP represents the aggregate value of final products and services provided by ecosystems for human well-being, socioeconomic development, and sustainable development. Its functional classification primarily encompasses three categories: ecosystem provision value, ecological regulation services value, and ecological cultural services value. The accounting of ecological product value, within the framework of GEP, can be conducted from two perspectives: functional quantity and monetary value. Functional quantity is estimated using ecological data, while monetary value involves determining market prices for functional quantity. The value accounting of soil and water conservation ecological products focuses on regulating services, specifically covering eight items: water conservation, soil conservation, flood regulation and storage, oxygen release, carbon sequestration and sink enhancement, species conservation, climate regulation, and non-point source pollution reduction. These accounting subjects and formulas not only possess potential for localized adaptation but also exhibit high transferability. They can provide an effective solution for different countries to estimate the value of soil and water conservation measures based on their specific national conditions. Specific functional quantity and monetary value related to soil and water conservation are presented in Table 2 [60, 85, 86].

Data Support: From Multi-Source Integration to Reliability Assessment

Data quality and integration capabilities are crucial safeguards for the ecological product value accounting of soil and water conservation measures. Against the backdrop of transitioning from benefit description to value accounting, the scientific rigor and credibility of accounting results largely depend on the spatio-temporal resolution of input data, the coupling precision of multi-source dimensions, and the localization level of model parameters.

At the multi-data level, on one hand, MODIS and Landsat imagery are dynamically inverted to derive NDVI and NPP, supporting functional assessments such as carbon sequestration [87, 88]. On the other hand, we employ unmanned aerial vehicle (UAV) photogrammetry and light detection and ranging (LiDAR) technology to construct centimeter-level high-precision digital elevation models (DEMs), precisely characterizing the reshaping effects of engineering structures such as check dams [89] and terraced fields [90] on microtopography. Addressing scale effects and matching challenges, the research focuses on resolving spatial heterogeneity conflicts between micro-level measures at the plot scale and basin-level accounting units. Robust scale-up methods are developed to minimize information loss during spatial conversion [91]. Meanwhile, high-frequency time-series models are introduced to fit the hysteresis of processes such as soil nutrient cycling, capturing the nonlinear dynamic characteristics of value changes and overcoming the limitations of traditional annual static snapshots. To ensure the scientific rigor and credibility of the accounting, ground truthing is conducted at typical sample sites to perform residual correction on model outputs, including InVEST and RUSLE, while enhancing the localized dynamic optimization of parameters. Finally, through multi-model ensemble simulation and sensitivity analysis, the impacts of input fluctuations on GEP are quantified, providing reliable data support for green finance decision-making and trans-regional ecological compensation.

International Comparison: Differential Analysis of Accounting Systems

Globally, natural capital accounting serves as a vital tool for measuring sustainable development [92, 93]. Although China and the international community share common objectives in advancing ecosystem accounting, their practical implementations exhibit significant differences due to variations in resource endowments, governance systems, and policy orientations.

In terms of accounting system architecture, although GEP accounting is highly consistent with the United Nations SEEA-EA in its underlying logic, differences exist in application focus and practical implementation. SEEA-EA aims to establish a globally applicable standardized framework and achieves a deep integration of ecosystem asset stocks and service flows. This mechanism not only strengthens the linkage between ecological accounts and national economic accounts but also lays a foundation for the smooth evolution of natural capital accounting toward the System of National Accounts (SNA) [94]. In contrast, China's

GEP accounting aligns with the localized principle that "lucid waters and lush mountains are invaluable assets". From early-stage local governance to modern smart management, China's soil and water conservation has undergone four stages of systematic evolution, forming a comprehensive control system covering engineering, biological, and tillage measures. It places greater emphasis on quantifying regulating services such as soil conservation and water retention [95], providing a reliable yardstick for evaluating the effectiveness of regional ecological protection.

In terms of accounting indicator selection, the SEEA-EA framework tends to focus more on the intrinsic value of biodiversity and non-material services such as cultural and recreational values provided by ecosystems, reflecting the pursuit of specific habitat quality and landscape connectivity in developed countries after industrialization [96]. In contrast, China's GEP accounting is more refined in the calculation of functional quantities [97]. By comparing the changes in physical quantities before and after the implementation of measures such as terraced fields and check dams, it enables dynamic monitoring of ecological barrier functions and provides scientific data support for the construction of regional security patterns.

In terms of application logic and value transformation mechanisms, the international mainstream adopts a market-oriented approach. Payment for Ecosystem Services (PES) is used to establish property rights relationships and realize the optimal allocation of ecological resources, thereby attracting participation from private capital and non-governmental organizations. At the same time, China has developed a government-led application logic centered on ecological compensation. Accounting results are directly linked to the government's green development performance assessments and fiscal transfer payments [10], achieving a strong linkage from value accounting to policy governance.

Ecological Product Value of Soil and Water Conservation Measures: Challenges and Future Directions

To better advance the conversion and trading of ecological products, in 2025, research by scholars, including Chunhong Hu [98], provided crucial theoretical guidance for discovering the value of soil and water conservation ecological products and their market-oriented operation. The potential ecological product inventory for soil and water conservation that they constructed offers flexibility for application across different regions and scales, providing methodological guidance for the market-oriented implementation of ecological value.

Against the backdrop of increasingly severe global environmental issues, soil and water conservation, as the cornerstone of ecological civilization construction, has become even more prominent in its strategic position. As explicitly stated in the Opinions on Establishing and Improving the Mechanism for Realizing the Value of Ecological Products [61], a comprehensive establishment of the relevant mechanism shall be achieved by 2035. Effective soil and water conservation measures are not only crucial for curbing erosion and enhancing land productivity but also serve as the core safeguard for maintaining ecosystem health and sustainable development. However, in the current process of modernization, the enormous ecological product value generated by these measures is confronted with multiple dilemmas in terms of assessment, realization, and market transformation. How to scientifically reveal and fully realize the ecological product value of soil and water conservation has become an urgent issue to be solved in the present era.

Technical Application Aspect

The complexity of soil and water conservation measure types constitutes the primary challenge for ecological product value accounting at the technical application level. As an ecological project for maintaining regional ecosystems, soil and water conservation measures primarily exert positive intervention in and regulation of ecological processes in specific regions – particularly hydrological processes, soil erosion dynamics, and related biogeochemical cycles – through engineering, biological, and tillage approaches [99]. Among these, engineering measures, biological measures, and tillage measures serve as the three core components of soil and water conservation practices. They not only differ in their operational mechanisms but also exhibit differentiated characteristics under the influence of specific geomorphic units. Therefore, in-depth analysis of the value differentiation arising from the coupling of measure types and geomorphic backgrounds constitutes the foundation for constructing a high-precision ecological product value accounting system.

Engineering measures exert ecological effects through terrain reshaping and runoff regulation, presenting particularly prominent technical challenges in their value assessment. Taking soil erosion as an example, to effectively reduce sediment discharge from watersheds, large-scale construction of gully control measures at various levels is required [100, 101]. However, calculations of sediment interception processes often exhibit significant discrepancies with actual observations. This primarily stems from models' inadequate interpretation of complex hydrosediment processes, human disturbance, and precision parameters, directly increasing the subjectivity of assessment outcomes and undermining the ability to support high-precision ecological product value accounting [102]. Therefore, future research must focus on integrating multi-source technologies and optimizing across scales. Incorporating centimeter-level Digital Elevation Models (DEMs) obtained through high-precision unmanned aerial vehicle (UAV) photogrammetry and airborne

LiDAR [103], combined with distributed hydrological models, enables dynamic and refined simulations of surface runoff and sediment processes influenced by engineering measures. Ultimately, this approach can effectively mitigate the subjective biases inherent in single-method assessments, yielding ecological evaluations that more accurately reflect the effectiveness of soil and water conservation measures [104].

Biological measures utilize vegetation and its associated biological activities to enhance ecosystems, with their assessment primarily relying on monitoring the species composition, density, and value of vegetation communities. Previous studies predominantly employed annual methods to simulate the evolution of plant carbon sequestration capacity and biodiversity maintenance functions. However, due to the highly nonlinear and random nature of ecosystem succession processes, traditional approaches exhibit significant lag in capturing dynamic responses and marginal changes in ecological product values, coupled with substantial uncertainty. To overcome this quantitative bottleneck, multi-source remote sensing fusion technology has emerged as a crucial pathway for precise assessment. LiDAR [105] excels in detailed three-dimensional mapping of vegetation canopy structures, while hyperspectral remote sensing [106] holds immense potential for analyzing vegetation biochemical composition. By integrating these technologies and applying multidimensional algorithms, researchers can achieve visual reconstruction of vegetation's three-dimensional spatial distribution and biomass. This enables precise diagnosis of community health and primary productivity levels, significantly enhancing the predictive accuracy of spatiotemporal heterogeneity in biological soil and water conservation measures.

Cultivation practices reshape surface microtopography and optimize cover structures to alter slope runoff and runoff storage mechanisms, thereby enhancing soil and water conservation functions that reduce surface runoff and increase precipitation infiltration [107]. However, past research has primarily been validated at the micro-scale of individual plots or slopes, exhibiting significant scale limitations. Faced with spatially fragmented and numerous farming units, overcoming scale effects to integrate dispersed field practices into basin-level ecosystem contributions represents a critical challenge for ecological product valuation. Future research will focus on the in-depth application of distributed hydrological-ecological models at the watershed scale. This technology aims to transcend traditional isolated single-point assessment models by establishing a scaling mechanism from "patches" to "watersheds", integrating the comprehensive value of measures from "point" to "area". Through dynamic simulations under different climate and management scenarios, it will precisely quantify the ecological regulation service surplus of farming practices at the macro-scale.

Value Accounting Aspect

The core issue at the value accounting level lies in reconciling the horizontal comparability of assessment models with ecological heterogeneity. Taking Gaodi Xie's Equivalent Factor Method as an example, its primary limitation stems from the static dependence of core parameters on specific regional ecosystems. Direct application to other areas leads to biased and distorted results, thereby undermining the credibility and fairness of accounting outcomes. As Hu pointed out [98], China's vast territory creates uncertainties in zone-based systems. To address this challenge, future research and practice should focus on developing a new generation of dynamic accounting models. This requires dynamic adjustments through localized parameters such as biomass and soil attributes, coupled with remote sensing and ecological simulation technologies, to build a GEP accounting system that combines a standardized core with regional adaptability. Only when accounting results possess cross-regional reliability and comparability can they provide a reliable value measurement for constructing fair ecological compensation and precise green finance [108, 109], ultimately promoting the transition of natural capital accounting from academic research to mainstream policy application.

Management Perception Aspect

At the management and institutional level, the core challenge in realizing the value of soil and water conservation ecological products lies in bridging the cost-benefit gap caused by "positive externalities". Specifically, this manifests as upstream protectors bearing the costs of ecological measures while downstream beneficiaries receive core ecological benefits such as flood control and water purification without compensation. Such internalization of protection costs in the upper reaches and externalization of benefits have severely dampened the enthusiasm of ecological protection entities in the upper reaches. The absence of standardized value assessment traps soil and water conservation ecological products in a dilemma where "their value is difficult to estimate, and their benefits are difficult to monetize" [110]. Therefore, the key to solving this widespread problem lies in establishing a scientifically based cross-regional ecological compensation mechanism [111]. First, it is essential to rely on standardized GEP accounting to provide a credible and fair value benchmark for ecological transactions between the upper and lower reaches, thereby solving the problem of "how much to compensate" [112]. Subsequently, a diversified ecological compensation system must be designed around the "beneficiary pays" principle, integrating government fiscal transfers with market-based transactions. The ultimate goal of this institutional design is to promote the transformation of the governance model from a single government-led approach to collaborative governance involving multiple subjects, such as the government, enterprises, and social organizations [113], thereby internalizing ecological protection into a sustainable and self-improving economic activity.

Conclusions

This review systematically examines the dual developmental trajectories of soil and water conservation technologies and ecological product value theory, revealing their historical logic of gradual integration against the background of ecological civilization construction. The analysis shows that soil and water conservation measures have evolved from single engineering control to a three-dimensional system integrating engineering, biological, and tillage practices. Ecological product value accounting has progressed from the equivalent factor method to a value realization mechanism dominated by ecological product valuation and supported by ecological compensation. Their deep integration provides a scientific methodological tool for transforming the ecological benefits of soil and water conservation into quantifiable and convertible economic values. Finally, based on an understanding of existing challenges, this study prospectively proposes the future trend of synergistic evolution across three dimensions: "technology, accounting, and management", providing a theoretical reference for promoting the value realization of ecological products from soil and water conservation.

Although this study has made certain progress in theoretical systematization and methodological integration, it still has the following limitations: 1) Limited literature scope. This study primarily relies on Web of Science core databases for quantitative analysis. While this ensures an international perspective, it inadequately covers Chinese core journals and domestic policy practice outcomes, thereby weakening the governance experience of China's distinctive soil and water conservation practices. 2) Incoherent coupling of accounting methods. In the existing value accounting system, there is a logical discontinuity among the equivalent factor method, the biophysical model simulation method, and the market value conversion method. The lack of unified standards for parameter selection and accounting boundaries across different methods leads to poor consistency in research results when compared across regions and scales, and an integrated technical framework has yet to be developed, covering the entire chain of "technology, accounting, and management". 3) Technical bottlenecks in scale alignment. Soil and water conservation measures exhibit significant spatial heterogeneity, whereas ecological product value accounting typically focuses on regional or watershed-scale units. Current research still encounters technical bottlenecks in constructing a multi-scale transmission mechanism of "project-watershed-region", making it challenging to accurately quantify the marginal effects of plot-scale measures on regional GEP contributions.

Given the aforementioned limitations, future research on the ecological product value of soil and water conservation measures should focus on the following four directions. 1) Deepen research on multi-scale coupling and value transmission mechanisms: There is an urgent need to develop scaling-up methodologies from engineering units to watershed systems and construct cross-scale ecological product value transmission models. By revealing the nonlinear effects of soil and water conservation measures across different spatial scales and scientifically characterizing value transmission pathways, this research will provide a basis for targeted policy implementation. 2) Promote alignment with international standards for natural capital accounting: While deepening the domestic GEP accounting system, research should be intensified to enhance compatibility with the UN SEEA-EA framework. By standardizing accounting indicators and dynamic adjustment factors, the international comparability of China's soil and water conservation ecological product accounting outcomes will be elevated, contributing a "Chinese solution" to global ecological governance. 3) Innovate market-driven value realization pathways: Explore transitions from government-led to market-driven models. Deepen institutional experiments in water rights trading, carbon credit trading, and green financial products to establish a diversified compensation system involving governments, enterprises, and social organizations, ensuring the long-term effectiveness and sustainable development of soil and water conservation outcomes. 4) Strengthen the enabling role of artificial intelligence and digital twin technologies: Leverage big data, the Internet of Things, and digital twin technologies to construct basin-level digital twin ecosystems. This enables real-time monitoring of ecological benefits from soil and water conservation measures and dynamic value updates, supporting intelligent and precise decision-making in ecological product management.

In summary, promoting the value realization of ecological products from soil and water conservation measures is essentially a systematic reform involving concepts, technologies, and institutions. Its core lies in breaking through the limitations of traditional soil and water loss control and establishing a value realization-oriented concept of ecological products. Currently, research on the value of ecological products from soil and water conservation measures is in a critical period of evolving from theoretical deepening to institutional construction. The focus of future research should not only be on improving the dynamism of accounting methods but also on exploring a systematic value realization path integrating science and technology, institutions, and the market. Only on the basis of scientific accounting, by promoting the coordination of diversified systems and market transformation, can the effective conversion of "lucid waters and lush mountains” into “invaluable assets” be truly realized.

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During the preparation of this review article, the authors used DeepSeek’s web-based chat service in fast mode to generate a preliminary draft for part of Section 4.2 and to assist with language editing in Section 5 (Conclusions). The authors subsequently reviewed and substantially revised all AI-assisted content and independently verified the factual statements, scientific interpretations, terminology, and citations against the original published sources. DeepSeek was not used to generate or analyze research data, perform statistical analysis, or independently formulate the scientific conclusions. The authors take full responsibility for the accuracy and integrity of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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