Heritage Science

REVIEW

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Research progress on world natural heritage conservation: its buffer zones and the implications

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Abstract

In recent decades, World Heritage Sites (WHSs) have faced external severe threats in the context of global economisation and urbanisation. The buffer zone as a conservation layer and management tool for WHSs has attracted increasing scholarly attention and debate. However, there is limited understanding of buffer zones' social and ecological role in the conservation of World Natural Heritage Sites (WNHSs) and a lack of summary of research progress on buffer zones. To fill this gap, this study systematically reviews the existing knowledge and research gaps on buffer zones in WNHSs worldwide. We used a systematic literature review framework of Search, Assessment, Synthesis and Analysis (SALSA) through the WoS and CNKI databases to obtain 188 articles that met the inclusion criteria.

The aim was to analyze the temporal and regional distribution of publications, types of studies, main processes and landmark achievements, gaps, and implications for future research. Results indicated that: (1) there is an overall upward trend in the number of publications, reaching a maximum in 2020, with the most published in Asia and Europe. The research process presents two main categories of ecologically and socially oriented. (2) The main landmark achievements include theoretical research, technology and methods, model construction, benefit monitoring and evaluation, experimental demonstration, etc. Among them, theoretical research is the most numerous (58.51%). (3) On this basis, 8 key scientific issues are summarised. Reviewing the research progress and summarising the critical scientific issues will provide practical guidance for the effective implementation of the role of buffer zones in global WNH conservation, especially for karst WNHSs with fragile ecological environments. (4) The future of Karst WNH conservation should be based on the effect of human-land relationship in promoting heritage protection. Examining the institutional factors of ecological problems and the management of degraded ecosystems from a socio-economic perspective. The purpose is to seek a socio-ecological system that is composed of the social, economic, ecological and cultural dimensions of the buffer zone. Focus on the coupling between eco-industrial development and WNH conservation, and strengthen buffer zone communities' adaptive and collaborative management. Explore techniques and methods of conservation adapted to the characteristics of the fragile ecosystem of karst itself, and conduct experimental demonstrations.

Keywords: World natural heritage, Buffer zone, Conservation, Development, Karst, Literature review

Introduction

WNHSs face severe external threats in global economization and urbanization. There is a trend of integrating the heritage site itself with the surrounding environment and combining culture, nature and local economy [1, 2]. Therefore, WNH conservation is no longer limited to the closed preservation of the core area but has shown a

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trend of outward-looking and regionalized overall trend [3]. WH conservation and management are based on the principles of authenticity and integrity, with the outstanding universal value (OUV) as the focus [4]. Changing systems require an emphasis on protecting the value of its natural resources rather than the system's state [5]. WH conservation research is gradually shifting from a paradigm of "balancing conservation and development" to "conservation for development". This change is also the impetus for a shift in the conservation philosophy of WNH from island-like isolated to network-like linked, from neglecting communities to valuing them, and from absolute to gradient conservation [6, 7], while paying more attention to human needs and development.

Changing perceptions of WH conservation have driven the growing role of a buffer zone. Scholars have put the buffer zone as the research focus, along with the increasingly prominent threats from the exterior. They expect the establishment of it as the primary method to mitigate external threats, protect and enhance the integrity of the WHSs' OUV, thus buffer zone theory is increasingly studied [8–11]. Buffer zones are all contiguous and non-contiguous areas outside the heritage core, identified by visual, cultural, ecological and other elements that mitigate threats outside the heritage to protect the integrity of the OUV and different values [12, 13]. However, the buffer zone is not only a geographical spatial area but also a method, strategy and means to manage the WNH [14]. As an essential management tool in strengthening the control and protection of the transition between the WHS and the surrounding territory, buffer zones can set restrictions to protect the landscape, environment, land use and other aspects. Still, they can also actively encourage development that benefits the site's community, the sustainable use of resources around the heritage and the preservation of the fundamental interests of the local inhabitants [15]. One of the difficulties of buffer zones is how to balance conservation and development, seek the best combination of WH conservation and construction of surrounding areas, achieve the goals of ecological connectivity, visual integrity, and cultural continuity, and focus on the maintenance of public interests and sustainable resource use [16]. Methodological frameworks for buffer zone conservation, including aspects of buffer zone management, integrated planning, visual analysis, and landscape strategies, have been developed [17]. Still, most of them are studies on cultural heritage, focusing less on natural heritage.

WNHSs emphasize conservation, its buffer zones involve management subjects more advocate development, and there is a mutually beneficial or conflicting relationship between the two. A good development model for buffer zones can ease the pressure on resource use, drive local economic development, and promote WNHSs' conservation and management effectiveness. But the development process may have environmental pollution, population pressure, visual impact, and the gap between rich and poor threaten WNH conservation. How deal with the relationship between WHS conservation and buffer zone development needs to consider both the absolute preservation of heritage values and the development requirements of buffer zones [18]. In order to avoid inappropriate development and to ensure the sustainable and harmonious development of WH conservation and socio-economic development, it is a key issue to rationalise the ecological, economic and social relationship between a heritage site and its buffer zone. Especially for developing countries with many geological and geomorphological WNHS that combine aesthetic and special geomorphological values, but with fragile ecological backgrounds. The contradiction between resource conservation and local development needs [19–22], poses a severe challenge to WH conservation and management, but few studies have focused on the role that buffer zones play in mitigating conflicts. There is an urgent need to explore how particular landform WNHS can fully exploit the function of buffer zones to achieve sustainable development of population, resources, environment and society.

Karst landscapes are widely distributed around the world, covering 22 million km^2 [23], accounting for 10–15% of the land area [24]. They are found on all continents, mainly in the Mediterranean region, eastern Europe, Southeast Asia, southern China, southeastern USA, and the Caribbean [25]. Karst landscape interiors are among the most diverse hydrogeological environments on earth, and they are closely linked to processes in the atmosphere, hydrosphere and biosphere, as well as to human history and development [25]. They provide a variety of valuable natural resources, such as fresh water, building materials, carbon-based energy and biodiversity [26], and also have a tourism value due to their aesthetic, cultural and other values. With carbonate rocks as the basis of formation and exogenous water as the driving condition, karst has shaped qualities with remarkable geological or geomorphological features and natural beauty, making it one of the most remarkable landscapes in the world [25, 27, 28]. Numerous karst properties have been inscribed on the World Heritage List (WHL) for their OUV as natural phenomena that are outstanding features of the most important stages of the Earth's evolutionary history. There are 30 karst WNHSs (including mixed cultural and natural heritage) worldwide, accounting for about 14% of the total number of WNHSs, mainly in Europe and North America, Asia Pacific, Africa and

other regions. China and Vietnam being the two states parties with the highest distribution [29].

However, the low soil formation rate and high permeability of carbonate rocks create a fragile ecological environment where disturbance by unreasonable human activities can lead to soil erosion, vegetation degradation, and, ultimately, the phenomenon of rock desertification [26, 30–32]. Rock desertification describes the process of transforming karst areas covered with vegetation and soil into rocky landscapes virtually devoid of soil and vegetation. It occurs mainly in the European Mediterranean, the Dinaric Mountains, the southern regions of China, the South Central Peninsula, the Malay Archipelago, and Cuba [30, 33–36]. In southern China alone, it affects millions of people [37]. Rock desertification generates not only ecological problems such as increased soil erosion and reduced biodiversity but also social problems such as population poverty and cultural backwardness, which ultimately seriously threaten regional ecological and environmental security and constrain regional socio-economic development [37, 38].

Furthermore, due to their unique hydrogeological structure, water resources in karst aquifers are particularly vulnerable to contamination, as chemical and microbial contaminants can quickly enter the subsurface and spread rapidly through the pipeline network without adequate attenuation [25]. As a result, rock desertification and aquifer pollution have become major issues for environmental protection in karst areas [39]. Management systems and socio-cultural use are the factors that profoundly impact the degree of threat to the karst WNHSs. Their buffer zones are more exploited at the economic level than at the resource level [40, 41], so there is an urgent need to explore win–win strategies for conserving and developing this type of heritage. However, studies have mainly focused on the conservation and management of core areas, but not enough attention has been paid to its buffer zones. Scholars have focused primarily on the ecological functions of buffer zones [10, 16], while studies on economic functions and social needs are relatively weak. Therefore, it is necessary to summarise the existing landmark achievements and progress from a global perspective of WNH's buffer zone conservation to reveal the future direction of research on the conservation and development of karst WNHSs, and to provide scientific reference for the global governance of this type of WNH.

Methodology

The methodology adopted for this study was a systematic literature review (SLR), which Booth et al. define as a systematic, explicit and reproducible method for identifying, evaluating and synthesising existing work done and documented by researchers, academics and practitioners. The Search, Assessment, Synthesis and Analysis (SALSA) framework is a method for identifying search protocols that SLR should follow, which ensures that the methodology is accurate, systematic, exhaustive and reproducible [42]. Most scientific work [43–45] applies this methodological approach to reduce the risks associated with publication bias and improve their work's acceptability. Figure 1 describes the methodology used, forming a framework for the steps from protocol to the final report. Each step and the research methodology used to obtain its results are explained in detail in the following subsections.

Protocol

A systematic review characterised by transparency, transferability and replicability requires a research protocol. The most critical stage in defining the programme is determining the study's scope, which helps develop answerable research questions and establish the study's boundaries.

The refined research questions were:

1. What is the distribution of publications in terms of time and region?
2. Which types of studies are the most and least numerous?
3. What progress and landmark have been achieved in existing research?
4. What research gaps and key scientific issues are to be addressed in the future?
5. What are the current challenges to the conservation and development of karst WNH?
6. What are the directions for research on karst WNH conservation?

These are the research questions that this study aims to answer by adopting the SLR approach.

Search and appraisal

The search phase involves identifying sources of information that may be relevant to this study. Doing this entailed identifying where these sources could be found and then searching them. We searched journals, conference papers and master's theses on Web of Science (WoS) and China National Knowledge Infrastructure (CNKI) to identify relevant studies. The first search was conducted using "topic" as the search term, "WNH + conservation", and "WNH + buffer zone" as the search strings. The data was last updated on 31 December 2021.

An appraisal is a stage where the selected articles are evaluated according to the needs of the review, primarily the results of the search, to determine those papers

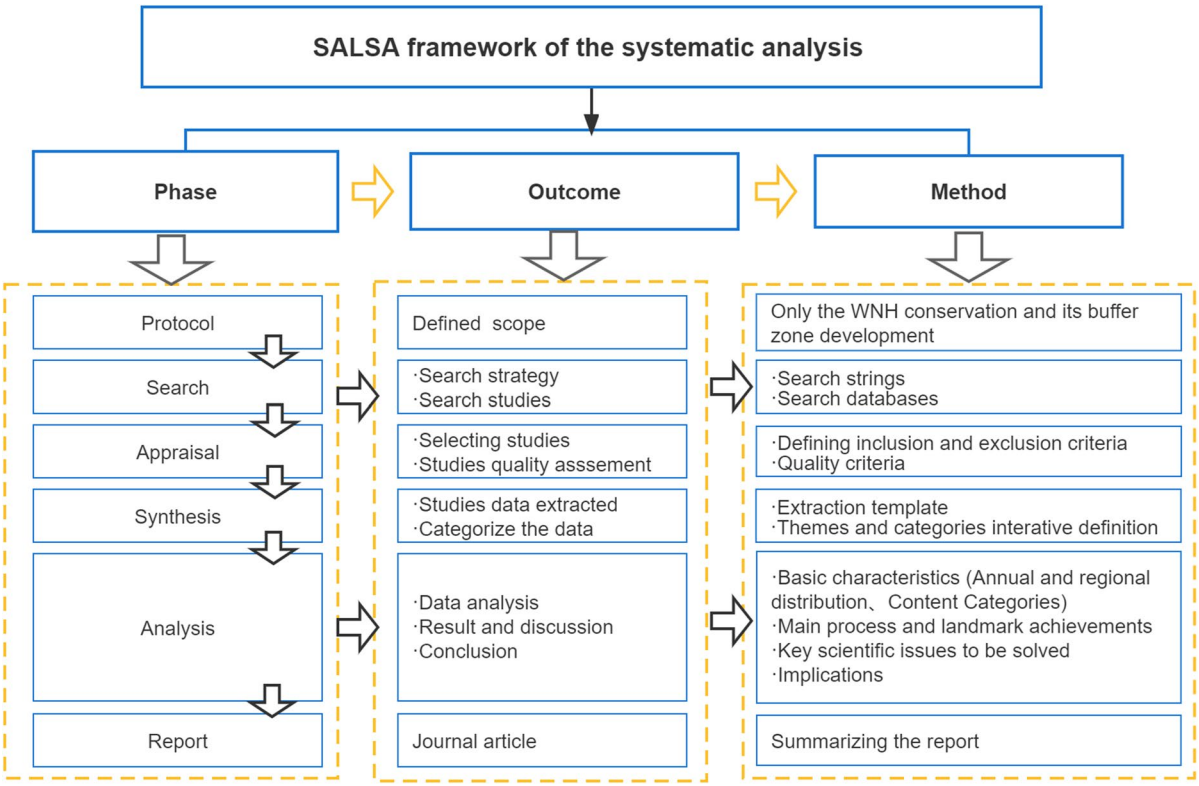

Fig. 1 SALSA framework for system review

relevant to the scope of this study and to describe their validity. By applying inclusion and exclusion criteria, papers that met the inclusion criteria were selected for further investigation and content assessment. Predetermined inclusion and exclusion criteria were used to achieve this systematic review (Table 1). Based on the research content of this paper, the retrieved English and Chinese literature was manually screened and selected, and the general screening process and the flow of choosing relevant literature are shown in Fig. 2. In the initial stage, 1202 records were found (330 from WoS and 872 from CNKI). Later, when grey literature, reports, keynote speeches, book chapters, non-English language papers and literature that did not contain buffers zone were eliminated, only 479 articles remained for reading the main text. Of these articles, 328 assessed the relationship between WNH conservation and buffer zone development. These articles were downloaded for further screening steps. Duplicate papers and articles lacking explicit buffer zone development were manually removed during the body reading process. Finally, 188 articles remained that met all the inclusion criteria used in this SLR work. Of these articles, 125 were in English and 63 in Chinese.

Table 1 SLR study selection of literature using inclusion and exclusion criteria

Criteria	Decision
When the predefined keywords exist as a whole or at least in the title, keywords or abstract section of the paper	Inclusion
Papers from the WOS database should be written in English	Inclusion
Studies that present pieces of evidence on the WNH'S buffer zone study	Inclusion
Papers that are duplicated within the search documents	Exclusion
Papers that are not accessible	Exclusion
Papers that are not primary research	Exclusion
Studies without a buffer zone	Exclusion

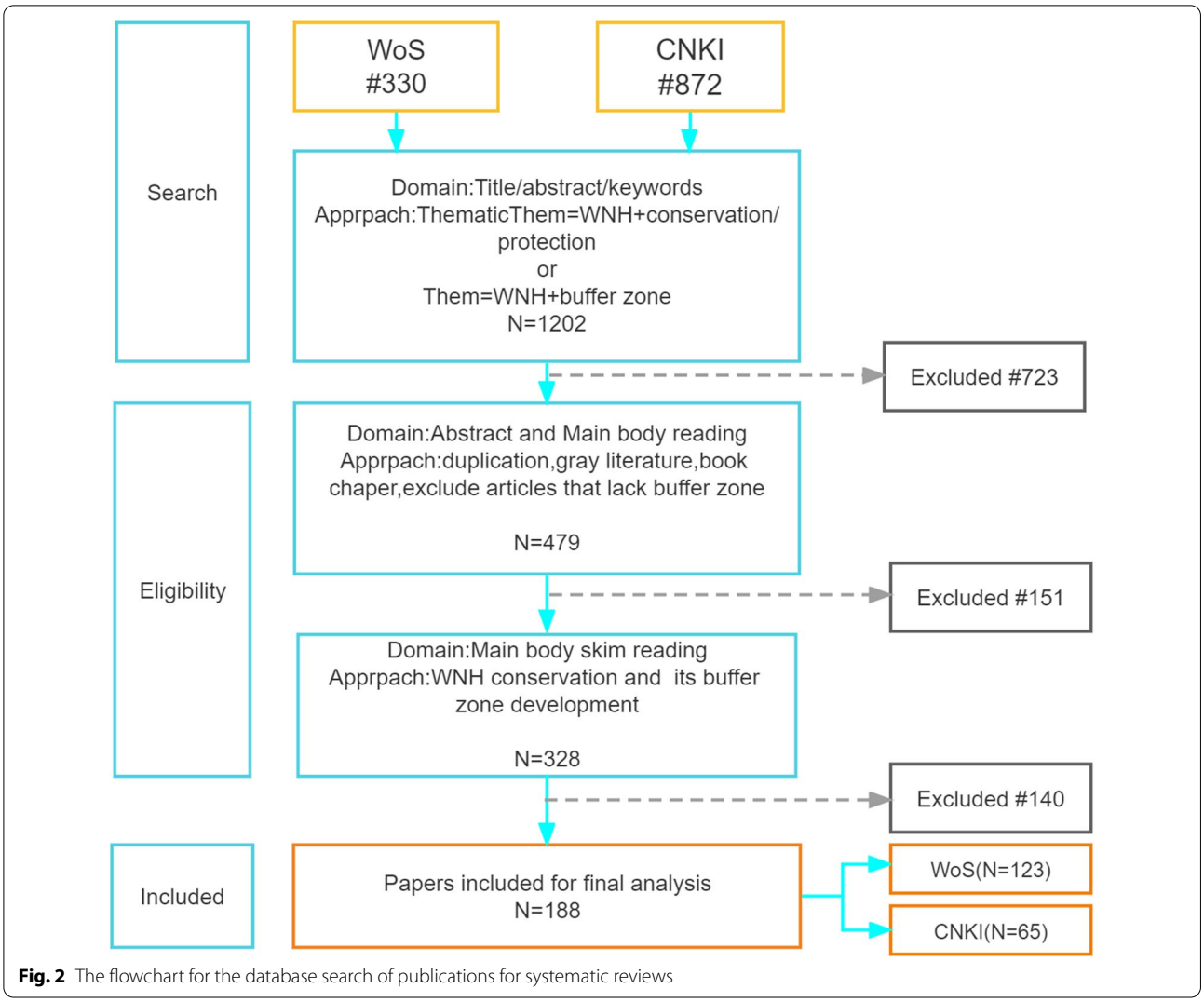

Fig. 2 The flowchart for the database search of publications for systematic reviews

Synthesis

The synthesis phase involves extracting and classifying relevant data from the selected papers to draw knowledge and conclusions. Data extraction involved identifying and removing relevant data from the 188 selected publications. The variables of interest to achieve the objectives of SLR are shown in Table 2. The data associated with each selected literature was extracted into an Excel

Table 2 The criteria used for the extraction of information from the selected articles

Criteria	Categories considered	Justification
Annual distribution	Year of publication	To investigate the earliest stages of research and most published articles
Distribution of regions and institutions	Country and institution of the first author	To examine the most published continents and institutions to reveal key research strengths
Classification and content of the literature	Research themes (By keywords and abstract reading)	To discover the main research areas and frontiers
Main process and landmark achievements	Theory, methodology, techniques, research focus, research findings (By main body skim reading)	To distil the progress and content of existing studies to support comparative analysis
Implications for future research	Research gaps (By comparative study)	To identify gaps in the existing study and find breakthroughs for future research

spreadsheet for data processing. The classification step consisted of sorting and processing the extracted data in preparation for further analysis. The final results are presented in charts and various types of graphs.

Result and discussion

Annual distribution of the literature

The research on the conservation of WNH sites and the development of buffer zones generally shows an upward trend. The annual distribution of research literature can be roughly divided into three stages (Fig. 3). The first phase was 2000–2008, with relatively few studies. The total number per year was no more than 5, indicating that this phase was embryonic. The first analysis of the interaction between heritage conservation and buffer zone development dates back to 2000. Since the Davos Conference in 2008, the World Heritage Committee (WHC) has shown a trend of rational understanding, scientific delineation, effective management, and flexible application of the buffer zones in various countries. Reflecting on the nature and functional elements of the buffer zones, the research on them in heritage protection has gradually shown intensiveness. Therefore, after the rapid fluctuation growth in 2009–2015, the following rapid growth appeared in 2016–2020. Overall, the number of studies surged to the highest level in 2020.

Distribution of regions and institutions of the literature

The sample literature is mainly from more than 30 countries, so due to space limitations, the top 5 countries and institutions by region in terms of the number of publications are mainly shown (Fig. 4). Asia has the highest number of publications, followed by Europe. The research literature is focused primarily on China and Australia. The WNH sites that have received more scholarly attention mainly include the Great Barrier Reef, Nanda Devi, Bogda, Jiuzhaigou, Sanqing Mountain, Pamukkale, and Pitong Mountain, and the Wadden Sea Reserve. The earliest Chinese literature was published in 2000 by Li on the buffer zone design method for Yancheng Nature Reserve. The earliest overseas was a conference paper published by Bainbridge in 2001 on determining buffer zone scope and function in Ukaramba-Drakensberg National Park, South Africa.

The research institutions with more publications are located in Asia (Guizhou Normal University, Institute of Ecology and Geography, Chinese Academy of Sciences, Xinjiang, Tsinghua University, Kunming University of Technology, Renmin University of China, Peking University), followed by Europe (the University of Bern, University of Jelena, University of Ghent, University of Catania), Oceania (James Cook University, University of Queensland, University of Sydney), and Africa (Northwest University, South Africa). This trend reflects the rapid development of research on conservation and buffer zone development in Chinese WNH sites, but most studies are practical [46–49], theoretical studies are more common abroad.

Classification and content of the literature

The literature is divided into six dimensions for analysis: theoretical research, technical methods, model construction, benefit monitoring and evaluation, experimental demonstration, and others (Fig. 5). Through the analysis of the proportion of its number in the exhaustive research, it is found that theoretical research accounts for about 58.51% of the total research literature, accounting for the central part of the current research. The second

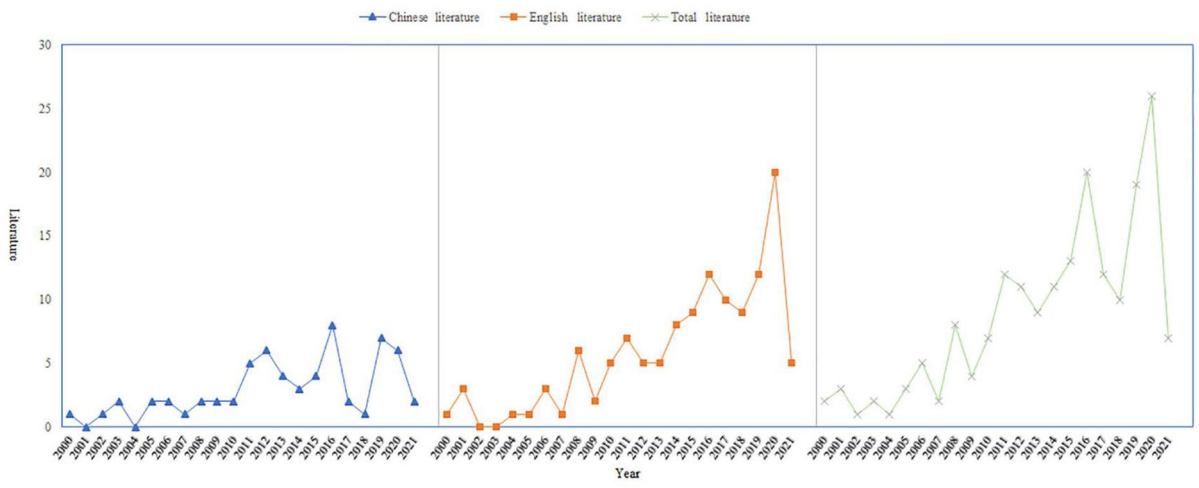

Fig. 3 Literature trends of research on conservation and buffer zone development in WNH sites from 2000 to 2021

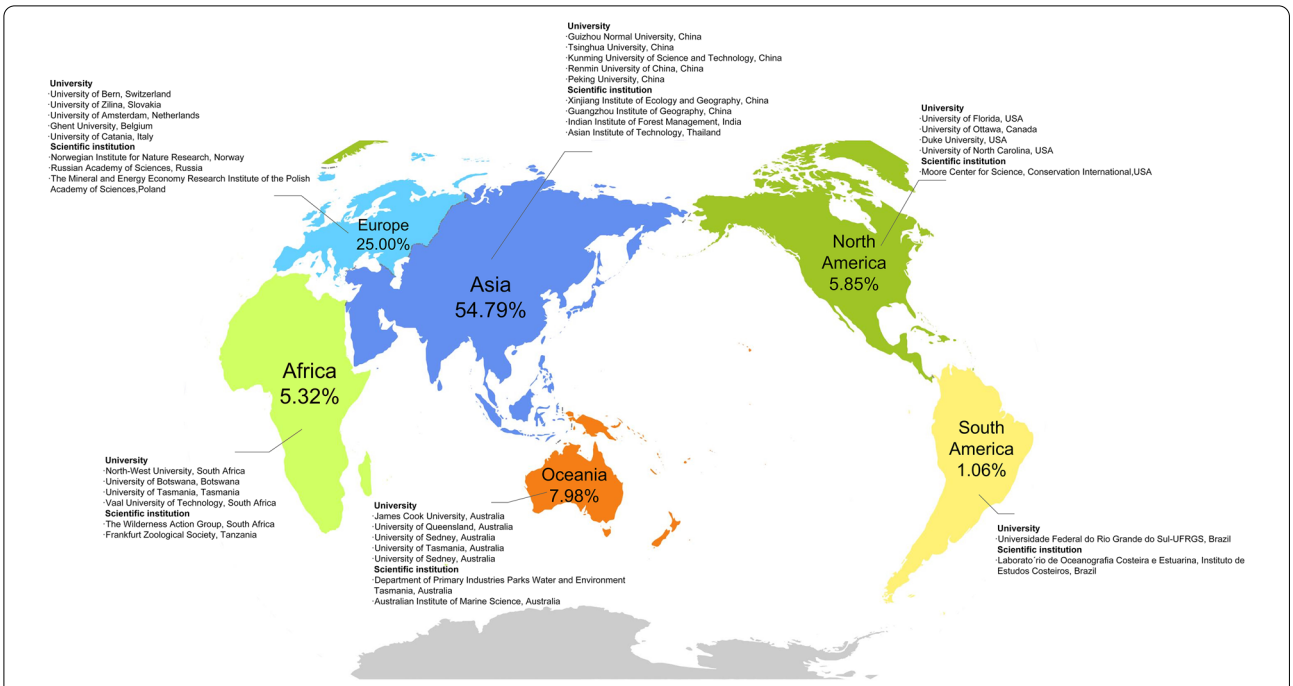

Fig. 4 Distribution map of regions and institutions

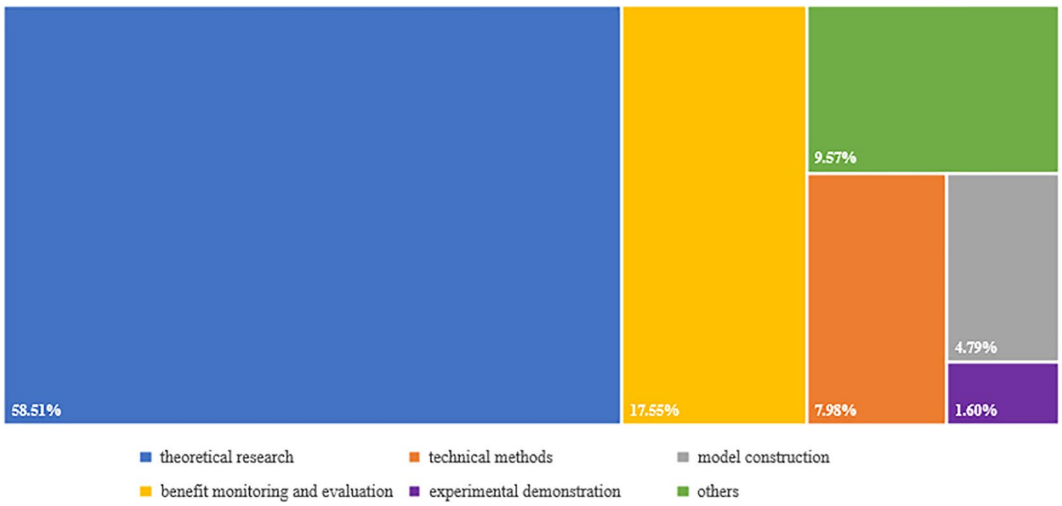

Fig. 5 Classification of the literature

is the research on benefit monitoring and evaluation, accounting for about 17.55% of the total research. There are relatively few studies on technical methods, model construction, experimental demonstration, and others. In terms of research content, the buffer zone has shifted from focusing on its physical spatial connection with heritage to comprehensively considering its social, economic, and cultural linkages. The research topics include heritage conservation and tourism development, community development, community participation, stakeholders, sustainable resource utilization, identification of OUV influencing factors, landscape pattern and process, zoning management and protection, and ecosystem service health assessment, etc. In the process of research, there are two main research categories: ecology-oriented and society-oriented. In the subsequent theoretical

discussion, the trend of integration of environmental protection and community interests has gradually presented [16]. In contrast, there are few studies on social-ecological orientation.

Main process and landmark achievements

Theoretical research

(1) Continuously deepen and expand the research on the concept and connotation of the buffer zone to provide the theoretical basis for the delineation of it and the setting of its objectives and functions.

The buffer zone connotes both the protective role played by the periphery to the core area and the impact and negative effects of the heritage itself on the surrounding area. Due to the different problems that the leading institutions and professional teams try to solve, different research categories have been formed to understand the concept and function of buffer zones, which are ecologically oriented, community development-oriented, and comprehensively consider ecology and community [16]. Shelford formally proposed the concept of "Buffer zones" in 1941 based on previous studies, which were included in the Operational Guidelines for the Implementation of the World Heritage Convention (1977 edition) and made relevant provisions. With the change of WH protection concept and practice feedback, the definition and relevant provisions of the buffer zone are always in the process of evolution. The buffer zone was first promoted by the MAB and then adopted by the ICDP program. Ebregt and De Greve [8] summarized buffer zone studies into two categories: the resolute environmentalist (used to avoid the negative impacts of human activities on the core area) and those who are social protectionists (considering buffer zones as part of socio-economic development of the whole area, including protected and unprotected areas). In the later studies, the discussion on the objectives and functions of buffer zones gradually shifted toward viewing them more as a socio-ecological concept rather than just an area that is geographically delineated and imposes restrictions on resource use. Increased scholarly interest in stakeholder and traditional user rights has made buffer zone thinking more socio-economically valuable. As the buffer zone connotation and function discussion deepens, the setting of it requires more careful consideration of ecological processes, biodiversity conservation, cultural heritage, visual landscape, and other delineation factors.

(2) Identifying the main threat factors of buffers to the conservation of OUV's integrity of heritage sites and revealing the intrinsic connection, interaction laws, and constraints between heritage sites and edge systems are the theoretical basis for exploring the synergistic mechanism of heritage site conservation and buffer zone development.

The human-land conflict caused by the use of natural resources by the residents in the buffer zone is one of the main threats to WNH conservation. The development and construction processes in the surrounding areas have a significant impact on the heritage site, such as land encroachment, pollution of the surrounding environment, and visual impact of tall buildings, leading to the phenomenon of "islanding" of the heritage site [50]. Based on the technical assessment report of IUCN and the resolution of the WHC, Zhou et al. [51] identified and quantitatively evaluated the threat factors of 186 WNHSs on the 2006 list and pointed out that the impact of development in the vicinity of heritage sites and environmental pollution in the periphery of the world are the main threats. Allan et al. [52] reveal the main threats to WH conservation by quantifying the population pressure and forest loss in heritage sites and buffer zones. International case studies focus on island-based heritage with globally diverse marine ecosystems, where the expansion of coastal cities and industries becomes a significant threat factor. Scholars have raised concerns about the future conservation and resilience of coral reef ecosystems and residents' livelihoods [5]. Chinese scholars have focused more on the role and technology demonstration played by buffer zones in terms of ecosystem and environmental protection of WNHSs, and relatively few systematic studies on the synergy between buffer zone development and heritage site conservation, mainly discussing the tourism industry development strategies unilaterally and planning in rural areas around WNHSs.

(3) Research on the coordination mechanism of tourism development and ecological environment protection is the theoretical basis for exploring the coupling of heritage protection and tourism development in the buffer zone.

Synergistic effects are crucial for balancing nature conservation and socio-economic development and improving the socio-ecological resilience of the region [53]. Many scholars have conducted synergistic studies of WNH conservation and buffer zone tourism development in case studies, and tourism-ecological coordination mechanisms have become a hot spot for research. The evaluation of the coordination between the two and sustainable development is the focus of academic attention. The discussion mainly focuses on ecotourism development strategy, coordinated development

of environmental protection and economy, synergistic development of biodiversity conservation and heritage tourism, and conservation of heritage sites and tourism development in marginal zones [20, 48, 54–57]. Scholars' common research theories and methods are the optimal control theory, coupled coordination function model, integrated evaluation method, and hierarchical analysis. Several studies have demonstrated that ecotourism can be integrated with sustainable livelihood practices. Maikhuri et al. [19] in a study of the Nanda Devi Biosphere Reserve, emphasized the role of ecotourism activities in the buffer zone, which can promote a mutually beneficial combination of environmental protection and sustainable livelihoods. In addition, Chinese scholars have also paid more attention to the interaction between new rural construction and WNH conservation in the context of buffer zone tourism development. They emphasize that rural communities are an important component of WNHSs ecosystems and tourism environments.

(4) Based on the origins, types, and consequences of conflicts of rights and interests in the conservation of WHSs, scholars have explored the interaction between conservation and community development of WNHSs in terms of perceived differences among community residents, community participation, the game between heritage conservation and residents' livelihood issues, stakeholder co-governance mechanisms, and social justice, laying the theoretical foundation for the study of human-land relations .

The human-nature connection can shape perspectives on resource conservation and influence behavior in response to perceived environmental threats [58]. Promoting personal connections to the environment may have practical implications for resource management and conservation outcomes [59]. Studies have been conducted to explore effective WNH conservation and management measures mainly from economic and sociological perspectives, emphasizing the need for a thorough assessment of the relationship between WNHS and people, rather than heritage conservation through policy restrictions alone [49, 60]. Most scholars create alternative livelihood opportunities to improve the economic status of local people as an effective means of human-nature conservation conflicts [20]. Social exchange theory is often used to study residents' attitudes and behaviors towards heritage conservation [61–64]. The high level of perceived negative economic and environmental impacts of tourism is the leading cause of residents' dissatisfaction with tourism development and lack of participation [65]. In a recent study, Rastegar et al. [66] emphasizes the social justice perspective to understand the different impacts of WNH management on different communities and cultural groups as a basis for sustainable management strategy development in WHS. In addition, research on the driving mechanisms and influencing factors of pro-environmental behaviors of different stakeholder groups in heritage conservation from a social-emotional perspective has become a focus of recent scholarly attention [67], further deepening the study of stakeholder cooperation mechanisms.

Technical methods

(1) To strengthen the management of OUV threat factors, research conservation and management techniques for graded zoning, and classification of WNH sites.

Functional zoning is a feasible means to deal with the relationship between conservation and utilization of WNHSs. Reasonable zoning can reconcile the contradiction between conservation and development and maximize the WNH conservation while contributing to the development of the local economy. Studies have been conducted to construct a technical system for conserving natural landscape, ecological processes, and essential species habitat WHSs. For example, the construction of the classification and protection system of natural landscape heritage sites is mainly based on the aesthetic value assessment model of the aesthetic value representation elements of the landscape. The evaluation is primarily based on the superposition of the spatial partitioning of landscape beauty, sensitivity, and vulnerability to determine the comprehensive spatial partitioning and protection level of landscape protection. The ecological process WHSs are mainly based on OUV characterization elements, influencing factors, and integrity interaction mechanism. Through the superposition analysis of the vulnerability, sensitivity, disturbance, and integrity, obtain the distribution of OUV importance of the heritage sites, and propose the conservation and management model to carry out classification zoning and grading. The important species habitats are mainly analyzed by coupled hotspot analysis techniques for importance, vulnerability, and sensitivity and combined with bundle analysis for heritage site classification and zoning planning studies. Based on the above methods, the established category and zoning conservation models are the "Bogda model" [68] and the "Bayanbulak model" [69]. In addition, studies have been conducted to analyze the extent of existing visual impacts of anthropogenic features in WNHSs and its buffer zones using view area analysis in GIS as a method to validate heritage zoning [10, 70].

(2) Establish sustainable heritage conservation management techniques based on the need to protect the integrity of WNHSs highlighting OUV, with the help of modern science and technology such as geographic information systems (GIS) and remote sensing (RS).

Researchers are using RS and GIS technology to describe the authenticity and integrity of the representation of WNHSs and the composition of conflict elements brought about by tourism development. Combining knowledge from multiple fields such as human geography, landscape ecology, and tourism to carry out the identification of conflicting elements in WNHSs [71], bridges the gap in the study of technical presentation and spatial expression of conflicting elements identification and provides a scientific decision-making basis for resolving the conflict between the conservation of authenticity and integrity of WNHSs and tourism development. In addition, RS and GIS provide a scientific decision-making basis for an ecological health assessment [68, 72], landscape pattern evolution characteristics, and its driving mechanism [51, 73], quantitative evaluation of visual landscape environmental impact [74], ecological corridor identification and construction [75], and ecosystem service value assessment [72], provide technical support to give full play to the advantages of spatial analysis and visualize the spatial interaction between core areas and buffer zones. The human footprint is often used as the primary indicator to assess the human pressure on heritage [52]. Landscape index analysis is often used to construct a model for assessing the spatial integrity of landscape patterns, and integrated connectivity index analysis and covariance analysis are often used to construct a diagnostic model for landscape spatial connectivity [76]. In a recent study, Garrard and Fielke [77] used repeated photography methods to assess changes in protected mountain landscapes to understand many of the complex factors that play a role by measuring specific experiences, avoiding the one-sided effects caused by objective indicators. In addition, GeoDetector is frequently used as a new statistical method to detect spatially stratified variation in geographic elements and reveal their driving patterns in studies [76]. The minimum cost model (MCR) is widely used in ecological corridor identification, and construction studies, and Ye et al. [75] proposed a new idea of ecological corridors in WNHSs on this basis, proposing the organic integration of the MSPA method and MCR model.

Model construction

(1) To ensure the sustainability of heritage tourism, conduct research on localized tourism development models aligned with sustainable development goals.

Scheyvens [78] calls on tourism geographers to consider using the SDGs to analyze the links between tourism and sustainable development in a wide range of contexts and at different scales. Dube and Nhamo [79] in seeking to respond to the SDGs, proposes the "4C" model, which focuses on conservation, community, culture, and commerce in the WNHSs and surrounding areas, and articulates how tourism businesses and visitors can work with society, government, and civil society to achieve socio-economic and environmental development, as required by the 17 SDGs. For example, addressing hunger through organic agriculture to meet community needs and the healthy food needs of some huts (SDG2) and introducing "sports food" for host communities to ensure good health and well-being under SDG3. Encourage and support start-ups within communities, reduce poverty, reduce inequality (SDG10), and stimulate economic development (SDG 8). In comparison, tourism players in Africa and elsewhere have begun to apply the SDG framework. However, China has emphasized sustainable heritage tourism development but has primarily remained in theoretical discussions and specific case studies has yet to establish a replicable, localized tourism development model that responds well to the SDGs.

(2) Based on the zoning management of WNH, the conservation concept of core zone protection, buffer zone treatment and development, and peripheral zone prevention and control is proposed. The model of "comprehensive heritage display + special industry development + regional linkage development" is built.

Xiong et al. [80] proposed a model for conservation and sustainable development of the Libo World Heritage site, emphasizing construction measures, development measures, and infrastructure construction in the core, buffer zone, and peripheral areas of the site successively. To promote the rapid economic development of the community while effectively improving the environmental quality of the site, relying on heritage resources and developing particular industries in the buffer zones and peripheral areas of WHSs is a meaningful way to directly utilize the derived values of heritage [46]. The above model focuses on optimizing industrial structure and the development needs of stakeholders. It is being progressed

and affirmed by scholars as an integrated endogenous development model established to mitigate the impact of human activities in protected areas [81], making progress and gaining recognition. In the process of exploring this model, China has integrated cooperatives into heritage tourism and new rural construction, encouraging farmers to adjust their planting structure and promoting the structural transformation of modern agriculture utilizing "company + base + farmers". We have also been developing eco-agriculture and creating ecosystem complexes consisting of organic agricultural production bases, economic forests, orchards, vegetable gardens, wetlands, and village eco-economy parks in WNHSs and surrounding areas according to local conditions. However, most of them are in the exploration stage, and the economic and social benefits are not significant.

Experimental demonstration

(1) Develop energy use and ecological restoration technologies and conduct experimental demonstrations in the local area, considering the natural constraints of WNH conservation and buffer zone development.

Sharma et al. [82] based on the energy use supply and demand patterns developed by NDBR under specific agro-climatic conditions, the traditional water mill improvement technology was developed and experimentally demonstrated to meet the continuously escalating energy demand in buffer zone villages local area. The results show that the power output can be increased to 5 kW per high altitude for traditional gharats. The grinding efficiency of the upgraded gharats is increased by three to four times, which is vital for meeting the household, commercial, and industrial energy needs of dispersed villages. Nakamura and Komiyama [83] using ecological restoration techniques to improve salmon migration and restore ecosystem connectivity in Japan's Shiretoko. By modifying dams, the project successfully restored upstream movements of salmonids and expanded their habitat in streams above some dams while maintaining the integrity of disaster prevention functions.

(2) Draw on advanced management models and experiences in buffer zones and conduct experimental demonstrations in WNH conservation and management practices.

Nepal is one of the few countries globally that has enacted buffer zone laws and has received excellent resource conservation and community development results. Australia is the first country to introduce public participation in the co-management model of WHSs. It has fully safeguarded the interests of Aboriginal people and other critical stakeholders in heritage resource development, which has played an essential role in enhancing management effectiveness, capacity building and sustainable livelihoods. Chinese scholars such as Zhuang and Wang [21, 84] have summarized successful international experiences and applied them to Chinese WNH conservation and community planning practices in Taishan, Huangshan, and Jiuzhaigou. They found that there are currently significant gaps, with the value system of heritage sites and communities not yet studied in-depth, emphasis on physical space construction and economic development, and light on soft power cultivation. The problems of community cultural protection and capacity building are not given enough attention.

Benefit monitoring and evaluation

(1) Using the "PSR" model, the WNH monitoring and evaluation index system was constructed by the Delphi method and hierarchical analysis to monitor the conservation and management status .

WH monitoring is an essential tool for the conservation of OUV, which can provide background data support and analysis of change trends for WH conservation and provide a scientific basis for management decisions. According to heritage conservation needs, the monitoring content of WHSs can be broadly divided into four significant aspects, namely, value monitoring, display monitoring, environmental monitoring, and threat factor monitoring [85]. Studies have focused on the monitoring of heritage and its physical environmental factors and disasters. The monitoring mainly considers natural and social factors such as meteorology, hydrology, soil, vegetation, population, and buildings [86]. Most scholars use the "pressure-state-response" model to construct the index system and use hierarchical analysis to determine the weights of each index [87]. Wang and Du [86] used GIS and MCDA to optimize the monitoring system of WNH and concluded that forest, tourism resources, biodiversity, and conservation priority are the four significant factors that determine the Monitoring of Bogda.

(2) Evaluation of WH governance performance from ecological and social perspectives based on assessing the strengths and weaknesses of the ecosystem service values of WHSs and its buffer zones, tourism governance modelsand development models of heritage community settlements, respectively.

Valuing ecosystem services is considered an effective tool for quantifying the benefits of natural ecosystems [88, 89]. Duan et al. [72] used remote sensing imagery, GIS, and ecosystem service value models to analyze the changes in ecosystem service values of woodlands, grasslands, watersheds, and stone forests in the Shilin Karst Heritage site and its surrounding buffer zone in Yunnan from 1992 to 2009, based on which the conservation and management effects of the heritage were evaluated. The results show that the ecosystem service values in the northern part of the Shilin Karst and the buffer zone are lower than those in other areas, and further conservation should be carried out in the north region. The socially-oriented heritage governance performance evaluation focuses on tourism governance and community development model [90], emphasizes efficiency, equity, accountability, and adaptability of heritage management, and pays attention to local cognition and community participation in WNH conservation.

(3) Conduct research on assessing ecosystem service values and ecosystem health conditions of WHSs and its buffer zones and compensation strategies from landscape classification and heritage conservation monitoring.

Estimating the value of ecosystem services is a prerequisite for achieving ecological compensation. The study of compensation for ecological assets will help better protect and increase the ecological assets of WNHSs and protect the welfare of indigenous inhabitants, thus better protecting the authenticity and integrity of WHSs [91]. Duan and Li [92] applied the market value method, and opportunity cost method to evaluate the value of ecosystem services in Yunnan Shilin World Heritage site and buffer zone analyzed the depletion of ecological assets, and conducted a study on the compensation of ecological assets. Ecosystem health assessment based on ecosystem landscape changes can spatially understand the dynamics of ecosystem health levels, and land-use changes are often used to reveal landscape patterns [76]. The inclusion of land cover in ecological health studies has become a trend. The VOR model is most widely used in ecosystem health assessment, which is based on ecosystem vitality (EV), ecosystem organization (EO), and ecosystem resilience (ER) to evaluate ecosystem health. Wang et al. [68] analyzed the spatial differences and dynamic changes of ecosystem health based on the spatial distribution changes of ecosystem landscape types. They evaluated the ecosystem health of the study area from the perspective of heritage protection monitoring. The results showed that the ecosystem health degree of the buffer zone was lower than that of the heritage area and showed significant spatial changes.

Key scientific issues to be solved

Strengthen research on the theoretical system of buffer zones and explore the international application of buffer zone planning adapted to its heritage protection and management system.

Since the research on buffer zone development only stays at the problem level without deepening the study of specific measures, the lack of flexibility and adaptability in application leads to the buffer zone gradually becoming an "empty shell". It is necessary to strengthen the research on the theoretical system. Buffer zones are a management tool that should be flexible and elastic in use. As climate changes, socio-economic factors change, and heritage conservation technology improves, the boundaries of buffer zones and management policies may change accordingly as awareness and conservation targets expand. In the future, nominating countries need to be guided to pay more attention to the rationality of application when delineating buffer zones and during the heritage approval process by the Committee. To pay more attention to exploring case studies and best practice guidelines, and to explore the international application of buffer zone planning adapted to their heritage conservation and management systems, with more emphasis on the interpretation of OUV, the application of visual analysis tools, the integrated conservation of regional landscapes, and the functioning of social buffers.

Establish an evaluation index system that synergistically highlights the need for monitoring the OUV protection and the characteristic attributes of heritage sites themselves and explore a monitoring and evaluation model for WNH with maximum applicability.

The traditional indicator systems for landscape monitoring, ecological health, and ecological safety monitoring cannot accurately deconstruct OUV, resulting in weak research on the monitoring and evaluation system of the WNHSs' OUV. Future research should establish an evaluation index system based on the conservation effectiveness of authenticity and integrity to meet the requirements of monitoring the conservation status of OUV while coordinating the monitoring needs of different types of protected sites. The integrity of WHSs relies on the connection of the broader landscape, and changes in the ecological environment of buffer zones should be the focus of monitoring to avoid the impact of edge effects on core areas. In addition, a collaborative sky-ground monitoring system should be considered [17, 93] to establish

the dynamic monitoring needs of heritage sites in different times and spaces, establish the critical technology combination model for dynamic monitoring, develop technical standards and norms for monitoring WNHSs, form the ecological health diagnosis method to provide cognitive and scientific conservation of change-driven mechanisms in WNHSs scientific basis.

Strengthen research on adaptive community management from a social-ecological system perspective and establish a virtuous cycle management model that feeds the community and manages resources.

The matching of scale between ecosystems and social systems is a promising analytical approach to organizing governance systems [94]. As an essential component of WNH socio-ecological systems, communities have a crucial role in their resilience cycle. Given that community socio-ecological systems around WNHSs are inherently resilient. Blueprint-based management cannot fully utilize this quality. Future research should emphasize buffer zones' conservation function, change the previous perspective, and integrate ecological and sociological research. Investigation methods to explain the intrinsic relationship between OUV conservation and community development in complex ecosystems of WNHSs and explore and identify the ways, mechanisms, and means of regulation of community activities on OUV. A key research direction will be strengthening communities' adaptive and collaborative management and exploring the relationship between relevant heritage value conservation indices and community diversity. Resilience theory emphasizes the importance of studying the historical relationship between society and its environment [95, 96]. The study of community resilience mechanisms on WH conservation may become a breakthrough point for adaptive management research. In addition, community participation in most developing countries has not received sufficient attention at the practical level. The importance of pro-environmental behaviors of local people in achieving ecological conservation goals has not been well interpreted. Future research needs to focus on the relationship between community development and environmental protection and study the influence of residents' perceptions of changes in livelihood capital on their pro-environmental behavior [64, 70].

In response to different dilemmas of buffer zone development, such as waste of resources, an unclear path of autonomous development of rural communities, and single industrial structure, explore the model of synergistic development of WNH protection and buffer zone tourism industry.

WH development goals are mainly achieved in buffer zones, but not at the expense of core conservation goals, and should also consider the needs of local socio-cultural and economic [97]. Rational development of tourism and other industries can positively contribute to the conservation of WNH. However, the conservation of it should not be limited to the tourism industry of sightseeing. It should focus on the integrated development of multiple industries and promote synergy between tourism and other industries [98]. The opportunities for synergy between tourism and other industries such as agriculture have not been fully explored [99, 100]. Future research should explore endogenous integrated development models with characteristic regional resources [81] and strengthen quantitative multi-industry synergy mechanisms. In response to the increasing level of tourist demand, WH tourism development should focus on building local product supply chains and realizing the localization mechanism of industrial chains.

Pay attention to the protection of multiple values of heritage sites, focuses on studying the cultural genes of WNHSs and explore the mechanism of local culture and traditional knowledge in buffer zones for WH protection.

Given that traditional heritage conservation and utilization focus on heritage materials and structures, modern approaches focus on preserving OUV and cultural heritage symbols. Future research should pay more attention to the geographies of WNH, the multiple values and dynamic changes, and the essential properties of heritage and its identity, emotion, and memory [101]. It is necessary to pay attention not only to the heritage itself but also to the historical and cultural background of the heritage site, the role of the local values of the heritage for conservation. To explore multiple livelihood development paths through the revitalized use of intangible cultural heritage in the buffer zone and cultural and

creative tourism activities to alleviate the contradiction between resource conservation and economic development needs.

Carry out technical research on identifying conservation elements and spatial pattern display of OUV, reveal the spatial pattern characteristics of heritage values in the study area, and provide a scientific basis for WNH classification and zoning management.

In response to the lack of techniques for identifying and extracting OUV representation and disturbance elements, future research should build an index system for evaluating different types of WNHSs. To evaluate OUV representation elements, apply on-site surveys, questionnaires, expert consultation, and other technical methods for rapid assessment, and extract key disturbance elements. In addition, focus on socio-spatial factors as a zoning principle, and measure the differences in the perception of residents and tourists in core areas and buffer zones on the socio-spatial consequences caused by zoning, based on which more effective zoning measures can be explored [76].

To reveal the spatial interaction pattern between heritage sites and buffer zones from the perspective of spatial and temporal evolution and to carry out research on the mechanism of the role of the human-land relationship in promoting heritage conservation and buffer zone development.

There is a strong relationship between WHSs and its buffer zones regarding the living environment, social interaction, material exchange, and information [102]. The existing studies have mainly applied landscape ecology principles to study the spatial linkages in landscape patterns and ecological processes from an ecologically oriented perspective. Furthermore, fewer studies integrate ecological and social orientations and studied the perceptions and attitudes of buffer zone residents toward heritage sites, community participation, and stakeholders on heritage site conservation from a socially oriented perspective. Future research should examine the changing relationship between people and the environment from a socio-economic perspective and reveal the social connections between the two spaces by understanding the relationship between buffer zone livelihoods and heritage site resources. In addition, comparative studies of the spatial distribution of ecosystem service values make value assessment methods more helpful in guiding future conservation and management efforts. In the future, accounting for the value of environmental services generated by the buffer zone landscape should be incorporated into policy and planning processes. Attention should be paid to the landscape services provided by agricultural activities in the buffer zone for tourism in the heritage site. The spatial relevance should be explored from multiple perspectives.

Build a conservation management system and model that highlights universal values as the core and carry out experimental demonstrations.

Because there are few experimental demonstrations on heritage site conservation and buffer zone development, and most of them are preliminary explorations in local experiments. The future should refine the macro-management model that can be promoted from laws and regulations, management system, management planning, scientific research and monitoring, and sustainable use for experimental demonstration. On this basis, explore the micromanagement methods suitable for the heritage itself.

Implications for future research on karst world natural heritage

Problems with karst world natural heritage conservation

Approximately 16.5% of the world's population lives in karst landscapes [25]. The physical characteristics of these landscapes make them highly vulnerable to damage and degradation, and the ecosystems are more fragile. The slow soil formation process, thin soil layers, calcium-rich and weak alkaline soils, low land productivity, steep hills, little arable land, and rapid infiltration of surface rainfall [103] has led to poor overall environmental function, low biological production and slow growth rates in this area, and consequently low natural production potential of arable land and low population carrying capacity. In some places, there is even the phenomenon that "one side of the land cannot support one side of the people" [80]. The occurrence of rock desertification adds to the already difficult living conditions in karst areas [37]. Karst aquifers often provide abundant groundwater reserves, supplying fresh water to approximately 25% of the world's population [24]. So they are a valuable resource associated with human health, food security and industry, playing an essential role in the historical and economic development of many countries and regions today [104]. However, these aquifers are increasingly threatened by numerous environmental issues such as pollution, over-exploitation and the effects of climate change [105].

In recent years, the overall economic and urban development has led to an intensive and unsustainable expansion of settlements, infrastructure and industry,

tourism development and the intensification of agricultural land use, putting increasing pressure on karst landscapes [106]. Especially for karst WNHSs with high conservation attributes, once damaged, karst ecosystems (both surface features and subsurface resources) take a long time to recover, and the process is complicated. It is therefore crucial that the overall management of this category of heritage is carried out appropriately and prudently.

According to the State of Conservation Report published by the WHC [107] and the WH Outlook published by the IUCN [41], invasive species, climate change and tourism impacts are currently the three most significant threats to the OUV protection. A further analysis based on the different influencing factors shows that anthropogenic factors pose a much higher threat to this category of heritage than natural factors, both in terms of type and number. The main human influences are management and institutional factors and social/cultural use of the heritage. Architectural development, transport facilities, services and socio-cultural use, which often revolve around the tourism activities of heritage projects, have been widely discussed by scholars [6, 108]. They generally agree that major factors such as management systems, tourism development and rock desertification threaten the sustainability of the karst WNH. Compared with the major advances and landmark achievements of the current global research on WNH conservation and its buffer zone development, the following problems still exist in studying this type of heritage.

(1) Research on the economic functions and social needs of buffer zones is relatively weak, and there is a lack of research on the social buffering mechanism of buffer zones for karst WNH conservation.

Ecological issues are essentially socio-economic issues [109], and existing studies have mainly focused on the ecological function of karst WNH's buffer zones, exploring its role in ecological connectivity and biodiversity conservation. Still, their social buffer effect on WNH conservation is not apparent. However, the buffer zones of karst WNHSs are mostly remote rural areas where fragile ecological environments are often accompanied by rock desertification [103]. The 'economic depression' in the 'mountain paradise' is a true reflection of the environmental and developmental pressures of the sites [80], with severe human dependence on the land and slow economic development and backward industrial structure. Since the inscription, the buffer zone's communities have been restricted in their use of resources. They have benefited unevenly from the compensation, and there is an urgent need to explore effective mechanisms for the economic development of the buffer zone so that it can give full play to the dual effects of heritage conservation and community economic development.

(2) Traditional management models are at odds with the needs of local people.

Communities have the right to make decisions about the conservation and use of their local heritage, and they should be empowered to ensure effective community participation [6]. However, the traditional top-down management model of most karst WNHSs ignore the development needs of communities [22]. The loss of young residents in buffer zones and the relocation of residents have become a common problem in WNH conservation and management in economically disadvantaged areas [110–112]. Increasing community participation in tourism development programmes, retaining young people and promoting the integration of traditional livelihood diversification and WNH conservation has become an urgent issue to be addressed [113]. In terms of resettlement, local governments often adopt relocation policies, which are often managed in such a way as to force local people to move out of the homes they have lived in for generations. Such actions completely ignore human values and traditions, deny human knowledge and practice, and sever important links between nature and culture. This model of conservation and management can easily lead to resentment and opposition from communities. This problem is not uncommon in karst WNHSs in China, for example [21, 114, 115].

(3) Lack of OUV monitoring indicator system and dynamic health assessment.

The existing karst WNH monitoring mainly focuses on ecological safety and landscape monitoring, which cannot effectively reveal the conservation status of OUV. It has not yet clarified the relationship between the unique attributes of WNHSs and their value criteria [116, 117]. In addition, the buffer zone, as a protective layer of the WNHS, lacks a monitoring system that links the buffer zone's function to the conservation of the heritage site values. The current tracking of the socio-ecological function effects of the buffer zone is inadequate. Research on how to control the impact of human activities such as tourism and agriculture on groundwater in the buffer zone to promote the WNH's OUV conservation needs to be strengthened.

(4) Conservation and management effects need to be improved.

Management factors threaten karst WNHSs most [29]. Since 2014, the overall effectiveness of conservation and management of WNHSs has been declining [118]. The traditional top-down model still exists in many karst WHSs, lacking conservation and management mechanisms adapted to the characteristics of their fragile ecological environments and a synergistic approach to heritage conservation and development that integrates nature and humanity. Firstly, rock desertification and the new crown epidemic have reinforced the dilemma of localizing the conservation and management of karst WNHSs. The difficulty of making WNHSs positive for people's livelihood and contributing to addressing poverty has been a constant source of concern for managers and policymakers. Secondly, education on WNH conservation is insufficient, and most residents lack awareness of the role of buffer zones [119] and the importance of karst aquifer protection, resulting in their endogenous motivation to protect the heritage environment from being strengthened.

Implications for future research

Drawing on the significant research progress and achievements mentioned above, and given the unique characteristics and problems of karst areas, future research on conserving this type of heritage needs to focus on the following points.

(1) Review the institutional factors of ecological problems and degraded ecosystem management from a socio-economic perspective, explore the synergistic model of heritage site protection and its buffer zone development, reveal the mechanism of the role of eco-industrial development in the buffer zone as to heritage site conservation, and strengthen theoretical research on karst WNHSs' buffer zone.

Future research needs to seek total solutions socially and economically, focusing on local development needs, strengthening the socio-economic functions of buffer zones, and exploring the transformation of economic growth patterns. Eco-industry, emphasizing the interaction between humans and the ecological environment, has also been used as an effective way to manage rock desertification in karst areas [80, 120]. The operation of agroecosystems in the process is most closely linked to the ecological environment by humans. There is an urgent need to develop resilient agricultural planting techniques that adapt to environmental changes, build high-yielding and sustainable mixed agroforestry models, and explore their role in revitalizing eco-industries [121, 122]. Make full use of carefully maintained agroforestry to provide striking natural beauty and combinations of woody plants and crops in various shades and shapes. To create buffer zones as eco-agro-tourism sites to avoid overcrowding and commercial destruction of resources to the detriment of community 'overtourism' [123]. A comprehensive eco-industrial development plan and industrial spatial layout with ecotourism and sustainable livelihoods at its core [112], to build an endogenous development model that feeds into community development and resource recycling.

(2) Pay attention to the relationship between heritage environmental conservation and community development, deepen research on stakeholder cooperation mechanisms and strengthen adaptive and collaborative management of buffer zone communities.

Adaptive Collaborative Management (ACM) is an extension and expansion of the concept of adaptive management, which aims to pursue sustainable resource use and socio-ecological resilience. Specifically, it refers to systematically monitoring and observing environmental changes, integrating multi-level knowledge through long-term stakeholder communication and cooperation, deepening the understanding of the social-ecological system, testing and revising management measures in a dynamic process of trial and error, and ultimately achieving the goal of synergistic interests, healthy system operation and sustainable resource management [124]. Future research should first focus on the impact of changes in community residents's livelihood capital on their pro-environmental behaviour in the context of diversified industrial development and establish and improve ecological compensation mechanisms, heritage conservation participation mechanisms and community coordination mechanisms [21, 22]. Secondly, the relationship between heritage value conservation and community diversity needs to be emphasized, more bottom-up work should be carried out. The role of traditional ecological wisdom in heritage conservation should be considered, and communities' relocation and resettlement should involve multiple stakeholders in the decision-making process [112]. Finally, the intangible part of the cultural lineage in WNH conservation is valued [125]. Based on the rich and varied intangible cultural heritage nurtured by the unique geographical environment and landscape structure of karst [126], cultural and creative industries are developed in the communities around the WNHSs to achieve the upgrading and optimization of tourism and rural industrial structures and to enhance the cultural consciousness and identity of the nationalities of the conservation subjects. To consider the

important role of local culture and traditional knowledge in WNH management.

(3) Establish an assessment indicator system that synergistically highlights the need for monitoring OUV and the unique attributes to enhance the effectiveness of heritage monitoring and management.

Firstly, to establish a monitoring and evaluation index system corresponding to the OUV, focus the research on impact factors on the WNHSs' OUV, and carry out research with different focuses on key monitoring and comprehensive one with the help of advanced technologies such as GIS and RS, to explore a monitoring and evaluation model with maximum applicability. In addition, for the monitoring needs of the more ecologically fragile karst WNHSs, the health diagnostic assessment is a key technology of the dynamic monitoring and assessment application system. It is urgent to establish an active monitoring and assessment index system that can reflect the health of karst soils, aquifers, and other ecosystems [127]. Finally, the monitoring scope of buffer zone poverty and community resilience should be included in the monitoring scope [128].

(4) Explore techniques and methods of conservation and management adapted to the characteristics of fragile ecosystems in karst WNHSs, and conduct experimental demonstrations.

The special landscape types and fragile ecosystems of WNHSs make their conservation and management different from those of other landscape types [24], requiring more attention to the unification of ecological, social and cultural benefits. First of all, facing the contradiction between resource utilisation limitation caused by the fragile ecological environment and local development needs, reasonable water and soil conservation plans, rock desertification management, and pollution control in the buffer zone should be formulated. Scientific construction of forestry, grassland, agroforestry, water conservation, rural energy and infrastructure should be carried out to improve the quality of the ecological environment and agricultural production and living conditions in the buffer zone [80, 129]. To explore optimal regulation and control schemes in the process of experimental demonstrations. In addition, research on the localization dilemma of WNHSs under the impact of the New Crown epidemic should be strengthened, with a focus on the synergistic mechanisms and pathways for multiple livelihoods of residents in ecologically fragile areas and poor regions and the establishment of localized tourism development models aligned with the SDGs. Finally, education on heritage knowledge should be strengthened, emphasising the function of buffer zones, conservation priorities and knowledge on protecting karst aquifers. To guide residents to engage in human production and management activities such as tourism and agriculture rationally and enhance the effectiveness of karst WNH management.

Conclusions

This paper presents a systematic literature review of 188 articles retrieved from the WoS and CNKI. The main findings are as follows: (1) research on the development of buffer zone is generally on the rise, with China and Australia being the countries with the most publications. (2) Ecologically oriented research accounts for most of the research, with research on the resource conservation function of a buffer zone being the most common, mainly exploring the relationship between heritage site and its buffer zones in terms of resource integrity and regional connectivity. Studies on socio-ecological orientation are relatively rare. (3) The main landmark achievements are focused on theoretical research, technology and methods, model construction, benefit monitoring and evaluation, and experimental demonstration, among which theoretical research is the most numerous and technology research, model construction and experimental demonstration are relatively few.

This paper summarizes some critical scientific issues and outlooks on the research of WNHSs conservation and buffer zones development from the following aspects: the research on monitoring and evaluation system and technical system of conservation management based on OUV needs to be further strengthened, the research on the theoretical system of a buffer zone should be strengthened, more attention should be paid to exploring case studies and best practice guidelines, and the buffer zone planning adapted to its own heritage conservation and management system should be explored. How to achieve synergy between heritage site conservation and buffer zone socio-ecological system, innovate the model of synergistic development between heritage site conservation and buffer zone eco-industry, realize heritage zoning management and conservation through OUV characterization of heritage sites and identification and extraction of disturbing elements, promote stakeholder synergy and strengthen adaptive management, reveal the Spatio-temporal interaction between heritage sites and buffer zones from a socio-economic perspective should be addressed in the future study. The Karst landscape and fragile ecological environment make the conservation of karst WNHSs face more severe challenges. The contradiction between

local economic development and heritage conservation restrictions is more prominent. Future research needs to explore the benign development of the social-ecological system comprising the buffer zone's social, economic, ecological and cultural dimensions, focusing on the synergy between eco-industrial development and heritage site conservation in the buffer zone. The relationship between heritage environmental protection and community development should be emphasized. Research on stakeholder cooperation mechanisms should be deepened to strengthen buffer zone communities' adaptive and collaborative management. An assessment index system that highlights the OUV and unique attributes of karst WNHSs will be established. Conservation techniques and methods adapted to the fragile ecosystem characteristics of the karst epikarst will be explored, and pilot demonstrations will be carried out to clarify better the linkage and mutual feedback mechanisms between heritage sites and their buffer zones.

Abbreviations

WH: World heritage; WNH: World natural heritage; WHS: World heritage site; WNHS: World natural heritage site; CNKI: China national knowledge infrastructure; OUV: Outstanding universal value; WHC: World Heritage Committee; SLR: Systematic literature review; MAB: Man and the Biosphere Program; ICDP: Integrated Conservation and Development Project; IUCN: International Union for Conservation of Nature; GIS: Geographic information system; RS: Remote sensing; MCR: Minimum cost model; SDGs: Sustainable development goals; PSR: Pressure-state-response; MCDA: Multiple criteria decision making; EV: Ecosystem vitality; EO: Ecosystem organization; ER: Ecosystem resilience; ACM: Adaptive Collaborative Management.

Supplementary Information

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Additional file 1: Appendix S1. List of the 188 publications considered in literature review.

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Author contributions

JZ and KNX developed the concept of this work. JZ wrote the manuscript, KNX and ZJL reviewed the whole text and made comments and suggestions to improve it. LXH edited parts of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

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Declarations

Competing interests

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

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References

1. UNESCO. Managing natural world heritage (world heritage resource manual). Paris: UNESCO; 2012.
2. Hockings M, James R, Stolton S, Dudley N, Mathur V, Makombo J, et al. Enhancing our heritage toolkit: assessing management effectiveness of natural world heritage sites. Paris: UNESCO; 2008.
3. Yu KJ, Li B, Li DH. Ecological infrastructure approach for regional protection of natural and cultural heritage: a case study of Fujianhuigui Wuyi Mountain. City Plan Rev. 2008;10:88–91 **(in Chinese)**.
4. Gruber S. Convention concerning the protection of the world cultural and natural heritage. Paris: UNESCO 17th Session General Conference; 1972.
5. Kabat P, Bazelmans J, Van Dijk J, Herman PM, Van Oijen T, Pejrup M, et al. The Wadden Sea Region: towards a science for sustainable development. Ocean Coast Manag. 2012;68:4–17.
6. Albert MT, Richon M, Viñals MJ, Witcomb A. Community development through world heritage. Paris: UNESCO World Heritage Center; 2012.
7. Yang R. Suggestions on improving the management of natural and cultural heritage in China. Chin Landsc Archit. 2003;19(11):41–3 **(in Chinese)**.
8. Ebregt A, De Greve P. Buffer zones and their management: policy and best practices for terrestrial ecosystems in developing countries. Netherlands: International Agricultural Centre, Theme Studies Series; 2000. p. 64.
9. Trau AM, Ballard C, Wilson M. Bafa Zon: localising world heritage at Chief Roi Mata's Domain, Vanuatu. Int J Herit Stud. 2014;20(1):86–103.
10. Kruger SC, Rusworth IA, Oliver K. The verification of wilderness area boundaries as part of a buffer zone demarcation process: a case study from the uKhahlamba Drakensberg Park world heritage site. Washington: Ninth World Wilderness Congress Symposium, US Department of Agriculture; 2011. p. 190–5.
11. Yang R, Zhuang YB, Luo TT. Buffer zone and community issues of Mount Huangshan world heritage site, China. Davos: International Expert Meeting on World Heritage and Buffer Zones; 2008.
12. UNESCO. Operational guidelines for the implementation of the world heritage convention. Fuzhou: UNESCO World Heritage Centre (WHC); 2021. p. 34.
13. Martin O. World heritage and buffer zones: patrimoine mondial et zones tampons: International expert meeting on world heritage and buffer zones. Davos: UNESCO-World Heritage Centre; 2009.
14. Cun RH. Discussion on buffer zone and its management. World For Res. 2002;15(3):74–80 **(in Chinese)**.
15. WHC. Position paper, world heritage papers 25-world heritage and buffer zones. Paris: WHC; 2009.
16. Jia QL. Research on the planning and implementation mechanism of the world heritage buffer zone from the perspective of the scenic area in China [Doctoral dissertation]. Beijing: Tsinghua University; 2015. **(in Chinese)**.

17. Wang X. Research on the role of buffer zone in world heritage protection: take Liangzhu site for example. China Cult Herit. 2020;6:58–66 **(in Chinese)**.
18. Wiesmann U, Liechti K, Rist S. Between conservation and development. Mt Res Dev. 2005;25(2):128–38.
19. Maikhuri R, Nautiyal S, Rao K, Saxena K. Conservation policy-people conflicts: a case study from Nanda Devi Biosphere Reserve (a world heritage site), India. For Policy Econ. 2001;2(3–4):355–65.
20. Kala CP, Maikhuri RK. Mitigating people-park conflicts on resource use through ecotourism: a case of the Nanda Devi Biosphere Reserve, Indian Himalaya. J Mt Sci. 2011;8(1):87–95.
21. Zhuang YB, Yang R. Practices and trends analysis of community planning for Chinese natural world heritage properties. Landsc Archit. 2012;1:78–81 **(in Chinese)**.
22. Zhang RR, Brown S. Benefit or burden? The world heritage listing of libo karst, China. Int J Herit Stud. 2022;28(5):578–96.
23. Yuan DX, Jiang YJ, Shen LC, Pu JB, Xiao Q. Modern karstology. Beijing: Science Press; 2016. p. 99 **(in Chinese)**.
24. Ford D, Williams PD. Karst hydrogeology and geomorphology. Chichester: Wiley; 2007. p. 5.
25. Goldscheider N, Chen Z, Auler AS, Bakalowicz M, Broda S, Drew D, et al. Global distribution of carbonate rocks and Karst water resources. Hydrogeol J. 2020;28(5):1661–77.
26. Van Beynen PE, Van Beynen KM, Williams PW. Karst management in, Karst in UNESCO world heritage sites. New York: Springer; 2011. p. 472–5.
27. Yuan DX, Liu ZH, Lin YS, Shen JF, He SY, Xu SY, et al. China's Karst dynamic system. Beijing: Geological Publishing House; 2002. **(in Chinese)**.
28. Ford D, Williams PD. Karst hydrogeology and geomorphology. New Jersey: Wiley; 2013.
29. Mc Keever P, Narbonne G. Geological world heritage: a revised global framework for the application of criterion (viii) of the world heritage convention. Gland: IUCN; 2021.
30. Yuan DX. Rock desertification in the subtropical karst of South China. Z Geomorphol Suppl. 1997;108:81–90.
31. Xiong KN, Li P, Zhou ZF, An YL. Remote sensing of Karst stony desertification-A typical research of GIS: Taking Guizhou Province as an example. Beijing: Geology Publishing House; 2002. p. 18 **(in Chinese)**.
32. Wang KL, Zhang CH, Chen HS, Yue YM, Zhang W, Zhang MY, et al. Karst landscapes of China: patterns, ecosystem processes and services. Landsc Ecol. 2019;34(12):2743–63.
33. Kranjc A. Dinaric Karst: an example of deforestation and desertification of limestone terrain. V: deforestation around the world. United States: InTech; 2012. p. 73–94.
34. Clements R, Sodhi NS, Schilthuizen M, Ng PK. Limestone karsts of Southeast Asia: imperiled arks of biodiversity. Bioscience. 2006;56(9):733–42.
35. Sunkar A. Deforestation and rocky desertification processes in Gunung Sewu Karst landscape (proses deforestasi dan rocky desertifcation di landskap Karst Gunung Sewu). Media Konserv. 2008. https://doi.org/10.29244/medkon.13.3.%25p.
36. Febles González J, Vega Carreño M, Amaral Sobrinho N, Tolón Becerra A, Lastra BX. Soil loss from erosion in the next 50 years in Karst regions of Mayabeque Province, Cuba. Land Degrad Dev. 2014;25(6):573–80.
37. Jiang ZC, Lian YQ, Qin XQ. Rocky desertification in Southwest China: impacts, causes, and restoration. Earth Sci Rev. 2014;132:1–12.
38. Xiong KN, Yang C. Scientific Development for a Stronger heritage-conservation and development of China's world natural heritage. China Wkly. 2018;6:26–7 **(in Chinese)**.
39. Huo SJ, Sun JH, Sun KQ. An analysis on resource management of geoheritage: a case study of South China Karst. Adv Mater Res. 2012. https://doi.org/10.4028/www.scientific.net/AMR.518-523.5909.
40. Hong SY. Factors affecting Karst world natural heritage properties in the world and the threat intensity [Masteral dissertation]. Guiyang: Guizhou Normal University; 2020. **(in Chinese)**.
41. Osipova E, Emslie SM, Osti M, Murai M, Åberg U, Shadie P. IUCN world heritage outlook 3: a conservation assessment of all natural world heritage sites. Gland: IUCN; 2020.
42. Booth A, Sutton A, Clowes M, Martyn-St JM. Systematic approaches to a successful literature review. Thousand Oaks: Sage Publications; 2012.
43. Habibi S, Valladares OP, Peña DM. Sustainability performance by ten representative intelligent Façade technologies: a systematic review. Sustain Energy Technol Assess. 2022;52: 102001.
44. Liu Y, Dupre K, Jin X. A systematic review of literature on contested heritage. Curr Issue Tour. 2021;24(4):442–65.
45. Heinsch M, Cootes H, Wells H, Tickner C, Wilson J, Sultani G, et al. Supporting friends and family of adults with a primary brain tumour: a systematic review. Health Soc Care Commun. 2022;30(3):869–87.
46. Liu XM, Su H. Exploration of development route for characteristic towns from the perspective of the conservation and uilization of world natural heritage: taking the programming practice of the shigu characteristic town in Lijiang as an example. Dev Small Cities Towns. 2020;6:36–44 **(in Chinese)**.
47. Yang Q, Tian YH, Tong YL. The mechanism of community participation in protecting and developing world natural heritage sites: taking Langshan scenic area of Hunan province as an example. Econ Geogr. 2020;2:233–40 **(in Chinese)**.
48. Su MM, Wall G. Community participation in tourism at a world heritage site: Mutianyu Great Wall, Beijing, China. Int J Tour Res. 2014;16(2):146–56.
49. Liu Q, Yang ZP, Wang F. Conservation policy-community conflicts: a case study from Bogda Nature Reserve, China. Sustainability. 2017;9(8):1291.
50. Chen YH, Qing F, Chen YD. An overview of world cultura and natura heritage. Study Nat Cult Herit. 2004;2(5):64–73 **(in Chinese)**.
51. Zhou NX, Huang ZF, Lin ZS. Changes in landscape spatial pattern in Wulingyuan world heritage site as a tourism destination. Geogr Res. 2008;27(4):734–44 **(in Chinese)**.
52. Allan JR, Venter O, Maxwell S, Bertzky B, Jones K, Shi YC, et al. Recent increases in human pressure and forest loss threaten many natural world heritage sites. Biol Cons. 2017;206:47–55.
53. Heslinga JH, Groote P, Vanclay F. Understanding the historical institutional context by using content analysis of local policy and planning documents: assessing the interactions between tourism and landscape on the Island of Terschelling in the Wadden Sea Region. Tour Manag. 2018;66:180–90.
54. Kirkpatrick J. Ecotourism, local and indigenous people, and the conservation of the Tasmanian Wilderness World Heritage Area. J R Soc N Z. 2001;31(4):819–29.
55. Bego F, Malltezi J. Ecotourism opportunities and challenges in Butrint, Albania, a unique UNESCO and Ramsar site. J Coast Res. 2011;61(10061):150–7.
56. Digun-Aweto O, Fawole O, Saayman M. The effect of distance on community participation in ecotourism and conservation at Okomu National Park Nigeria. GeoJournal. 2019;84(5):1337–51.
57. Ma J. Research on the coordination of biodiversity conservation and heritage tourism development under the background of ecological and environmental threshold: a case study of Wulingyuan world natural heritage [Doctoral dissertation]. Changsha: Hunan Normal University; 2016. **(in Chinese)**.
58. Devine-Wright P, Howes Y. Disruption to place attachment and the protection of restorative environments: a wind energy case study. J Environ Psychol. 2010;30(3):271–80.
59. Halpenny EA. Pro-environmental behaviours and park visitors: the effect of place attachment. J Environ Psychol. 2010;30(4):409–21.
60. Stræde S, Treue T. Beyond buffer zone protection: a comparative study of park and buffer zone products' importance to villagers living inside Royal Chitwan National Park and to villagers living in its buffer zone. J Environ Manag. 2006;78(3):251–67.
61. Digun-Aweto O, Oladele A. Nikorogha community perceptions on tourism potentials of River Osse, Edo State, Nigeria. J Food Agric Environ. 2018;16(3/4):56–60.
62. Olya HG, Shahmirzdi EK, Alipour H. Pro-tourism and anti-tourism community groups at a world heritage site in Turkey. Curr Issue Tour. 2019;22(7):763–85.
63. Olya HG, Alipour H, Gavilyan Y. Different voices from community groups to support sustainable tourism development at Iranian world heritage sites: evidence from Bisotun. J Sustain Tour. 2018;26(10):1728–48.
64. Zhang YL, Xiao X, Zheng CH, Xue L, Guo YR, Wu QT. Is tourism participation in protected areas the best livelihood strategy from the perspective of community development and environmental protection? J Sustain Tour. 2020;28(4):587–605.

65. Akbar I, Yang ZP, Han F, Kanat G. The influence of negative political environment on sustainable tourism: a study of Aksu-Jabagly world heritage site, Kazakhstan. Sustainability. 2020;12(1):143.
66. Rastegar R, Zarezadeh Z, Gretzel U. World heritage and social justice: insights from the inscription of Yazd, Iran. J Sustain Tour. 2021;29(2–3):521–40.
67. Goldberg JA, Marshall NA, Birtles A, Case P, Curnock MI, Gurney GG. On the relationship between attitudes and environmental behaviors of key Great Barrier Reef user groups. Ecol Soc. 2018. https://doi.org/10.5751/ES-10048-230219.
68. Wang Z, Yang ZP, Shi H, Han F, Liu Q, Qi JW, et al. Ecosystem health assessment of world natural heritage sites based on remote sensing and field sampling verification: Bayanbulak as case study. Sustainability. 2020;12(7):2610.
69. Ha SC, Yang ZP. Evaluation for landscape aesthetic value of the natural world heritage site. Environ Monit Assess. 2019;191(8):1–20.
70. Zhang YL, Xiao X, Cao RB, Zheng CH, Guo YR, Gong WX, et al. How important is community participation to eco-environmental conservation in protected areas? From the perspective of predicting locals' pro-environmental behaviours. Sci Total Environ. 2020;739: 139889.
71. Ma J. An evaluation model and analysis with thekey elements of impact in world naturalheritage sites based on remote sensing [Doctoral dissertation]. Wuhan: Wuhan University; 2019. **(in Chinese)**.
72. Duan J, Li YH, Huang J. An assessment of conservation effects in Shilin Karst of South China Karst. Environ Earth Sci. 2013;68(3):821–32.
73. Wang C, Wang G, Guo ZR, Dai LJ, Liu HY, Li YF, et al. Effects of land-use change on the distribution of the wintering red-crowned crane (*Grus japonensis*) in the coastal area of northern Jiangsu Province, China. Land Use Policy. 2020;90: 104269.
74. Zhang LB, Wang W, Wu CX, Xiong YJ. Quantitative method of visual landscape EIA based on GIS: a case of the Ming Tombs. Acta Ecol Sin. 2008;6:2784–91 **(in Chinese)**.
75. Ye H, Yang ZP, Xu XL. Ecological corridors analysis based on MSPA and MCR model—a case study of the Tomur world natural heritage region. Sustainability. 2020;12(3):959.
76. Shi H, Shi TG, Yang ZP, Wang Z, Han F, Wang CR. Effect of roads on ecological corridors used for wildlife movement in a natural heritage site. Sustainability. 2018;10(8):2725.
77. Garrard R, Fielke S. Blockchain for trustworthy provenances: a case study in the Australian aquaculture industry. Technol Soc. 2020;62: 101298.
78. Scheyvens R, Biddulph R. Inclusive tourism development. Tour Geogr. 2018;20(4):589–609.
79. Dube K, Nhamo G. Sustainable development goals localization in the tourism sector: lessons from Grootbos private nature reserve, South Africa. GeoJournal. 2020;2:1–18.
80. Xiong KN, Li GC, Wang LY. Study on the protection and sustainable development of South China Karst Libo world natural heritage site. Chin Landsc Archit. 2012;28(8):66–71 **(in Chinese)**.
81. Sturiale L, Scuderi A, Timpanaro G, Matarazzo B. Sustainable use and conservation of the environmental resources of the etna park (UNESCO heritage): evaluation model supporting sustainable local development strategies. Sustainability. 2020;12(4):1453.
82. Sharma RC, Bisht Y, Sharma R, Singh D. Gharats (watermills): indigenous device for sustainable development of renewable hydro-energy in Uttrakhand Himalayas. Renew Energy. 2008;33(10):2199–206.
83. Nakamura F, Komiyama E. A challenge to dam improvement for the protection of both salmon and human livelihood in Shiretoko, Japan's third natural heritage site. Landsc Ecol Eng. 2010;6(1):143–52.
84. Wang YL. Multiple values Identification basedResearch on the community planning in the national park of China [Doctoral dissertation]. Beijing: Tsinghua University; 2014. **(in Chinese)**.
85. Shen YP, Lin CH, Wang H, Huang M. Establishment of supervision and monitoring system for the Danxia world natural heritage site in Taining. J Anhui Agric Sci. 2012;32(40):15746–8 **(in Chinese)**.
86. Wang ZG, Du XH. Monitoring natural world heritage sites: optimization of the monitoring system in Bogda with GIS-based multi-criteria decision analysis. Environ Monit Assess. 2016;188(7):1–17.
87. Liu XY. The study of Monitoring and Evaluation System of World Natural Heritage-with a special reference to the Shibing site [Mastera dissertation]. Guiyang: Guizhou Normal University; 2018. **(in Chinese)**.
88. Costanza R, D'Arge R, De Groot R, Farber S, Grasso M, Hannon B, et al. The value of the world's ecosystem services and natural capital. Nature. 1997;387(6630):253–60.
89. Kreuter UP, Harris HG, Matlock MD, Lacey RE. Change in ecosystem service values in the San Antonio area, Texas. Ecol Econ. 2001;39(3):333–46.
90. Qian C, Sasaki N, Shivakoti G, Zhang YJ. Effective governance in tourism development—an analysis of local perception in the Huangshan mountain area. Tour Manag Perspect. 2016;20:112–23.
91. Fu YY, Xiong KN, Zhang ZZ. Ecosystem services and ecological compensation of world heritage: a literature review. J Nat Conserv. 2021. https://doi.org/10.1016/j.jnc.2021.125968.
92. Duan J, Li YH. An assessment of ecological capital and compensation for Yunnan Shilin world heritage site. Resour Sci. 2010;32(4):752–60 **(in Chinese)**.
93. Liu Q, Yang ZP, Han F, Shi H, Wang Z, Chen XD. Ecological environment assessment in world natural heritage site based on remote-sensing data. A case study from the Bayinbuluke. Sustainability. 2019;11(22):6385.
94. Cumming GS, Redman CL. Scale mismatches in social-ecological systems: causes, consequences, and solutions. Ecol Soc. 2006;11(1):14.
95. Anderies JM, Janssen MA, Ostrom E. A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecol Soc. 2004;9(1):20.
96. Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T, Rockström J. Resilience thinking: Integrating resilience, adaptability and transformability. Ecol Soc. 2010. https://doi.org/10.5751/ES-03610-150420.
97. Conradin K, Hammer T. Making the most of world natural heritage-linking conservation and sustainable regional development? Sustainability. 2016;8(4):323.
98. Alazaizeh MM, Ababneh A, Jamaliah MM. Preservation vs use: understanding tourism stakeholders' value perceptions toward Petra Archaeological Park. J Tour Cult Chang. 2020;18(3):252–66.
99. Cumming GS, Allen CR, Ban NC, Biggs D, Biggs HC, Cumming DH, et al. Understanding protected area resilience: a multi-scale, social-ecological approach. Ecol Appl. 2015;25(2):299–319.
100. Heslinga JH, Groote P, Vanclay F. Using a social-ecological systems perspective to understand tourism and landscape interactions in coastal areas. J Tour Futures. 2017. https://doi.org/10.1108/JTF-10-2015-0047.
101. Zhang CZ, Jiang QY. Critical heritage studies: a literature review and reflection. Study Nat Cult Herit. 2021;6(1):81–91 **(in Chinese)**.
102. Li YY. Some considerations about the fringe characteristics of China's world heritage sites. Tour Trib. 2005;20(3):23–32 **(in Chinese)**.
103. Yuan DX. Discussion on karst environment system. Carsol Sin. 1988;3:9–16 **(in Chinese)**.
104. Parise M. A procedure for evaluating the susceptibility to natural and anthropogenic sinkholes. Georisk. 2015;9(4):272–85.
105. Stevanović Z. Karst aquifers-characterization and engineering. German: Springer Publications; 2015.
106. Parise M, Gabrovsek F, Kaufmann G, Ravbar N. Recent advances in karst research: from theory to fieldwork and applications. Geol Soc Lond Spec Publ. 2018;466(1):1–24.
107. UNESCO WHC. State of conservation information system. Paris: UNESCO WHC; 1979.
108. Pedersen A. Managing tourism at world heritage sites: a practical manual for world heritage site managers. Managing World Heritage Sites. Paris: UNESCO WHC; 2002.
109. Cai YL. Socio-economic perspectives on ecological issues. Adv Earth Sci. 2020;35(7):742–9 **(in Chinese)**.
110. Su MM, Wall G, Xu K. Tourism-induced livelihood changes at mount Sanqingshan world heritage site, China. Environ Manag. 2016;57(5):1024–40.
111. Zhang CZ. Ecotourism Based on world natural heritage sites: the role and status of communities. Tour Trib. 2021;36(9):7–8 **(in Chinese)**.
112. Zen IS, Saleh M, Afrizal T, Yaumidin UK, Titisari PW, Hendrayani Y. Quo vadis development: assessing the livelihood of indigenous people's communities in Malaysia and the potential for community-based conservation effort. Environ Dev Sustain. 2021;23(4):6502–23.
113. Zhang J, Xiong KN, Liu ZJ, He LX. Research progress and knowledge system of world heritage tourism: a bibliometric analysis. Herit Sci. 2022;10(1):1–18.

114. Wang Y, Zhuang YB, Yang Y. Research on optimization of community planning in national parks of China: a case study of jiuzhaigou valley. Chin Landsc Archit. 2017;33(8):24–9 **(in Chinese)**.
115. Xu R, Wu Y, Shi J. Factors influencing the residents' subjective well-being from the perspective of tourism perception: an empirical study on Jiuzhaigou National nature reserve. J Nanjing Tech Univ. 2017;16(4):104–14 **(in Chinese)**.
116. Furtado F. Monitoring world heritage. City Time. 2004;1(2):6.
117. Zhang DS, Hu LH. Identification of OUV characterization indexes of world species diversity natural heritage. Chin Landsc Archit. 2019;35(3):97–101 **(in Chinese)**.
118. Osipova E, Shadie P, Zwahlen C, Osti M, Shi Y, Kormos C, et al. IUCN world heritage outlook 2: a conservation assessment of all natural world heritage sites. Gland: IUCN; 2017. p. 92.
119. Fang RN, Zhang J, Xiong KN, Woo KS, Zhang N. Influencing factors of residents' perception of responsibilities for heritage conservation in world heritage buffer zone: a case study of Libo Karst. Sustainability. 2021;13(18):10233.
120. Ma XM. Approaches to effective integration between rural vitalization and poverty alleviation: A Case study of the desertification areas of Yunnan, Guangxi and Guizhou. J Yunnan Norm Univ. 2020;52(3):84–91 **(in Chinese)**.
121. Luo X, Xiong KN, Zhang J, Chen D. A Study on optimal agroforestry planting patterns in the Buffer zone of world natural heritage sites. Sustainability. 2021;13(20):11544.
122. Xiong KN, Xiao J, Zhu DY. Research progress of mixed agroforestry ecosystem services. Acta Ecol Sin. 2022;42(3):851–61 **(in Chinese)**.
123. Nair PR, Kumar BM, Nair VD. An introduction to agroforestry-four decades of scientific developments. Cham: Springer International Publishing; 2021. p. 21–8.
124. Zen IS, Purwanto Y, Titisari PW, Hendrayani Y, Ariffin SAIBS. Take stock Bali Island as the potential of biosphere reserve site. IOP conference series. Earth Environ Sci. 2019;298(1):012021.
125. Nian SF, Zhang HL, Mao L, Zhao WJ, Zhang H, Lu YH, et al. How outstanding universal value, service quality and place attachment influences tourist intention towards world heritage conservation: a case study of Mount Sanqingshan National Park, China. Sustainability. 2019;11(12):3321.
126. Zhang J, He LX, Xiong KN, Xiao J, Yang Y. Spatial distribution pattern and influencing factors of intangible cultural heritage in karst areas: a case study of Guizhou Province. Resour Environ Yangtze Basin. 2021;30(5):1055–68 **(in Chinese)**.
127. Xiang B, Wen T, Guo H, Liu HC, Liu Z. Research on platform design scheme of natural heritage monitoring and protection management based on spatiotemporal data fusion. Chin Landsc Archit. 2020;36(11):95–9 **(in Chinese)**.
128. Cherrington EA, Griffin RE, Anderson ER, Sandoval BEH, Flores-Anderson AI, Muench RE, et al. Use of public Earth observation data for tracking progress in sustainable management of coastal forest ecosystems in Belize, Central America. Remote Sens Environ. 2020;245: 111798.
129. Gillieson D, Gunn J, Auler A, Bolger T. Guidelines for cave and Karst protection. Gland: IUCN; 2022.

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