Sustainability in Environment
ISSN 2470-637X (Print) ISSN 2470-6388 (Online)
Vol. 10, No. 1, 2025
www.scholink.org/ojs/index.php/se

Original Paper

Soil Conservation Services and Its Enlightenment for Improving Ecosystems for Rocky Desertification Management: A Literature Review and Bibliometric Analysis

Xiaoyu Yan[1], Kangning Xiong[1*], Lulu Cai[1], & Yating Mu[1]

[1] School of Karst Science, Guizhou Normal University, State Engineering Technology Institute for Karst Desertification Control, Guiyang 550025, China

[*] Corresponding author, E-mail: Xiongkn@163.com

Received: November 23, 2024 Accepted: December 22, 2024 Online Published: January 02, 2025
doi:10.22158/se.v10n1p18 URL: http://dx.doi.org/10.22158/se.v10n1p18

Abstract

Soil conservation service (SC), as one of the most crucial ecosystem services (ES), plays a vital role in promoting the restoration of ecosystem structure. Severe soil erosion in karst areas has resulted in the ongoing degradation of soil conservation services. Understanding the current and evolution of research in this field is essential for establishing a theoretical foundation for the future management of rocky desertification in karst areas. Based on the Web of Science (WOS) and China Knowledge Network (CNKI) databases, 224 articles on SC were collected. This paper summarizes the research progress, results, and development trends from various aspects through systematic review and qualitative analysis of the literature. The findings are visually presented using spatial visualization and analysis tools such as SATI and Gephi. Key scientific issues and future development trends of existing SC are summarized with a view to improving SC in rocky desertification areas. It is of great significance to further improve the layout of ecological engineering construction and rocky desertification management in karst regions.

Key words

karst region, soil conservation service, soil erosion, ecosystem service

1. Introduction

Soil, as a non-renewable natural resource, is a fundamental environmental resource for human survival. The closely related SC is essential for ecosystems to maintain soil quality and conserve water. However, 15 out of the 24 ES (62.5%) are degraded globally, including SC (ME Assessment, 2005). This is because soil erosion weakens SC, and SC degradation contributes to soil erosion. Global soil erosion accounts for 10.95 percent of the world's total area and has emerged as one of the three major ecological challenges in the global environment, leading to adverse effects on soil conditions, water quality, species diversity, and the provision of ESs (Gao et al., 2023). It also highlights the importance of enhancing SC to reduce soil erosion.

Since the 1990s, ESs have become an international research hotspot in ecology and economics. SC is an indispensable ES that serves as an indicator for quantitatively evaluating the soil erosion status of an area. It functions to reduce soil erosion and control sediment deposition (Costanza et al., 1997). Therefore, evaluating SC can provide intuitive information for assessing ecological sustainability and can be further utilized in natural resource management and policy formulation. In recent years, various themes have been analyzed, including the spatial and temporal evolution of SC (Zhu et al., 2019), the driving mechanisms (Wang et al., 2023), and the spatial flow analysis (Xu & Pan, 2022), as well as the evaluation of SC at different scales (watershed, regional, national, global) (An et al., 2022; Gurung et al., 2018; Kottagoda & Abeysingha, 2017; Liu et al., 2021b). As a great deal of research has been conducted on SC, it is crucial to summarize the existing findings and look to the future. However, there is no systematic summary and analysis of the progress of research on SC, and its development trends and potential research hotspots are not yet clear. SC is still under-researched, especially in karst areas. Therefore, it is necessary to review the research area of SC to propose enlightenments for enhancing soil conservation functions in rocky desertification areas.

Karst areas are rich in biodiversity and provide a wide range of ES. Karst landscapes are an important background for the occurrence of soil erosion in the region, with rocky desertification being a prominent feature of soil degradation. Over the past half-century, increased exploitation of natural resources has led to the gradual transformation of karst areas, once covered by shrubs and evergreens, into bare soil. Soil quality has declined dramatically, resulting in an imbalance in the ecosystem and the loss of various ES capacities, especially SC (Jiang et al., 2014). Enhancing the SC capacity has also become a top priority. To overcome this dilemma, in recent years, the SC capacity of karst areas has been improved through the implementation of ecological restoration projects increased vegetation cover (Tong et al., 2018). Against the backdrop of severe rock desertification, enhancing SC can effectively prevent and manage soil erosion and truly realize the harmonization of ecological and economic benefits. Currently, some scholars have conducted relatively superficial studies on SC in karst areas (Ran et al., 2020; Wang et al., 2020; Xu et al., 2022). There are numerous unresolved key scientific questions and a lack of insightful understanding in this research area. Therefore, it is crucial to identify potential research hotspots and emerging trends in SC in rocky desertification areas.

In this study, we systematically reviewed and statistically analyzed research advances in SC worldwide with the aim of addressing existing knowledge gaps and facilitating access to information on new SC. We present the distribution of current literature and research findings on SC, offer different perspectives on SC research, consolidate information on areas requiring more attention in the future in rocky desertification regions, and explore the enlightenments of SC research for improving the ecosystems of karstic rocky desertification management.

2. Materials and Methods

2.1 Literature Acquisition Source

Literature search based on the China Knowledge Network Database (CNKI) and Web of Science (WOS) core databases, deadline: December 31, 2023. Search by "subject" and "(ecosystem service, ecological system service)" + "(soil conservation, soil retention)" as search terms. Among them, 173 documents were obtained from CNKI, including 97 journal papers, 78 master's theses, 4 doctoral theses, 3 conference papers, 0 newspaper articles, 0 featured journals, 0 books, 1 achievement, 0 yearbooks, 0 patents, and 0 standards. WOS obtained 98 documents: 94 articles, 4 reviews, 0 conference papers, 0 book chapters, and 0 books. A total of 271 documents were obtained from the initial screening of the two types of databases. Finally, after removing duplicates and documents that don't align with the research objectives, a total of 146 documents in Chinese and 78 documents in English were collected. These included 157 journal papers, 59 master's theses, 4 doctoral dissertations, 3 conference papers, 0 newspaper articles, 0 books, 1 achievement, and 0 yearbooks. In the end, CNKI and WOS obtained a total of 224 documents (Figure 1).

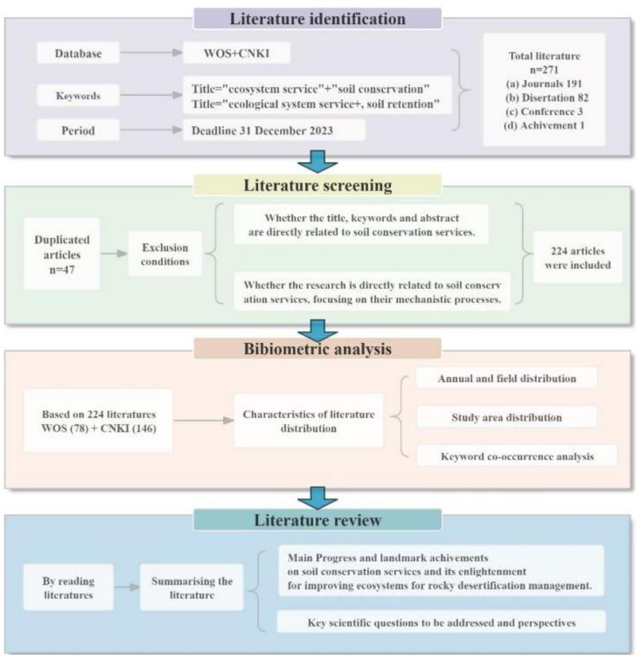

Figure 1. Flowchart of Literature Acquisition and Literature Review

2.2 Literature Statistics Analysis

The data collected from WOS and CNKI databases were screened and further analyzed bibliometrically. In addition, we analyzed and plotted the data using Microsoft Excel 2020 and Origin 2021.

Co-occurrence analysis was conducted using SATI and Gephi software. Closely related keywords are grouped into one category to form a clustering network, and the clustering results are visualized to directly display the position and size of each knowledge node in the knowledge structure network. Nodes represent specific keywords. Labels and nodes are proportional to the frequency of keyword occurrence, while the co-occurrence frequency is reflected in the thickness of the connecting lines.

3. Results

3.1 Bibliometric Analysis

3.1.1 Annual and Distribution of Literature

From 2000 to 2023, the research on SC can be roughly divided into three stages (Figure 2). The first stage (before 2000) was in the initial stage, and domestic and foreign literature were published sporadically, with no more than 3 articles per year. China became involved in this field later than foreign countries, initiating SC research in the 1970s. In the second stage (2000-2013), the total number of articles is experiencing slow growth, with no more than 5 articles increasing from the previous year. The number of foreign literatures is higher than that of Chinese literature, but both are basically consistent with the growth trend of total literature. In the third stage (2013-2023), the total number of articles experienced a surge, and the research content gradually deepened. China has continued to increase its overall awareness of sustainable development, further promoting academic prosperity. Starting in 2016, China gradually surpassed foreign countries in the number of papers published, becoming one of the most influential countries in the field.

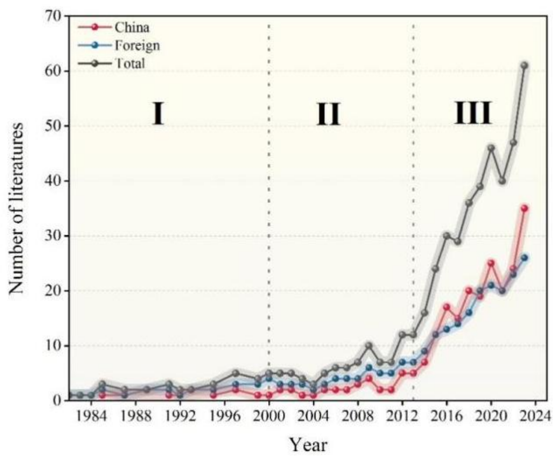

Figure 2. Annual Distribution of Research Literature

3.1.2 Research areas Distribution of Literature

Among the many domestic and foreign research fields related to SC, the distribution of literature is mainly dominated by the fields of environmental sciences and resource utilization (36.17%), followed by agricultural economics (23.36%). The combined percentage of these two fields accounts for more than 50% of the total number of other related fields, indicating that research on SC is closely associated with environmental resources and agricultural economics (Figure 3). Research in the 1970s and 1980s focused on resource utilization in agro-ecosystems (Shaw 2007). The distinct interdisciplinary nature of SC facilitates clarifying the strong links between the above topics, and improving the SC capacity can optimize the synergistic development of the natural resource environment and the agricultural economy. In addition to this, the response of SC to global environmental change (biodiversity, soil type, rainfall, temperature) is emerging as a trend for future research. Therefore, biology, geology, and meteorology are also potential emerging research hotspots.

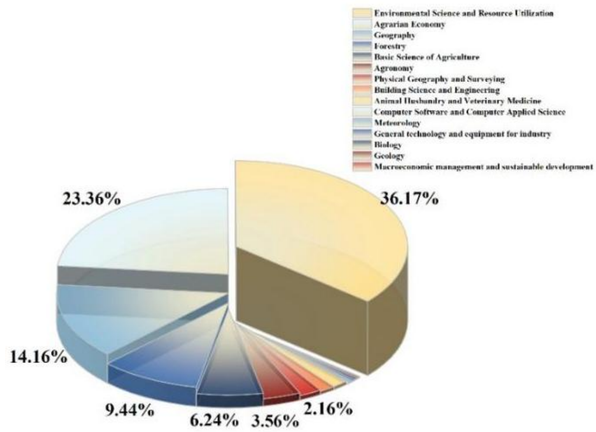

Figure 3. Field Distribution of the Literature

3.1.3 Study area Distribution of Literature

Among all the foreign literature searched, Asia had the highest literature. Followed by Europe, North America, Oceania, Africa, and South America, which accounted for 43.59%, 21.79%, 20.51%, 5.13%, 3.85%, and 2.56% of all the regions, respectively (Figure 4). In terms of countries, China published the most literature (n=19). The Chinese literature has more studies on SC in the northwestern and southwestern regions (Figure 5), with more than 10 publications in Sichuan, Chongqing, Guizhou, Gansu, and Qinghai, and relatively few studies in other provinces. Because more scholars are drawn to China's unique landscapes, like the karst landscape in Southwest China and the delicate functioning zone of the Northwest Desert Belt. In conclusion, the study of SC is closely related to the development of areas with high topography and agriculture. Rocky desertification ecosystem is highly typical, representative, and exemplary worldwide. Therefore, it is also necessary to conduct research on SC for it. Relevant research conducted in other regions holds significance for the karst region.

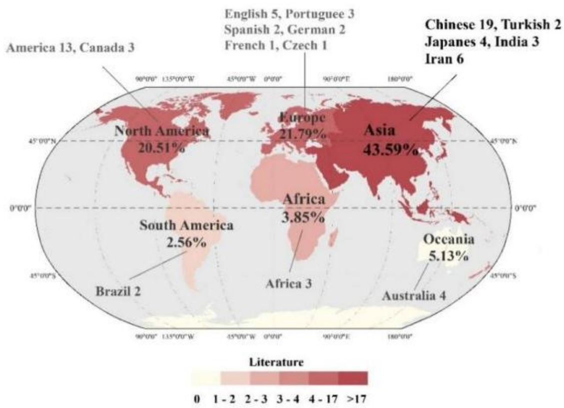

Figure 4. Research Areas in Foreign Language Literatures on Soil Conservation Research

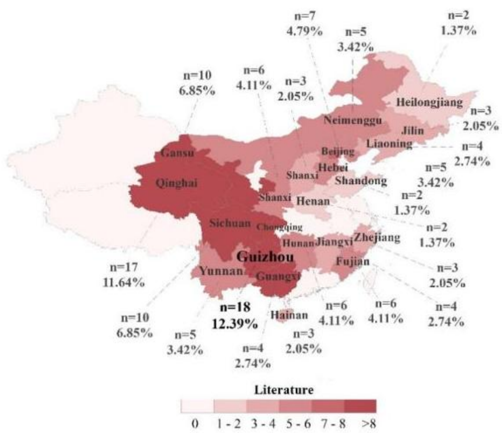

Figure 5. Soil Conservation Research Chinese Literature Research Area

3.1.4 Keyword co-occurrence Analysis

SATI and Gephi software were used to conduct keyword co-occurrence analysis to gain a deeper understanding of research hotspots and collaborations. The most essential information contained in an article is represented by its keywords, which also play a crucial role in the information retrieval process and help identify research hotspots within the topic. The minimum number of occurrences of a keyword was set to 5, and 50 out of the 289 keywords met this requirement (Figure 6). The most often used keywords are ecosystem service (Frequency=30), soil conservation (Frequency=23), In VEST model (Frequency=19), soil erosion (Frequency=10), trade-off (Frequency=9), land-use change (Frequency=7), water yield (Frequency=7), climate change (Frequency=7), biodiversity (Frequency=6), and ecological restore (Frequency=6) (Table 1). There is a strong link between various keywords. With "ES" as the center of research, keywords such as "soil erosion," "trade-off synergies," "spatial and temporal distribution patterns," and "ecological restoration measures" are developed around it.

Cluster 1 (Red) focuses on soil erosion and SC, exploring their responses to land uses. Cluster 2 (Yellow) focuses on trade-off synergies of ES in arid or agriculturally developed areas. Cluster 3 (Green) focuses on the spatial-temporal dynamics of SC based on different modeling approaches. The absence of other new methods as keywords in the later stages suggests a lack of innovation in methodological research in this area, which may impede research development. Cluster 4 (Blue) is more concerned on with the relationship between climate change or ecological restoration measures and SC. One of the primary determinants of SC is climate, assessing the impact of climate change on SC has emerged as a new hotspot. The keyword "China" appears more frequently. China has been implementing GFGP since 2000 to combat soil erosion. It is, therefore, an active country in this field of research.

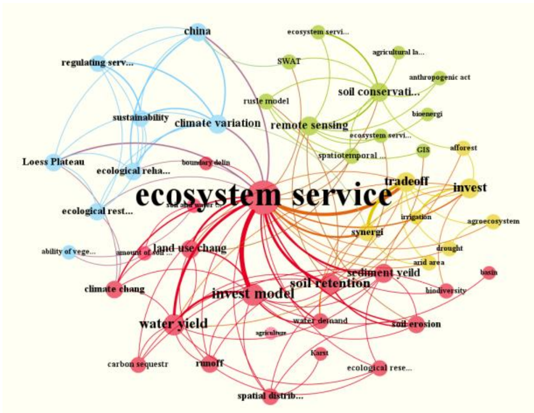

Figure 6. Co-occurrence Network of Keywords

Table 1. High Frequency Keywords

	Key-words	Frequncy
1	ecosystem service	30
2	soil conservation	23
3	InVEST	19
4	soil erosion	10
5	trade-off	9
6	land-use	7
7	water yield	7
8	climate change	7
9	biodiversity	6
10	ecological restore	6

3.2 Main Progress and Landmark Achievements on Soil Conversation

3.2.1 Methods for Evaluating Soil Conservation Capacity

Through extensive research into the mechanistic processes of soil erosion, scholars have proposed various assessment methods. The most widely utilized methods include traditional slope observation and modeling assessment. Slope observation is used to identify soil erosion conditions by setting up runoff samples manually or conducting spot observations on the farmland slope. It has the advantage of describing the mechanism of the soil erosion process in depth and the accuracy of the observation results, with many research findings accumulated (Sadeghi et al., 2020). However, this method is time-consuming, labor-intensive, and difficult to apply to large-scale studies. Soil erosion models were developed with this. Depending on whether they include mechanistic processes of erosion, models of soil erosion are categorized as empirical or physical. The former is based on field measurement data, combined with local characteristics to capture measurable parameters affecting soil erosion. It involves establishing mathematical and statistical relationships between the parameters and the amount of erosion. The Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE), which is the most widely used empirical model, have simple structures and low input data and parameter requirements. However, they are unable to describe the soil erosion process in detail from the perspective of physical processes. It has been widely used in watersheds (Olorunfemi et al., 2020) and semi-arid vulnerable areas (Huang & Yu, 2021). The creation of the InVEST model addressed the oversight of previous models in neglecting the role of plots in intercepting sediment, making it increasingly recognized as the most established method of assessment. Ma et al. (2021) found, based on the InVEST model, that GFGP enhanced ecosystem service functions in the hilly regions of southern China. Abolmaali et al. (2024) Conservation prioritization of ES in Iran using the InVEST model. Physical modeling utilizes physical concepts such as sand production, water flow, and sand transport as a basis to predict the amount of soil erosion over a specific period. These models, such as the Soil and Water Assessment Tool (SWAT), the Water Erosion Prediction Project (WEPP), and the Revised Morgan Morgan Finney (RMMF), were first introduced in the 1940s and have been evolving since then (Ellision 1947). One drawback of these models is its semi-distributed nature, which only allows for estimating the amount of sediment produced at the watershed outlet and the information cannot be spatially visualized. The advantage of the InVEST model, in contrast, is that it can depict regions of erosion and deposition inside a single raster cell. In general, many parameters of physical models are challenging to measure and calibrate directly, which results in uncertainties in the simulation outcomes (Xia et al., 2021). Therefore, empirical models are widely used in studies on soil erosion and SC.

The sources of erosion in karst areas are complex and diverse. The empirical model seldom considers gully erosion, gravity erosion, landslide erosion. Only slope erosion is typically considered. The RUSLE cannot be used in locations with steep slopes because of the considerable relief found in karst. Knisel (1980) proposed a runoff and soil erosion model for slope-scale evaluation, and it is also better suited for karst regions. Nonetheless, certain inadequacies and limitations persist. Some scholars believe that a physical model or semi-physical model is more advantageous for application in karst areas. Yu et al. (2012) discovered that the SWAT model applies well to small watersheds in the southwest karst region. Feng et al. (2014) utilized the RMMF model to assess soil erosion in Guangxi karst sub-watersheds. Since the evaluation results generally agrees with the runoff plot monitoring findings, indicating that the model was well-suited for the karst region. Therefore, when selecting appropriate SC model evaluation methods, decision-makers must consider the environmental features of karst regions and the similarities and differences in spatial patterns that may arise from the application of these methods. This is essential to improve the assessment's precision and provide robust technical support for evaluating SC in karst areas.

3.2.2 Patterns of Spatial and Temporal of Soil Conservation Services

Early studies on SC primarily focused on the macro-level mechanistic process of SC and lacked research that incorporated spatial location information (Chen et al., 2019). Clarifying the spatial-temporal distribution characteristics of SC is a prerequisite for identifying key region for SC. An increasing number of academics are focusing on the patterns of spatial- temporal distribution of SC, identifying high and low values of SC, and offering theoretical recommendations for managing soil erosion-prone areas and maintaining SC. Kong et al. (2018) found that the low-value area of SC is situated in the lower reaches of the Yangtze River. They suggested that efforts should be redirected towards downstream areas. The identification of significant areas in SC is, therefore, a form of assessment that supports planning for the conservation of ecosystem services. It is a key technical stage in the process designed to answer questions about when, where, and how ecological conservation can be effectively achieved.

As rocky desertification areas are linked to poverty, most scholars prefer to assess the value of karst ecosystem services (Hu et al., 2020; Wang et al., 2022). While this helps give priority to SC areas with high economic value, it is insufficient to reflect the essence of the ecological capacity of SC. Soil erosion is a critical issue in the management of rocky desertification, while SC is a direct result of reacting to how well the two are managed. To advance the management of rocky desertification, it is necessary to conduct further in-depth studies on the priority areas for SC. Ran et al. (2020) concluded that the spatial distribution of SC in the karst region remained steady between 2000 and 2015 and should focus on improving SC in the western part of the study area. Therefore, detailed tracking of spatial-temporal changes in SC is essential. Karst regions should through the GIS simulates the spatial-temporal distribution of SC to identify cold hotspot areas, aiming to maximize the effectiveness of rocky desertification management.

3.2.3 Response of Soil Conservation Services to Land Use Types

Several academics have integrated land use patterns with SC to clarify differences in SC under different land use/cover scenarios, which has emerged as a research hotspot in ecology and related disciplines. Changes in land use types can have both positive and negative effects on SC by increasing vegetation cover, thus improving SC, and by reducing vegetation, leading to soil erosion (Srichaichana et al., 2019). Keshtkar et al. (2022) found that the reduction of grassland and the expansion of artificial areas have led to an increase in soil erosion and a decrease in SC capacity. Returning cropland to forests and grasslands by altering land use can significantly reduce sources of erosion-prone land (Liu et al., 2020b). Secondly, a key element in improving the SC is the rise in biodiversity that results from beneficial land-use change. (Deng et al., 2019; Peng et al., 2020). Therefore, to support wise soil management decisions, it is essential to define how changes in land use affect the distribution pattern of SC.

The diversification of land uses in karst areas has resulted in significant differences in SC. More attention needs to be paid to the distribution characteristics of SC under each land use type so that targeted ecological restoration measures can be proposed. For example, forest grasslands have a greater SC capacity, and karst areas can improve SC by implementing GFGP and promoting urbanization (Rao et al., 2016). Land uses originate from nature, and nature-based solutions are an effective strategy to manage soil erosion. These solutions should be further developed in karst areas in the future to enhance the sustainability of SC.

Figure 7. Different Land Use Types in Karst Areas

Selecting suitable species for planting in karst areas can improve the soil's anti-erosion ability, have a certain improvement effect on rocky desertification soil, and have obvious benefits of soil and water conservation function

3.2.4 Driving Mechanisms for Soil Conservation Services

Although the general framework of SC is understood, most research stops at revealing evolutionary phenomena while neglecting the processes of the influencing factors. The role of influence on SC varies at different spatial and temporal scales. In the sandy area of eastern China, SC is controlled by climate change (Wang et al., 2023). Studies on driving factors in the Yellow River Basin have shown that topographic characteristics are the primary determinants of SC (Xiao et al. 2021). This shows that the dominant factors for SC in different regions are diverse, and the driving mechanisms are not yet clear. Clarifying the driving mechanisms of SC often requires linking SC distribution characteristics to other natural and anthropogenic factors rather than solely relying on a single indicator change. Domestic and international research mainly studies the effects of static and dynamic elements on SC. Scholars have mostly analyzed the effect of static elements on SC in terms of natural factors such as rainfall, topography, soil type, and geomorphology. For example, Pan et al. (2022) found that sufficient rainfall and dense vegetation growth in Shangri-La ecosystems favored SC. For the analysis of dynamic elements, the main consideration is the impact of human activities, which have a favorable impact on SC through the GFGP, or an unfavorable impact on SC through enclosing lakes, creating new farmland, and overgrazing (Guo et al., 2022; Kong et al., 2018). Typical statistical techniques that are frequently employed include correlation analysis, hierarchical analysis, logistic regression, and others (Guo et al., 2021; Xiong et al., 2017; Zhu et al., 2019). The advantage is that it is simple to implement and efficient when there are many factors. The disadvantage is that it is less accurate when the amount of data is small and unevenly distributed. Therefore, one of the future development trends is diversified spatial modeling analysis methods, such as Geographical Detector, Geo-Weighted Regression, and Structural Equation Modeling. Lu et al. (2023) revealed that the interaction between slope and annual precipitation in the Tibetan Plateau region has the greatest impact on SC based on the Geographical detector. In contrast to non-spatial models, spatial models consider spatial heterogeneity of drivers and non-linear relationships (Pribadi & Pauleit, 2016). They also reveal that SC is affected by multiple factors rather than a single, realizing a combination of multiple perspectives on the evaluation of mechanisms affecting SC.

The formation of karst landscapes is a dynamic, long-term process that also results in SC with spatial differences (Pei et al., 2019). To elucidate these differences, it is necessary to study the dominant factors of SC variation and identify Intrinsic driving mechanisms. The drivers of SC are primarily analyzed by traditional analytical methods in karst areas. Niu and Shao (2020) discovered that vegetation cover and rainfall on the Guizhou Plateau were positively correlated with SC through correlation analysis, and used residual analysis to conclude that anthropogenic activities had more positive than negative impacts on SC. Rao et al. (2016) used RDA analysis to find that land use and urbanization were the main factors affecting SC in karst areas. However, traditional analyses often use empirical knowledge to subjectively grade continuous independent variables, significantly affecting the explanatory power of the drivers. Secondly, the driving process of SC in karst area is complex, and the traditional methods overlook the comprehensive influence of multiple factors on SC. In the future, the karst region should integrate traditional analysis with spatial modeling to uncover the individual contributions of each driving factor and the synergistic effect of these factors.

4. Discussion

4.1 Key Scientific Issues to Be Addressed and Prospects

4.1.1 Regional Variations Exist in the Metrics Used to Assess Soil Conservation Services. Their Specificities Must be Considered to Adjust the Model Parameters and Improve the Accuracy of the Assessment

In terms of research areas and application methods, the application scope of SC assessment models has been continuously diversified. However, the issue of inconsistent accuracy of model parameters remains unresolved (Fu et al., 2005). Thus, determining how to utilize the observations to adjust the model parameters with limited accuracy becomes a key issue. In more than half of the actual model applications, parameterization is done using soil erosion measurements derived from field observations and sampling. The accuracy of model assessments needs continuous enhancement through parameter localization. Several authors have made a series of improvements for different study scales and regional characteristics. Correcting the support practice factor (P) by assigning weighted values to different land use types (Li et al., 2012). Naipal et al. (2015) improved the rainfall erosivity factor (R) and slope factor (S) by employing climatic zonation and fractal methods. Liu et al. (2020b) modified model parameters in northern Shaanxi using terrace data obtained from visually interpreted high-resolution imagery to improve simulation accuracy. The above studies have improved the accuracy of model assessments. Accordingly, to determine which parameters exert the greatest impact on the modeling outcomes and are good candidates for parameter calibration, a sensitivity analysis of the input parameters is first required.

Given the significant regional adaptation problems in evaluating soil conservation services in karst areas, parameters must be adapted to local conditions to localize the model. Long et al. (2014) attempted to use the WEPP model to evaluate soil erosion in a karst area. The findings indicated a significant discrepancy between the simulated erosion and the actual measurements and suggested that the model required adjustments by incorporating factors like soil leakage, topographic features, and bedrock exposure. The reasonable evaluation of SC, which is heavily reliant on the algorithmic selection of each model factor and the adaptation of model parameters to local conditions. In response to the sensitivity characteristics of soil erosion in karst areas, accounting specifications for ecosystem services in some karst areas now indicate that model parameters for assessing SC need to be corrected for rock desertification factors. It can help to assess more accurately the soil erosion situation in karst areas. To increase the accuracy of the model evaluation in the karst area, it is therefore required to grasp the degree of rocky desertification in the karst area and then extract the rocky desertification factors through Arcgis for adjusting the model parameters.

4.1.2 The Evaluation of Soil Conservation Services is Limited to Traditional Modelling Analysis. It Should be Integrated with a Variety of Methods and the Evaluation Indicators Should Be Expanded to Enrich the Evaluation System

Empirical models, although simple to operate, cannot be applied beyond the geographical conditions from which their statistical relationships originate. The extreme assumptions made by RUSLE have resulted in soil erosion often being overestimated. Most parameters in physical models often need simplification at large scales, leading to inaccurate assessments. In summary, despite significant progress in model development and input parameterization, there are still knowledge gaps in the validity, quality, and reliability of model application results. Due to the numerous parameters in the model, a large amount of data is required for it to operate, rendering it unsuitable for use in situations where data are relatively scarce. In addition to the traditional indicators related to soil erosion processes mentioned above, other indicators that represent ecosystem components and structure, and also serve as the foundation for SC, can be utilized as proxy indicators to measure the SC capacity (Table 2). Related studies have shown that biophysical data (biomass or NPP, water cover, soil infiltration capacity, slope, temperature, precipitation, and elevation) can also be used as proxy indicators for SC model assessment.

Lü et al. (2017) analyzed the spatial-temporal variability characteristics of SC in China by using a modeling framework based on the proxy indicators of NPP. The model involves significantly fewer parameters, which is beneficial for large-scale dynamic assessments. In addition to quantitative assessment of SC capacity using models, indicators such as land use or vegetation cover can also be used for qualitative assessment, to identify key areas for intervention. Integrating satellite imagery, remote sensing, and evaluation models can help assess dynamic changes in SC and be applicable to large-scale studies (Yan et al., 2020). However, satellite remote sensing data are limited by spatial resolution and cannot achieve high-precision monitoring studies. UAV remote sensing has grown quickly in the last several years and is widely used in soil erosion prediction models (Neugirg et al., 2016; Pijl et al., 2020), providing higher-resolution data. UAVs are currently advantageous due to their low cost, high efficiency, high precision, and high degree of weather and terrain adaptation (Xie & Yang, 2020). As a result, UAVs are superior to conventional methods for simulating the spatial distribution of SC. Not only enable spatial overlay studies but also compensate for the limitations of low resolution in RS and limited surface information, resulting in reduced model accuracy.Therefore, more new interdisciplinary methods and integrated techniques should be proposed and applied to the original traditional methods in order to promote further development in the field.

Currently, there is still a lack of research on breaking through traditional modeling in karst areas. Modeling is mainly combined with "3S" technology when carrying out SC evaluation. For example, low values of SC in karst areas were identified as being concentrated in the central plateau and western canyon areas based on GIS (Niu et al., 2020). However, the topography of the karst region has great variations in undulation, and the resolution of commonly used remote sensing images makes it difficult to achieve the research purpose in a small-scale study area. Therefore, the problem of low resolution can be solved by collecting terrain information with UAVs. Expanding the indicators for evaluating SC by taking into account the influencing factors for controlling the occurrence of rocky desertification (vegetation cover, land-use type, altitude, and slope) so as to comprehensively and thoroughly complete the SC assessment.

Table 2. Soil Conservation Service Evaluation Indicators

Indicator type		Indicator name	Indicator meaning
Indicators of soil erosion processes	Sand production by erosion	Soil erosion	The amount of material displaced by soil under the action of runoff on a given spatial and temporal scale.
	Transport deposits	Soil conservation	The amount of sediment that an ecosystem maintains intercepted at a given spatial and temporal scale

	Sediment export	Quantity of sand (transported or produced)	Sediment production at the outlet cross section of a watershed or sediment transport at a cross section of a river
Indicators of ecosystem structure		Vegetation cover, Land use, Topography	Different vegetation cover and land use have different abilities to control erosion or intercept sediment.
Biophysical data indicators		Biomass, NPP, Water cover, Soil infiltration capacity	Biophysical data is an important aspect in managing soil erosion and can be utilized as a proxy indicator in models.

4.1.3 SC Are mostly Analyzed at a Single Scale. By Sorting out the Dominant Processes of SC from Small to Large Scales, We Can Advance Research on Integrating SC Across Various Scales

SC is a directional flow service where changes in erosion in upstream areas not only have localized impacts but also have trade-off impacts on midstream and downstream, along water or sediment transport pathways. For example, reduction in water supply and wetlands may occur due to upstream SC projects (Yin et al., 2022). Soil redistribution processes due to sediment transport in the horizontal direction reflect the conversion from small to large scales of study in SC (Figure 7). Slope scale assessment relies heavily on understanding the mechanisms of soil erosion and exploring the process of SC formation. Many studies have explored the effects on slope erosion from the perspective of land use patterns and management strategies, leading to significant progress (Liu et al., 2020c; Su et al., 2021). Most current studies have focused on the small watershed scale (Fang et al., 2021; Qi et al., 2019). The watershed scale represents the entire rainfall-erosion-sand production system in nature for SC. It is also the ideal scale for studying the generation, flow, and use of SC. This scale can effectively depict the soil erosion and transport processes and analyze the local and remote impacts of SC changes. River erosion and sedimentation processes are gradually playing a dominant role at large scale (continental and global), so that river sediment delivery can be used as an indicator for evaluating SC capacity at large scale. Assessment models are typically fed with low-resolution data on a large scale, leading to inaccurate assessment results. Therefore, as the scale increases, improving assessment accuracy has become a common concern among scholars. In summary, the focus on SC flows varies at different scales. Therefore, effective SC assessment needs to be carried out at different spatial scales, such as slope-watershed-regional-global, along the pathway of soil erosion-transport-deposition, to reflect the dominant processes of SC at different scales.

Karst areas have a binary three-dimensional erosion system that combines slope erosion processes with watershed sand production and transport processes (Zeng et al., 2018). At the watershed and slope scales, the soil erosion processes are somewhat similar, but the values differ significantly due to the presence of channel erosion in the watershed. Therefore, the slope scale is insufficient to reflect the characteristics of SC in karst regions. Due to the simultaneous presence of surface runoff and subsurface seepage in karst areas, the surface-based law of soil erosion-migration-deposition equilibrium does not fully apply. A single scale is insufficient to reveal the complete process of SC formation, transport, and change. In the future, building upon existing technical guidelines, need to identify the multi-dimensional distribution dynamics of SC in karst areas from perspectives on the interweaving of sediment transport pathways (including underground piping systems) with different spatial-temporal scales.

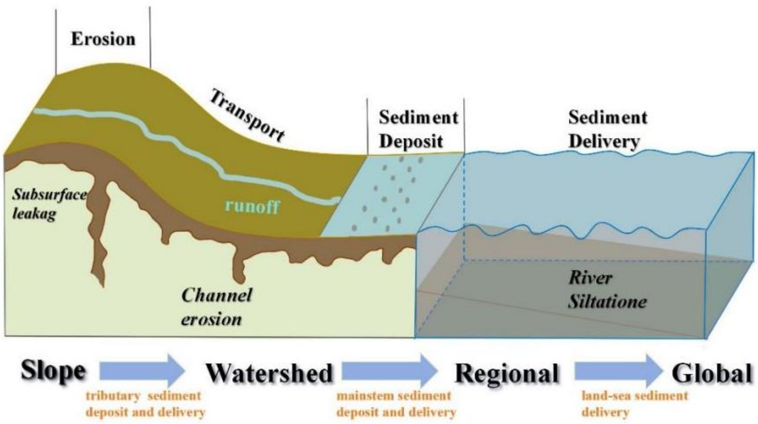

Figure 8. Scale Characteristics of Surface Erosion Sand Production, Transport and Deposition, and Sediment Export Processes. Soil Erosion Can Affect Soil Retention in other Areas such as the Middle and Lower Reaches of the River along the Water System or Sediment Transport Pathway, and Needs to be Carried out along the Soil Erosion-Transport-Deposition Pathway at Different Spatial Scales, such as Slope-Watershed-Regional-Global

4.1.4 Focusing Solely on the Correlation between SC and Ecological Factors. Ignores the Role of These three Components' Interactions on SC in Addition to the Impact of Socio-economic Factors on SC.

The direct impacts of soil degradation caused by irrational land management practices or harsh natural factors have been identified. Therefore, to improve SC and curb soil erosion, it has become a research priority to identify the driving mechanisms of SC from an ecological perspective (Xiao et al., 2021). SC is a natural process, but due to the continuous development of society, which accelerates the change of socio-economic needs and ecological civilization concepts rooted in land users (Hou et al., 2020), focusing only on the effects between SC and ecological elements may not achieve comprehensive ecosystem restoration and reconstruction. However, there is still a lack of systematic research on SC in terms of demographic, socio-economic, and cultural factors, which are also crucial for enhancing SC. The protection and restoration of SC should prioritize resolving the conflict between limited soils and socio-economic development, so the impact of socio-economic factors on SC should be more incorporated into future research themes. Secondly, there are interactions among the ecological-social-economic triad. Ecological changes can have significant socio-economic impacts—reducing poverty, altering farmers' income structures, and promoting urbanization. Ecological changes promote rural-urban labor migration, which helps mitigate the negative effects of population pressure on the effectiveness of ecological restoration and indirectly enhances SC (Li et al., 2017). Socio-economic factors can also influence ecological conservation—increasing ES capacity and enhancing soil quality. Adoption of efficient agricultural practices mitigates the negative impacts of the GFGP on agricultural development and promotes synergistic increases in vegetation cover and crop yields, thereby enhancing SC capacity (Sui et al., 2022). The need for socio-economic sustainability should be integrated into SC improvement, further elucidating how the three in their interactions can drive improvements in SC and providing a pathway for the sustainable management of socio-economic ecosystems.

As ecological restoration projects are continuously implemented in karst areas to enhance ES, more research has focused on quantifying the effects of SC after the implementation of ecological projects (Gu et al., 2022; Ran, Wang, Bai, Tan, Zhao, Luo, Chen, & Xi, 2020). The geographic overlap of poor and ecologically fragile areas in karst landscape creates complex ecological socio-economic impacts on it. Qiu et al. (2022) have been provided an overview of ecological restoration projects and socio-ecological system interactions in karst areas. However, few analyses have been made of the ecological-socio-economic impacts of SC in karst areas. Such analyses are important if SC improvements are to be sustainable. Increased socio-economic research perspectives are essential for continuously improve the driving mechanisms of SC in karst regions. Therefore, it is possible to select drivers representing ecological-socio-economic aspects such as ecological conservation policies, urbanization, agricultural development, and population. It is important not only to gain an in-depth understanding of the impact of socio-economic factors on SC but also to grasp the overall pulse of the interaction of the three elements as they are applied to SC, which in turn promote the improvement of the whole ecosystem.

4.1.5 SC Focus Primarily on Single Vegetation Management, Neglecting the Integrated Management of Composite Ecosystems. It Should be Combined with the Unique Composite Ecosystem of the Karst Region to Develop a Multi-level Integration Strategy for Ecosystems

Ecological restoration is primarily about availability and then diversification. Therefore, mono-vegetation management is the initial step, and species enrichment is carried out after the soil and water have improved. Advantages of monocultures include ease of handling and low cost. Additionally, monocultures of the same species can establish dominance within a community, leading to increased survival rates. Monoculture vegetation, however, has disadvantages such as low biodiversity, a simple ecological niche, insufficient soil retention capacity, and in the long run, it can lead to the absence of natural enemies for certain organisms, which can result in various ecological problems, such as large-scale insect disasters. Traditional silvicultural methods for enhancing SC are considered unsustainable (Yin et al., 2021). To improve soil structure and enhance SC capacity, conservation of biodiversity should be prioritized, and composite vegetation management is gradually becoming crucial for balancing soil erosion and soil yield. For example, composite vegetation practices in Vietnam were more profitable than monocultures, enhancing both SC and fruit tree yields (Do et al., 2020). A comparison of 55 tree species in Indonesia discovered that a combination of deep-rooted species and fine-rooted grasses contributed to soil stabilization (Hairiah et al., 2020). Consequently, the enhancement of SC should shift from focusing on the study of single ecological elements and processes to the integration of multiple elements, thereby enhancing the sustainability of SC capacity.

The extreme situation of karst regions presenting desertified landscapes is the main reason for their unilateral pursuit of increased vegetation cover, which does not effectively contribute to enhancing SC. Fragile karst areas are not suitable for overexploitation of agriculture, nor can they be stopped at high-intensity monoculture systems, but must be transformed into composite conservation systems for integrated management. Artificially combining perennial woody plants with one or more components, such as crops and livestock breeding, to form a multi-component, multi-level, multi-temporal composite ecosystem on the same land unit (Fig. 8). Currently, the karst region has achieved a mutually beneficial symbiosis and ecological restoration of agriculture, forestry, and animal husbandry through forest protection for agriculture, agriculture for animal husbandry, and animal husbandry for forest protection. The modest benefits of single-vegetation restoration have been resolved by this method, which has produced notable outcomes. Ouyang et al. (2016) improved SC by promoting mixed forests instead of monoculture. Xiao and Xiong (2022) further explained that composite ecosystems in karst areas not only enhance the land productivity but also provide crucial ecosystem services to ecologically fragile environments in the region, thus improving water source conservation and SC capabilities. Therefore, it is essential to pay attention to composite ecosystems as the core production body, selecting appropriate vegetation to optimize the community structure for establishing a composite ecosystem.

Figure 9. Complex Ecosystems in Karst Areas. The Combination of Woody Perennials and Crops in Karst Areas Improves their Ecosystem Functioning and Enhances and Maintains Soil Conservation Services

4.1.6 SC Are Currently Focused on Analyzing the Current Situation, and There Is a Need to Model Future Scenarios for SC and Predict Optimal Soil Conservation Trends in Karst Areas

Currently, research on SC is largely based on the time span from the past to the present. However, Due to the uncertainty of future SC changes, it is difficult to prevent soil degradation and implement measures solely based on past and current assessments. Projections of future SC can be revealed by simulating spatial-temporal distributions in SC under various climate or land use scenarios. Research has indicated that model parameters are sensitive to climate change and land use types, so tend to forecast the effects of both on SC (Anache et al., 2018; Teng et al., 2018). Currently, climate change prediction models are mainly based on Representative Concentration Pathways (RCPs) selected from the Coupled Model Intercomparison Project 5 (CMIP5) and General Circulation Model (GCM) to simulate future climate change. Considering the difficulty of capturing climate change, temperature and precipitation require more accurate and efficient forecasting models (Moazenzadeh & Mohammadi, 2019; Mohammadi et al., 2020), and thus scenario modeling based on land use is emerging as an effective method for predicting SC trends. Research methods include CA-Markov, PLUS, FLUS, and CLUE-S models constructed based on metacelluar automata (Jian et al., 2024; Nie et al., 2023). In recent years, scholars have employed various methods to simulate scenarios of future land use change, aiming to predict future changes in SC. Liu et al. (2020a) modeled natural growth and reforestation scenarios of land-use change in the Nile Basin for 2010–2100, with a decreasing trend in soil retention under both scenarios. Jian et al. (2024) used the In VEST-PLUS model to simulate a consistent upward trend in the supply-demand ratio of SC in the Loess Plateau under different scenarios for the year 2030. Thus, predicting future SC scenarios strengthens the directing role of precisely preventing soil erosion and optimizing land resources and compensates for the lack of existing research on the underlying logic between land use, SC, and multi-scenario-driven reactions.

There is a dearth of research on forecasting future ecosystem services in karst regions. Climate extremes in the karst region limit studies based on future climate scenarios, and there are very few studies based on land use scenarios. Gu et al. (2022) utilized the CLUE-S model to forecast alterations in SC under three scenarios for 2035 in a karst region. They concluded that the ecological conservation scenario had a higher SC capacity. Therefore, different future scenarios for SC need to be established to predict the optimal development trend of SC. Scenario modeling based on land use can reveal the drivers of land use change. However, most previous studies have considered the effects of climate, topography, and other factors, ignoring the variability of region-specific geographic conditions on modelled land use. In addition to this, vegetation cover is also a significant factor influencing land use patterns in karst areas, and Innovative use of Normalized Vegetation Index (NDVI) as one of the drivers of predictive modeling. Both land use and climate change strongly affect soil conservation in karst areas. A combination of climate and land use future scenario modeling is required to accurately predict SC trends. Related studies have suggested that the relationship between vegetation change and climate factors is the basis for exploring changes in soil retention under climate change scenarios (Liu et al., 2021a). This study hypothesizes that the accuracy of climate change scenario modeling can be improved by establishing a link between climate change and vegetation growth and that a combination of climate and land use scenario modeling can be realized in the karst region.

4.1.7 Lack of Relevant Research Analyzing the Supply-demand Relationship of SC. By Establishing a Framework for Evaluating the Supply-demand SC, the Coupling Mechanism of the Supply-demand SC is Clarified to Achieve Coordinated Regional Development

The ability of an ecosystem to provide goods and services at a given time is referred to as supply, and the goods and services obtained and consumed from the ecosystem are referred to as demand (Knowlton et al., 2021). SC should also consist of two components: an evaluation of the supply for natural systems and an assessment of the demand for human systems. Existing studies, however, tend to focus only on the SC supply without considering the corresponding demand. Therefore, mechanisms for the mutual feeding of SC and human demand are needed to understand the relationship between changes in SC supply and human well-being. The challenge in assessing SC supply-demand lies in measuring the beneficiaries of SC. Therefore, some scholars have quantified SC as supply by using the actual amount of soil erosion desired to be treated or eliminated as demand in the supply-demand balance (Yu et al., 2023). As human dependence on the ecological environment increases significantly, ES capacity has declined, triggering acute human-land conflicts. Against the backdrop of the growing imbalance between the supply and demand of ecosystems, there is a rising interest among scholars in quantitatively assessing the capacity of SC supply and demand, elucidating the current matching status between supply and demand, and mitigating the conflicts arising from this imbalance (Lorilla et al., 2019; Zhai et al., 2020). Priority should be given to the development and utilization of ecological resources in key areas where supply exceeds demand and development is highly uncoordinated. On the other hand, in key areas where supply and demand are imbalanced, there is typically a higher degree of urban development, and thus ecological improvements should be given priority (Yan et al., 2023; Zhang et al., 2023). Thus, for ecological land conservation and restoration planning, it is crucial to ascertain the coupling mechanism and the level of coordination between supply and demand based on the quantification of the supply-demand link. SC is used by humans and transferred from one area to another, creating SC flows and establishing spatial connections between supply and demand areas (Zhang et al., 2021). SC in the supply area represents all the ecosystem can provide, yet not all of it is transferred to the beneficiary area. Therefore, research to clarify specific SC flow pathways becomes necessary. Zheng et al. (2021) attempted to simulate the direction and amount of spatial flow of soil conservation services using the Dinf algorithm, which improved the credibility of developing SC policies. Comprehensive SC studies should integrate pathways and supply-demand to illustrate the flow of SC supply to humans through the transmission medium. That is, transitioning from a single SC supply and demand study to an analysis of soil retention flow pathways.

To pursue economic development, most karst regions have rarely considered maintaining the SC supply-demand balance. Research on the supply and demand matching pattern of SC is lacking greatly.

No quantification of the cascading benefits of SC in karst areas is available based on the most common "ecosystem attributes-ecosystem functions-benefits to people" framework. Therefore, there is a need to establish spatial linkages between the upper, middle, and lower reaches of the basin by simulating SC flow paths, identifying the supply-demand zones for services, and quantifying their spatial coupling degree. Limited human and material resources will be invested in regions of tight supply to achieve optimal resource allocation and reduce the supply-demand contradiction, based on the influence of supply and demand coupling on coordinated development.

5. Conclusions

This paper analyses and reviews 224 literature included in WOS as well as CNKI databases. The main findings are as follows:(1) SC research is gaining traction, with the total number of articles skyrocketing after 2013. (2) SC is closely related to the fields of water usage, agricultural development, and soil erosion. The connections between sustainability, climate change, and SC could be a potential future research trend. (3) China, Iran, and US dominate the field. (4) The various keywords are closely related to each other, with “ES”, “soil erosion”, “trade-offs and synergies”, “spatial-temporal distribution patterns”, and “ecological restoration measures” being the research hotspots in this field.

The paper summarizes several key scientific issues and enlightenments for rocky desertification areas: (1) Difficulty in harmonizing evaluation parameters for SC (2) A single method of SC evaluation (3) SC studies stay on a single scale of analysis. (4) Neglected socio-economic-ecological coupling with SC inside and out. (5) Improvements in SC are largely based on mono-vegetation management. (6) SC focuses on past-to-present research. (7) Lack of a comprehensive study of SC supply and demand. In the future, the research ideas can be broadened based on existing research, and the research system for SC can be improved according to the needs of decision-makers in different dimensions, combining the soil conditions in karst areas.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

This work was supported by the China Overseas Expertise Introduction Program for Discipline Innovation (Grant No. D17016) the Key Science and Technology Program of Guizhou Province (Grant No. 5411 2017 QKHPTRC) and the Project of Geographical Society of Guizhou Province (No. GS44-20041218).

References

Abolmaali, S. M. R., Tarkesh, M., Mousavi, S. A., Karimzadeh, H., Pourmanafi, S., & Fakheran, S. (2024). Identifying priority areas for conservation: using ecosystem services hotspot mapping for land-use/land-cover planning in central of Iran. *Environmental Management*, *73*(5), 1016-1031. https://10.1007/s00267-024-01944-y

An, Y. M., Zhao, W. W., Li, C. J., & Sofia Santos Ferreira, C. (2022). Temporal changes on soil conservation services in large basins across the world. *Catena*, *209*, 105793. https://doi.org/10.1016/j.catena.2021.105793

Anache, J. a. A., Flanagan, D. C., Srivastava, A., & Wendland, E. C. (2018). Land use and climate change impacts on runoff and soil erosion at the hillslope scale in the Brazilian Cerrado. *Science of The Total Environment*, 622-623, 140-151. https://doi.org/10.1016/j.scitotenv.2017.11.257

Chen, J., Xiao, H. B., Li, Z. W., Liu, C., Wang, D. Y., Wang, L. X., & Tang, C. J. (2019). Threshold effects of vegetation coverage on soil erosion control in small watersheds of the red soil hilly region in China. *Ecological Engineering*, *132*, 109-114. https://doi.org/10.1016/j.ecoleng.2019.04.010

Costanza, R., D'arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387*(6630), 253-260. https://10.1038/387253a0

Deng, L., Kim, D. G., Li, M. Y., Huang, C. B., Liu, Q. Y., Cheng, M., Shangguan, Z. P., & Peng, C. H. (2019). Land-use changes driven by 'Grain for Green' program reduced carbon loss induced by soil erosion on the Loess Plateau of China. *Global and Planetary Change*, *177*, 101-115. https://doi.org/10.1016/j.gloplacha.2019.03.017

Do, V. H., La, N., Mulia, R., Bergkvist, G., Dahlin, A. S., Nguyen, V. T., Pham, H. T., & Öborn, I. (2020). Fruit Tree-Based Agroforestry Systems for Smallholder Farmers in Northwest Vietnam—A Quantitative and Qualitative Assessment. *Land*, *9*(11), 451. https://doi.org/10.3390/land9110451

Fang, L., Wang, L., Chen, W., Sun, J., Cao, Q., Wang, S., & Wang, L. (2021). Identifying the impacts of natural and human factors on ecosystem service in the Yangtze and Yellow River Basins. *Journal of Cleaner Production*, *314*, 127995. https://doi.org/10.1016/j.jclepro.2021.127995

Feng, T., Chen, H., Wang, K., Zhang, W., & Qi, X. (2014). Modeling soil erosion using a spatially distributed model in a karst catchment of northwest Guangxi, China. *Earth Surface Processes and Landforms*, *39*(15), 2121-2130. https://doi.org/10.1002/esp.3625

Fu, B. J., Zhao, W. W., Chen, L. D., Zhang, Q. J., Lü, Y. H., Gulinck, H., & Poesen, J. (2005). Assessment of soil erosion at large watershed scale using RUSLE and GIS: A case study in the Loess Plateau of China. *Land Degradation & Development*, *16*(1), 73-85. https://doi.org/10.1002/ldr.646

Gao, J., Shi, C. Q., Yang, J. Y., Yue, H., Liu, Y., & Chen, B. Z. (2023). Analysis of spatiotemporal heterogeneity and influencing factors of soil erosion in a typical erosion zone of the southern red soil region, China. *Ecological Indicators*, *154*, 110590.

https://doi.org/10.1016/j.ecolind.2023.110590

Gu, Y. Y., Lin, N. F., Ye, X., Xu, M. J., Qiu, J., Zhang, K., Zou, C. X., Qiao, X. N., & Xu, D. L. (2022). Assessing the impacts of human disturbance on ecosystem services under multiple scenarios in karst areas of China: Insight from ecological conservation red lines effectiveness. *Ecological Indicators*, *142*, 109202. https://doi.org/10.1016/j.ecolind.2022.109202

Guo, M. M., Chen, Z. X., Wang, W. L., Wang, T. C., Wang, W. X., & Cui, Z. Q. (2021). Revegetation induced change in soil erodibility as influenced by slope situation on the Loess Plateau. *Science of The Total Environment*, *772*, 145540. https://doi.org/10.1016/j.scitotenv.2021.145540

Guo, X. J., Shao, Q. Q., & Luo, Y. (2022). Effects of different management measures on soil conservation and the influence of environmental conditions: a case study involving UAV remote sensing on the Loess Plateau. *Remote Sensing in Ecology and Conservation*, *8*(5), 683-697. https://doi.org/10.1002/rse2.271

Gurung, S. B., Geronimo, F. K., Hong, J., & Kim, L.-H. (2018). Application of indices to evaluate LID facilities for sediment and heavy metal removal. *Chemosphere*, *206*, 693-700. https://doi.org/10.1016/j.chemosphere.2018.05.077

Hairiah, K., Widianto, W., Suprayogo, D., & Van Noordwijk, M. (2020). Tree Roots Anchoring and Binding Soil: Reducing Landslide Risk in Indonesian Agroforestry. *Land*, *9*(8), 256.

Hou, D. Y., Bolan, N. S., Tsang, D. C. W., Kirkham, M. B., & O'connor, D. (2020). Sustainable soil use and management: An interdisciplinary and systematic approach. *Science of The Total Environment*, *729*, 138961. https://doi.org/10.1016/j.scitotenv.2020.138961

Hu, Z. Y., Wang, S. J., Bai, X. Y., Luo, G. J., Li, Q., Wu, L. H., Yang, Y. J., Tian, S. Q., Li, C. J., & Deng, Y. H. (2020). Changes in ecosystem service values in karst areas of China. *Agriculture, Ecosystems & Environment*, *301*, 107026. https://doi.org/10.1016/j.agee.2020.107026

Huang, T., & Yu, D. Y. (2021). Water-soil conservation services dynamic and its implication for landscape management in a fragile semiarid landscape. *Ecological Indicators*, *130*, 108150. https://doi.org/10.1016/j.ecolind.2021.108150

Jian, Z., Sun, Y. J., Wang, F., Zhou, C. H., Pan, F., Meng, W. X., & Sui, M. X. (2024). Soil conservation ecosystem service supply-demand and multi scenario simulation in the Loess Plateau, China. *Global Ecology and Conservation*, *49*, e02796. https://doi.org/10.1016/j.gecco.2023.e02796

Jiang, Z. C., Lian, Y. Q., & Qin, X. Q. (2014). Rocky desertification in Southwest China: Impacts, causes, and restoration. *Earth-Science Reviews*, *132*, 1-12. https://doi.org/10.1016/j.earscirev.2014.01.005

Keshtkar, M., Mokhtari, Z., & Sayahnia, R. (2022). Impact of Land Use/Land Cover Change on Soil Retention Service: A Case of Agricultural-Urbanized Landscape in Northern Iran. *Journal of Landscape Ecology*, *15*, 34-58. https://doi.org/10.2478/jlecol-2022-0010

Knisel, W. G. (1980). CREAMS: A field-scale model for chemicals, runoff and erosion from agricultural management systems. *USDA Conservation Research Report*, *26*, 640-640.

Knowlton, J. L., Halvorsen, K. E., Flaspohler, D. J., Webster, C. R., Abrams, J., Almeida, S. M., Arriaga-Weiss, S. L., Barnett, B., Cardoso, M. R., Cerqueira, P. V., Córdoba, D., Dantas-Santos, M. P., Dunn, J. L., Eastmond, A., Jarvi, G. M., Licata, J. A., Mata-Zayas, E., Medeiros, R., Mesa-Jurado, M. A. et al.,. (2021). Birds and Bioenergy within the Americas: A Cross-National, Social–Ecological Study of Ecosystem Service Tradeoffs. *Land*, *10*(3), 258. https://doi.org/10.3390/land10030258

Kong, L. Q., Zheng, H., Rao, E. M., Xiao, Y., Ouyang, Z. Y., & Li, C. (2018). Evaluating indirect and direct effects of eco-restoration policy on soil conservation service in Yangtze River Basin. *Science of The Total Environment*, 631-632, 887-894. https://doi.org/10.1016/j.scitotenv.2018.03.117

Kottagoda, S. D., & Abeysingha, N. S. (2017). Morphometric analysis of watersheds in Kelani river basin for soil and water conservation. *Journal of The National Science Foundation of Sri Lanka*, *45*, 273.

Li, Q., Xu, M. X., Zhao, Y. G., Gao, L. Q., Zhang, J., & Zhang, X. W. (2012). Gully Erosion Soil Quality Assessment on the Cultivated Slope Land in the Loess Plateau Region, China. *Journal of Natural Resources*, *27*(9), 1001-1012. https://doi.org/10.11849/zrzyxb.2012.09.001

Li, T., Lü, Y. H., Fu, B. J., Comber, A. J., Harris, P., & Wu, L. H. (2017). Gauging policy-driven large-scale vegetation restoration programmes under a changing environment: Their effectiveness and socio-economic relationships. *Science of The Total Environment*, 607-608, 911-919. https://doi.org/10.1016/j.scitotenv.2017.07.044

Liu, H., Liu, Y. X., Wang, K., & Zhao, W. W. (2020a). Soil conservation efficiency assessment based on land use scenarios in the Nile River Basin. *Ecological Indicators*, *119*, 106864. https://doi.org/10.1016/j.ecolind.2020.106864

Liu, H., Liu, Y. X., Zhao, W. W., & Peng, D. (2021a). Soil conservation assessment via climate change and vegetation growth scenarios in the Nile River basin. *Journal of Mountain Science*, *18*(4), 863-877. https://doi.org/10.1007/s11629-020-6304-z

Liu, W. C., Liu, J. Y., & Kuang, W. H. (2020b). Spatio-temporal characteristics of soil protection efforts of the Grain for Green Project in northern Shaanxi Province. *Journal of Geographical Sciences*, *30*(3), 401-422. https://10.1007/s11442-020-1734-7

Liu, X., Xin, L., & Lu, Y. (2021b). National scale assessment of the soil erosion and conservation function of terraces in China. *Ecological Indicators*, *129*, 107940. https://doi.org/10.1016/j.ecolind.2021.107940

Liu, Y. F., Liu, Y., Shi, Z. H., López-Vicente, M., & Wu, G. L. (2020c). Effectiveness of re-vegetated forest and grassland on soil erosion control in the semi-arid Loess Plateau. *Catena*, *195*, 104787. https://doi.org/10.1016/j.catena.2020.104787

Long, M. Z., Hua, W. K., & Xiong, K. (2014). Assessment of the applicability of the WEPP model (Hillslope Version) for soil erosion in karst rock desertification area, Guizhou Province.

Carsologica Sinica, (2), 201-207.

Lorilla, R. S., Kalogirou, S., Poirazidis, K., & Kefalas, G. (2019). Identifying spatial mismatches between the supply and demand of ecosystem services to achieve a sustainable management regime in the Ionian Islands (Western Greece). *Land Use Policy*, *88*, 104171. https://doi.org/10.1016/j.landusepol.2019.104171

Lu, R. R., Dai, E. F., & Wu, C. S. (2023). Spatial and temporal evolution characteristics and driving factors of soil conservation services on the Qinghai-Tibet Plateau. *Catena*, *221*, 106766. https://doi.org/10.1016/j.catena.2022.106766

Ma, S., Wang, L. J., Zhu, D. Z., & Zhang, J. C. (2021). Spatiotemporal changes in ecosystem services in the conservation priorities of the southern hill and mountain belt, China. *Ecological Indicators*, *122*, 107225. https://doi.org/10.1016/j.ecolind.2020.107225

Moazenzadeh, R., & Mohammadi, B. (2019). Assessment of bio-inspired metaheuristic optimisation algorithms for estimating soil temperature. *Geoderma*, *353*, 152-171. https://doi.org/10.1016/j.geoderma.2019.06.028

Mohammadi, B., Linh, N. T. T., Pham, Q. B., Ahmed, A. N., Vojteková, J., Guan, Y., Abba, S. I., & El-Shafie, A. (2020). Adaptive neuro-fuzzy inference system coupled with shuffled frog leaping algorithm for predicting river streamflow time series. *Hydrological Sciences Journal*, *65*(10), 1738-1751. https://10.1080/02626667.2020.1758703

Naipal, V., Reick, C., Pongratz, J., & Van Oost, K. (2015). Improving the global applicability of the RUSLE model – adjustment of the topographical and rainfall erosivity factors. *Geoscientific Model Development*, *8*(9), 2893-2913. https://10.5194/gmd-8-2893-2015

Neugirg, F., Stark, M., Kaiser, A., Vlacilova, M., Della Seta, M., Vergari, F., Schmidt, J., Becht, M., & Haas, F. (2016). Erosion processes in calanchi in the Upper Orcia Valley, Southern Tuscany, Italy based on multitemporal high-resolution terrestrial LiDAR and UAV surveys. *Geomorphology*, *269*, 8-22. https://doi.org/10.1016/j.geomorph.2016.06.027

Nie, W. B., Xu, B., Yang, F., Shi, Y., Liu, B. T., Wu, R. W., Lin, W., Pei, H., & Bao, Z. Y. (2023). Simulating future land use by coupling ecological security patterns and multiple scenarios. *Science of The Total Environment*, *859*, 160262. https://doi.org/10.1016/j.scitotenv.2022.160262

Niu, L. N., & Shao, Q. Q. (2020). Soil Conservation Service Spatiotemporal Variability and Its Driving Mechanism on the Guizhou Plateau, China. *Remote Sensing*, *12*(14), 2187.

Olorunfemi, I. E., Komolafe, A. A., Fasinmirin, J. T., Olufayo, A. A., & Akande, S. O. (2020). A GIS-based assessment of the potential soil erosion and flood hazard zones in Ekiti State, Southwestern Nigeria using integrated RUSLE and HAND models. *Catena*, *194*, 104725. https://doi.org/10.1016/j.catena.2020.104725

Ouyang, Z. Y., Zheng, H., Xiao, Y., Polasky, S., Liu, J. G., Xu, W. H., Wang, Q., Zhang, L., Xiao, Y., Rao, E. M., Jiang, L., Lu, F., Wang, X. K., Yang, G. B., Gong, S. H., Wu, B. F., Zeng, Y., Yang, W., & Daily, G. C. (2016). Improvements in ecosystem services from investments in natural capital.

Science, *352*(6292), 1455-1459. https://doi:10.1126/science.aaf2295

Pan, J. Y., Wang, J. L., Gao, F., & Liu, G. J. (2022). Quantitative estimation and influencing factors of ecosystem soil conservation in Shangri-La, China. *Geocarto International*, *37*(27), 14828-14842. https://10.1080/10106049.2022.2091160

Pei, J., Wang, L., Wang, X. Y., Niu, Z., Kelly, M., Song, X. P., Huang, N., Geng, J., Tian, H. F., Yu, Y., Xu, S. G., Wang, L., Ying, Q., & Cao, J. H. (2019). Time Series of Landsat Imagery Shows Vegetation Recovery in Two Fragile Karst Watersheds in Southwest China from 1988 to 2016. *Remote Sensing*, *11*(17), 2044.

Peng, J., Tian, L., Zhang, Z. M., Zhao, Y., Green, S. M., Quine, T. A., Liu, H. Y., & Meersmans, J. (2020). Distinguishing the impacts of land use and climate change on ecosystem services in a karst landscape in China. *Ecosystem Services*, *46*, 101199. https://doi.org/10.1016/j.ecoser.2020.101199

Pijl, A., Reuter, L. E. H., Quarella, E., Vogel, T. A., & Tarolli, P. (2020). GIS-based soil erosion modelling under various steep-slope vineyard practices. *Catena*, *193*, 104604. https://doi.org/10.1016/j.catena.2020.104604

Pribadi, D. O., & Pauleit, S. (2016). Peri-urban agriculture in Jabodetabek Metropolitan Area and its relationship with the urban socioeconomic system. *Land Use Policy*, *55*, 265-274. https://doi.org/10.1016/j.landusepol.2016.04.008

Qi, W., Li, H., Zhang, Q., & Zhang, K. (2019). Forest restoration efforts drive changes in land-use/land-cover and water-related ecosystem services in China's Han River basin. *Ecological Engineering*, *126*, 64-73. https://doi.org/10.1016/j.ecoleng.2018.11.001

Qiu, S. J., Peng, J., Zheng, H. N., Xu, Z. H., & Meersmans, J. (2022). How can massive ecological restoration programs interplay with social-ecological systems? A review of research in the South China karst region. *Science of The Total Environment*, *807*, 150723. https://doi.org/10.1016/j.scitotenv.2021.150723

Ran, C., Wang, S. J., Bai, X. Y., Tan, Q., Zhao, C. W., Luo, X. L., Chen, H., & Xi, H. P. (2020). Trade-Offs and Synergies of Ecosystem Services in Southwestern China. *Environmental Engineering Science*, *37*(10), 669-678. https://doi.org/10.1089/ees.2019.0499

Rao, E. M., Xiao, Y., Ouyang, Z. Y., & Zheng, H. (2016). Changes in ecosystem service of soil conservation between 2000 and 2010 and its driving factors in southwestern China. *Chinese Geographical Science*, *26*(2), 165-173. https://doi.org/10.1007/s11769-015-0759-9

Sadeghi, S. H., Sadeghi Satri, M., Kheirfam, H., & Zarei Darki, B. (2020). Runoff and soil loss from small plots of erosion-prone marl soil inoculated with bacteria and cyanobacteria under real conditions. *European Journal of Soil Biology*, *101*, 103214. https://doi.org/10.1016/j.ejsobi.2020.103214

Srichaichana, J., Trisurat, Y., & Ongsomwang, S. (2019). Land Use and Land Cover Scenarios for Optimum Water Yield and Sediment Retention Ecosystem Services in Klong U-Tapao Watershed, Songkhla, Thailand. *Sustainability*, *11*(10), 2895. https://doi.org/10.3390/su11102895

Su, Z. A., Zhou, T., Zhang, X. B., Wang, X. Y., Wang, J. J., Zhou, M. H., Zhang, J. H., He, Z. Y., & Zhang, R. C. (2021). A Preliminary Study of the Impacts of Shelter Forest on Soil Erosion in Cultivated Land: Evidence from integrated 137Cs and 210Pbex Measurements. *Soil and Tillage Research*, *206*, 104843. https://doi.org/10.1016/j.still.2020.104843

Sui, B. Y., Dang, X. H., Fan, L. X., Guo, B., Bi, W., & Liu, G. B. (2022). Interactions between soil conservation and dryland farming of heterogeneously eroding areas in Loess Hills, China. *International Soil and Water Conservation Research*, *10*(4), 574-585. https://doi.org/10.1016/j.iswcr.2022.01.003

Teng, H., Liang, Z., Chen, S., Liu, Y., Viscarra Rossel, R. A., Chappell, A., Yu, W., & Shi, Z. (2018). Current and future assessments of soil erosion by water on the Tibetan Plateau based on RUSLE and CMIP5 climate models. *Science of The Total Environment*, *635*, 673-686. https://doi.org/10.1016/j.scitotenv.2018.04.146

Tong, X. W., Brandt, M., Yue, Y. M., Horion, S., Wang, K., Keersmaecker, W. D., Tian, F., Schurgers, G., Xiao, X. M., Luo, Y. Q., Chen, C., Myneni, R., Shi, Z., Chen, H. S., & Fensholt, R. (2018). Increased vegetation growth and carbon stock in China karst via ecological engineering. *Nature Sustainability*, *1*(1), 44-50. https://10.1038/s41893-017-0004-x

Wang, S., Xu, M. F., Li, Q., Wang, R., Fu, G., Zheng, Z. H., & Wang, J. F. (2023). Analysis on trend evolution and driving factors of soil protection services in eastern sandy region of China. *Ecological Indicators*, *154*, 110816. https://doi.org/10.1016/j.ecolind.2023.110816

Wang, X. F., Zhang, X. R., Feng, X. M., Liu, S. R., Yin, L. C., & Chen, Y. Z. (2020). Trade-offs and Synergies of Ecosystem Services in Karst Area of China Driven by Grain-for-Green Program. *Chinese Geographical Science*, *30*(1), 101-114. https://10.1007/s11769-020-1098-z

Wang, Y. M., Zhang, Z. X., & Chen, X. (2022). Spatiotemporal change in ecosystem service value in response to land use change in Guizhou Province, southwest China. *Ecological Indicators*, *144*, 109514. https://doi.org/10.1016/j.ecolind.2022.109514

Xia, L., Bi, R. T., Song, X. Y., & Lv, C. J. (2021). Dynamic changes in soil erosion risk and its driving mechanism: A case study in the Loess Plateau of China. *European Journal of Soil Science*, *72*(3), 1312-1331. https://doi.org/10.1111/ejss.13067

Xiao, J., & Xiong, K. N. (2022). A review of agroforestry ecosystem services and its enlightenment on the ecosystem improvement of rocky desertification control. *Science of The Total Environment*, *852*, 158538. https://doi.org/10.1016/j.scitotenv.2022.158538

Xiao, Y., Guo, B., Lu, Y. F., Zhang, R., Zhang, D. F., Zhen, X. Y., Chen, S. T., Wu, H. W., Wei, C. X., Yang, L. A., Zhang, Y., Zang, W. Q., Huang, X. Z., Sun, G. Q., & Wang, Z. (2021). Spatial–temporal evolution patterns of soil erosion in the Yellow River Basin from 1990 to 2015: impacts of natural factors and land use change. *Geomatics, Natural Hazards and Risk*, *12*(1), 103-122. https://10.1080/19475705.2020.1861112

Xie, C. Q., & Yang, C. (2020). A review on plant high-throughput phenotyping traits using UAV-based sensors. *Computers and Electronics in Agriculture*, *178*, 105731. https://doi.org/10.1016/j.compag.2020.105731

Xiong, Q. L., Xiao, Y., Ouyang, Z. Y., Pan, K. W., Zhang, L., He, X. J., Zheng, H., Sun, X. M., Wu, X. G., Tariq, A., & Li, L. J. (2017). Bright side? The impacts of Three Gorges Reservoir on local ecological service of soil conservation in southwestern China. *Environmental Earth Sciences*, *76*(8), 323. https://10.1007/s12665-017-6588-7

Xu, B. C., & Pan, J. H. (2022). Simulation and measurement of soil conservation service flow in the Loess Plateau: A case study for the Jinghe River Basin, Northwestern China. *Ecological Indicators*, *141*, 109072. https://doi.org/10.1016/j.ecolind.2022.109072

Xu, G., Xiong, K. N., Shu, T., Shi, Y. J., Chen, L. S., Zheng, L. L., Fan, H. X., Zhao, Z. M., & Yang, Z. H. (2022). Bundling evaluating changes in ecosystem service under karst rocky desertification restoration: projects a case study of Huajiang-Guanling, Guizhou province, Southwest China. *Environmental Earth Sciences*, *81*(10), 302. https://10.1007/s12665-022-10400-1

Yan, H., Wang, L., Wang, T. W., Wang, Z., & Shi, Z. H. (2020). A synthesized approach for estimating the C-factor of RUSLE for a mixed-landscape watershed: A case study in the Gongshui watershed, southern China. *Agriculture, Ecosystems & Environment*, *301*, 107009. https://doi.org/10.1016/j.agee.2020.107009

Yan, X. L., Liu, C. H., Han, Z. L., Li, X. Y., & Zhong, J. Q. (2023). Spatiotemporal assessment of ecosystem services supply–demand relationships to identify ecological management zoning in coastal city Dalian, China. *Environmental Science and Pollution Research*, *30*(23), 63464-63478. https://10.1007/s11356-023-26704-z

Yin, C. C., Zhao, W. W., & Pereira, P. (2022). Soil conservation service underpins sustainable development goals. *Global Ecology and Conservation*, *33*, e01974. https://doi.org/10.1016/j.gecco.2021.e01974

Yu, D., Sun, L. N., Yu, J. F., & Wang, Z. H. (2012). Simulation on Soil Erosion and Streamflow in Maotiaohe Watershed of Guizhou Province Based on SWAT Model. *Chinese Agricultural Science Bulletin*, *28*(17), 256-261. https://10.11924/j.issn.1000-6850.2011-3982

Yu, J., Yi, L. W., Xie, B. G., Li, X. Q., Li, J. H., Xiao, J. Y., & Zhang, L. (2023). Matching and coupling coordination between the supply and demand for ecosystem services in Hunan Province, China. *Ecological Indicators*, *157*, 111303. https://doi.org/10.1016/j.ecolind.2023.111303

Zeng, F. M., Jiang, Z. C., Shen, L. N., Chen, W., Yang, Q. Y., & Zhang, C. (2018). Assessment of multiple and interacting modes of soil loss in the karst critical zone, Southwest China (SWC). *Geomorphology*, *322*, 97-106. https://doi.org/10.1016/j.geomorph.2018.08.043

Zhai, T. L., Wang, J., Jin, Z. F., Qi, Y., Fang, Y., & Liu, J. J. (2020). Did improvements of ecosystem services supply-demand imbalance change environmental spatial injustices? *Ecological Indicators*, *111*, 106068. https://doi.org/10.1016/j.ecolind.2020.106068

Zhang, C., Li, J., Zhou, Z. X., & Sun, Y. J. (2021). Application of ecosystem service flows model in water security assessment: A case study in Weihe River Basin, China. *Ecological Indicators*, *120*, 106974. https://doi.org/10.1016/j.ecolind.2020.106974

Zhang, H. J., Zhang, Z. C., Liu, K., Huang, C. B., & Dong, G. P. (2023). Integrating land use management with trade-offs between ecosystem services: A framework and application. *Ecological Indicators*, *149*, 110193. https://doi.org/10.1016/j.ecolind.2023.110193

Zheng, T., Zhou, Z. X., Zou, Y. F., Pulatov, B., & Biswas, A. (2021). Analysis of Spatial and Temporal Characteristics and Spatial Flow Process of Soil Conservation Service in Jinghe Basin of China. *Sustainability*, *13*, 1794. https://10.3390/su13041794

Zhu, M. Y., He, W. M., Zhang, Q. F., Xiong, Y. Z., Tan, S. D., & He, H. M. (2019). Spatial and temporal characteristics of soil conservation service in the area of the upper and middle of the Yellow River, China. *Heliyon*, *5*(12), e02985. https://doi.org/10.1016/j.heliyon.2019.e02985