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Indigenous knowledge and natural infrastructure resilience to climate change in developing countries: a bibliometric analysis

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It is widely recognized that natural infrastructure plays a pivotal role in sustaining Indigenous communities globally. Natural infrastructure encompasses ecosystems and environments that either occur naturally or have been deliberately altered through human intervention to provide multiple benefits for the environment and human wellbeing. While there has been extensive scholarly discussion regarding the importance of natural infrastructure in securing the livelihoods of Indigenous populations in developing nations and passing down their critical knowledge from one generation to another, the literature has not explicitly analyzed how Indigenous knowledge has facilitated the protection and conservation of natural infrastructure. Also, there has been limited analysis of the economic benefits of their conservation efforts. This article, utilizing bibliometric analysis as its methodological approach, aims to unpack how Indigenous knowledge has facilitated the protection and conservation of natural infrastructure. Several key themes emerged from this bibliometric analysis, including Indigenous governance strategies aimed at mitigating deforestation and addressing climate change and collective action taken to preserve natural infrastructure. Among others, a positive economic consequence of all three themes lies in their ability to improve the livelihood of Indigenous peoples by creating opportunities to receive payment for ecosystem services.

KEYWORDS

natural infrastructure, bibliometric analysis, developing countries, Indigenous knowledge systems, natural resource conservation

1 Introduction

Globally, there is substantial evidence to suggest that climate change is not an abstract entity but a lived reality (Simatele and Simatele, 2015; Donkor et al., 2019; Droulia and Charalampopoulos, 2021; Ebhuoma and Leonard, 2021). In 2023, for example, the provinces of Nova Scotia and Quebec, in Canada, experienced severe flooding, costing insured damage worth over C$170 million (US$125.5 million) in Nova Scotia alone (Insured bureau of Canada, 2023). Also, Canada is currently experiencing its worst wildfire season on record. All 13 provinces and territories in Canada have been affected, with large wildfire outbreaks in Alberta, British Columbia, Nova Scotia, Quebec, and Northern Territories. In August 2023, the entire capital city of Yellowknife, Northern Territories, was forced to evacuate due to fast encroaching wildfires (Schneyer, 2023). A somewhat similar occurrence has been witnessed in some European countries. Major wildfires burning for days in north-eastern Greece and on the fringes of the capital, Athens, have incinerated more tracts of forest and forced additional evacuations as firefighters struggled against strong winds and arid conditions (Becatoros, 2023). Also, Spain's Tenerife

and Turkey's north-western Canakkale province have been adversely affected by wildfires, although to a considerably lesser degree than Greece. Developing countries have not been spared from the devastating events of climate change.

The literature indicates that developing countries in Asia and Sub-Saharan Africa are highly susceptible to the adverse impacts of climate change due to their geographical, socioeconomic, and environmental characteristics (Knox et al., 2012; Kilroy, 2014; Aryal et al., 2020; Rao et al., 2020). Both regions encompass diverse ecosystems, including forests, grasslands, deserts, and coastal areas, all susceptible to climate variability and change. In Sub-Saharan Africa (SSA), climate change manifests through various phenomena such as rising temperatures, increasing droughts, sea-level rise, erratic rainfall patterns, and heavy rainfall resulting in flooding (Musavengane, 2019; Mavhura et al., 2021; Tantoh et al., 2022). Like their counterparts in Asia, local and Indigenous peoples are often the worst affected by climate change in SSA partly because of limited support systems and the fact that they rely extensively on the natural infrastructure to obtain their livelihoods (Ebhuoma and Simatele, 2019; Lawal et al., 2022; Nyadzi et al., 2022).

Natural infrastructure refers to an ecosystem or environment that occurs naturally or has been intentionally modified by human management to yield multiple advantages for both the environment and human wellbeing. It represents an actively controlled facet of the natural world, with the primary objective of delivering significant benefits, including but not limited to climate resilience, access to clean water, and the preservation of biodiversity [International Institute for Sustainable Development (IISD, 2023)]. This concept entails a deliberate and strategic approach to overseeing and preserving natural landscapes such as forests, wetlands, rivers, and coastal regions. To be classified as natural infrastructure, a specific region or system must fulfill three distinct criteria: first, it must possess a natural character or have been adapted to mimic natural conditions. For instance, this classification encompasses naturally existing wetlands and constructed wetlands, or floating treatment wetlands designed to replicate the functions of their natural counterparts. Second, it must be subject to targeted human intervention or management. Natural processes or systems that operate without deliberate human involvement do not fall under this category. This active management component distinguishes natural infrastructure, making it more beneficial than analogous natural systems found in neighboring areas or similar contexts. Third, it should provide augmented benefits, such as bolstering communities' resilience to climate-related challenges, improving water quality, and effectively retaining floodwaters (IISD, 2023).

The literature acknowledges that Indigenous peoples in developing countries such as Bangladesh, China, Thailand, Ghana, Nigeria, and Tanzania engage in ecological restoration and sustainable land conservation to ensure the overall health of the natural infrastructure that caters to their livelihood and spiritual wellbeing are protected (Msuya, 2007; Luo et al., 2009; Jimoh et al., 2012; Mukul and Saha, 2017; Chunhabunyatip et al., 2018; Nyadzi et al., 2022). These efforts ensure that Indigenous people's identities and knowledge systems are protected and passed on from generation to generation. Several pieces of literature have underscored the role of Indigenous knowledge systems (IKS) in facilitating climate change adaptation and ecosystem services protection in developing countries (Orlove et al., 2010). IKS refers to knowledge rooted in cultural identity, experiential with real-life scenarios and passed on from generation to generation, usually by word of mouth and repetitive engagements (Orlove et al., 2010). What is missing in the literature on IKS, however, is an article that underlines the mechanisms through which IKS continues to facilitate the protection of natural infrastructure in the face of a rapidly changing climate and a critical discussion of the economic implications for the continued protection of natural infrastructure.

Analyzing the economic implications in studies on Indigenous knowledge systems and the conservation of the natural infrastructure cannot be ignored based on three premises. Firstly, understanding the economic benefits of incorporating Indigenous knowledge into conservation efforts can reinforce the notion that its contribution to sustainable development cannot be overemphasized as it can promote policies and initiatives that prioritize the wellbeing of local communities while safeguarding the environment. Secondly, economic analysis of IKS to natural infrastructure conservation may provide valuable insights into the cost-effectiveness of different conservation strategies by identifying which approaches may yield the highest return on investment regarding both ecological outcomes and community wellbeing. Thirdly, decision-makers, including government agencies, non-governmental organizations (NGOs), and international organizations, can make more informed choices when they understand the economic value of Indigenous knowledge in natural infrastructure conservation. This can generate more significant support for conservation projects and collaboration among different parties. Lastly, economic analyses of successful Indigenous knowledge-based conservation projects can serve as models for replication in other regions, contributing to the scalability and replication of effective strategies.

In light of the above, a bibliometric analysis of existing literature is conducted to unpack how Indigenous knowledge has facilitated the protection and conservation of natural infrastructure necessary for the continuity of livelihood activities in developing countries.

2 Methodology

A bibliometric analysis was conducted to analyze how Indigenous knowledge has facilitated the protection and conservation of natural infrastructure in developing countries. Bibliometric analysis techniques such as term co-occurrence and thematic analysis are increasingly used to provide overviews of the progress and state of knowledge in different research areas (Van Eck and Waltman, 2022). Additionally, this technique proved especially useful for handling vast amounts of data reported in academic papers that may be challenging to review using other methods, such as systematic reviews. The input data utilized for term co-occurrence analysis was sourced from Web of Science, a highly regarded database renowned for its meticulous indexing of top-tier scholarly publications. To retrieve relevant publications, a broad-based search string was developed using a combination of different variants of terms related to rainforests, climate change, and depletion. The search string was developed iteratively. In other words, an initial search string was tested, and new terms were added to it after checking the

initially retrieved documents. This was continued until adding new terms to the string did not result in the retrieval of new relevant publications. The final search string used is as follows: [("traditional knowledge" OR "local knowledge" OR "indigenous knowledge" OR "indigenous knowledge systems") AND ("infrastructure" OR "forest protection" OR "culture infrastructure" OR "natural infrastructure" OR "natural environment" OR "asset protection" OR "green infrastructure") AND ("developing countries" OR "Africa" OR "Asia")].

On August 5, 2023, the search string was applied to search within the article title, abstract, and keywords in the indexed publications, regardless of their publication date. The search yielded 438 articles. After excluding the review articles, 142 articles were selected for further review. It is noteworthy to mention that articles dated 2009 and earlier were omitted, resulting in 126 articles which were then exported to Zotero for analysis in VOS viewer. The primary reason for selecting articles from 2010 onwards was to explore how relevant the concept of Indigenous knowledge has been in the last decade in terms of protecting and conserving natural infrastructure owing to the misconception of attributing Indigenous knowledge as archaic (Mapara, 2009). The resulting 142 articles underwent screening to ensure their suitability to meet the research objective. After narrowing down the selection to articles specifically from developing countries in Africa and Asia, and reading the abstracts and skimming through the articles, 53 articles were chosen for the final analysis, including studies conducted in South America (15 articles). Following this, a complete record and citation data of the selected articles to be used as input data for term co-occurrence analysis was downloaded and saved in Zotero, a referencing software. VOSviewer was chosen for the bibliometric analysis since it has a user-friendly interface and offers term co-occurrence outputs suitable for thematic analysis (van Eck and Waltman, 2010). The software can be used to do various analyses such as term co-occurrence analysis, co-citation analysis, and bibliographic coupling. This paper used the term co-occurrence since the aim is to determine the significant thematic areas addressed in the existing literature. The output of this analysis is a schematic where nodes represent key terms and links, indicating how they are connected to each other. The node size is proportional to the number of times a term has co-occurred with other terms in the network. Also, link width is proportional to the strength of the connections between terms. Terms that are strongly linked to each other form thematic research clusters that are shown in different colors on the term map (Figure 1). For more details on the processes for term co-occurrence analysis, kindly refer to the VOSviewer manual by Van Eck and Waltman (2022).

3 Results

3.1 Theme 1 (red cluster)— Conservation and management of natural infrastructure

Indigenous knowledge plays a crucial role in conserving and managing natural infrastructure and sustainable land-use practices in developing countries. Indigenous peoples' conservation and management techniques of natural infrastructure are often embedded in their cultural identities and spirituality (Chunhabunyatip et al., 2018; Lawal et al., 2022; Hakim et al., 2023). Indigenous peoples often possess an intricate understanding of the interconnectedness of various components of their ecosystems. This knowledge encompasses not only the biological aspects but also the cultural, spiritual, and social dimensions of the environment, as Indigenous peoples often see themselves as one with their natural infrastructure. The spiritual beliefs held by indigenous people have been a significant factor that has contributed significantly to natural infrastructure conservation in developing countries. In countries like Vietnam, Ghana, Thailand, and Indonesia, to mention but a few, Indigenous people's management and conservation of natural resources was underpinned by the belief that the spirits of their ancestors and gods reside in the forests. Consequently, the forests—deemed sacred or "holy" places—were respected and maintained by Indigenous peoples as abuse of the forest ecosystems may attract retribution from spiritual deities (Asante et al., 2017; Nguyen and Ross, 2017; Chunhabunyatip et al., 2018; Usop and Rajiani, 2021). To further buttress this point, Nguyen and Ross (2017, p. 143) stated:

> "In Dao culture [Vietnam], there are three elements that link resident communities to the natural and Spirit worlds. Dao people engage with Water Spirits and Forest Spirits through their ceremonies. They believe that there is a close relationship between water and the forest. Any activities that violate forest and water sources will impact on the Spirit world and will be penalized."

These Indigenous belief systems that revolve around assigning supernatural abilities to specific elements of the natural world, designating them as the abode of deities, appear to have played a substantial role in safeguarding and preserving vital natural resources like forests, water bodies, soil fertility, and wildlife from excessive use and misuse. It is, therefore, not surprising that scholars recommend that countries once rich in biodiversity with healthy conservation status and currently experiencing increasing natural resource degradation partly due to low public compliance with the existing state-based environmental regulations should adopt Indigenous and traditional norms and practices governing natural infrastructure as they achieved better public compliance during the pre-colonial era and even in contemporary times (e.g., Etemire and Sobere, 2020).

It is worth pointing out that Indigenous peoples have developed adaptive strategies that are tailored to the specific ecological conditions of their regions, another crucial factor responsible for the conservation and management of their natural infrastructure (e.g., see Nyong et al., 2007; Motsumi et al., 2012; Nkomwa et al., 2014; Ebhuoma and Simatele, 2019). These adaptive strategies—often finely attuned to natural variability and environmental changes—include insights about soil fertility management and crop diversification, contributing to sustainable land-use practices that can mitigate climate change and other environmental stressors (Mugambiwa, 2018). As highlighted in various Asian and SSA studies, Indigenous agricultural practices often prioritize water conservation and the integration of different crops and livestock in farmland to scale up soil fertility (e.g., Gupta et al., 2012; Gowing et al., 2020). In addition, soil conservation strategies

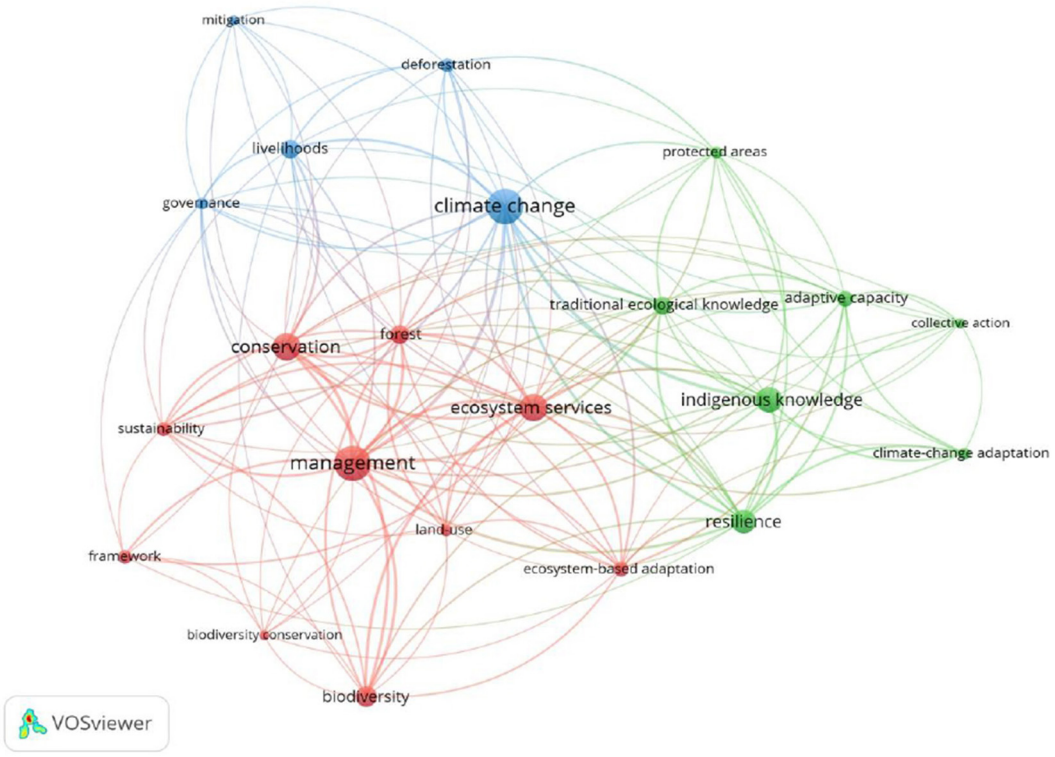

FIGURE 1
A bibliometric analysis showing themes related to Indigenous people protection and conservation of natural infrastructure in developing countries. The red cluster focuses in the role of management in conserving natural infrastructure. The blue cluster underscores the role of governance in protecting natural infrastructure within indigenous communities. The green cluster highlights the importance of weaving Indigenous knowledge and collective action, crucial for facilitating climate change adaptation and building resilience needed to protect natural infrastructure.

like agroforestry, terracing, rotational grazing, controlled burning, and crop rotation maintain soil health and prevent erosion, contributing to sustainable land-use practices that can serve as models for modern agricultural approaches in facilitating the conservation and management of the natural infrastructure that Indigenous people rely upon for their livelihoods (Gupta et al., 2012; Gowing et al., 2020). By preserving diverse natural infrastructure, Indigenous knowledge supports long-term ecosystem stability by avoiding overexploitation of natural resources. This is crucial to preserving their cultural heritage and promoting a strong sense of environmental stewardship.

3.2 Theme 2 (blue cluster)—Indigenous governance to mitigate deforestation and climate change

Indigenous and traditional governance systems—agreements in Indigenous and local communities that are subject to moral enforcement systems—in developing countries often play a significant role in governing the natural infrastructure to mitigate deforestation and climate change while supporting Indigenous people in obtaining their livelihoods. Indigenous and traditional forms of governance are deeply rooted in the cultural, spiritual, and ecological knowledge of Indigenous communities, and they often offer sustainable approaches that balance conservation with the wellbeing of the people. These governance structures guide how resources, such as timber, non-timber forest products, and wildlife, are utilized and harvested (Erinosho, 2015; Asante et al., 2017; Chunhabunyatip et al., 2018; Usop and Rajiani, 2021). Indigenous communities often have established rules and practices that regulate when, where, and how certain resources can be used. This sustainable approach ensures that resources are not overexploited, preserving them for future generations and maintaining a consistent source of livelihood. To substantiate this viewpoint, writing from an African context, Erinosho (2015) asserted:

> "From time immemorial, local or traditional communities have established rules for the control of, [and] access to, including the use of natural resources. For example, they prohibited the cutting of some trees [and even the killing of some animals] that were of spiritual importance; devised methods for gathering certain fruits and other by-products of trees; restricted access to sacred groves and mountains; designated certain periods of the year for fishing and hunting; and established use and access rules for water resource."

Table 1 highlights how spiritual beliefs and taboos govern how Indigenous peoples in developing countries have been able to conserve forest resources and other natural infrastructure. As Table 1 shows, Indigenous spiritual beliefs often prioritize

the conservation of biodiversity and the protection of sacred sites and culturally significant species, which ultimately helps to mitigate climate change through carbon sequestration (e.g., see Dar et al., 2019; Maru et al., 2023). This approach is aligned with the traditional belief that a balanced ecosystem is essential for their livelihoods. By protecting biodiversity, indigenous communities ensure the availability of resources like medicinal plants, food sources, and materials for crafts, which are essential for their wellbeing. A benefit of the Indigenous spiritual beliefs in preserving natural infrastructure is curbing deforestation. The ripple effect of this can be seen in how Indigenous peoples in Asia and African countries have benefited from reducing emissions from deforestation and forest degradation, plus the sustainable management of forests and the conservation and enhancement of forest carbon stocks (REDD+) projects (Lemaitre, 2011; Aguilar-Støen, 2017). In addition, Indigenous peoples have received payments for ecosystem services as part of the global climate change mitigation efforts in line with their efforts to tackle deforestation (Ravikumar et al., 2023). Through Indigenous governance—hinged on spiritual beliefs—in facilitating natural infrastructure protection, some Indigenous leaders were able to negotiate fair compensation for the role of forests in carbon sequestration, providing a supplementary source of income for Indigenous peoples.

As earlier highlighted, Indigenous and traditional governance of natural resources often stifle deforestation by promoting community-based forest management, which in turn helps to mitigate climate change through carbon sequestration. Indigenous peoples and local communities hold at least 17%, or 293,061 million metric tons (Mt) of the total carbon stored (Viswanathan, 2023). Indigenous governance of natural resources allows Indigenous people to have direct control over resource use and management decisions, ensuring that their livelihood needs are met while preventing deforestation and degradation of their natural resources. Another vital advantage Indigenous governance of the natural infrastructure presents for Indigenous peoples, courtesy of their cultural heritage and unique ecosystems, is their ability to engage in ecotourism or cultural tourism. As acknowledged by Johnston (2000), a significant attribute to the success of ecotourism in Indigenous communities depends on seeking the approval of Indigenous community leaders to ensure that it aligns with the community's values, sustains the environment, and benefits residents economically and culturally. Studies in Zimbabwe, South Africa, India, and Thailand, for example, have shown the enormous financial benefits ecotourism has brought to Indigenous people (Zeppel, 2009; Kazuhiro, 2010; Das and Chatterjee, 2015; Zanamwe et al., 2018). Ecotourism in some Indigenous communities has created a ripple effect in visitors by reinvigorating their willingness to become better stewards of the natural environment.

It is, however, important to note that the effectiveness of Indigenous and traditional governance in supporting livelihoods and natural infrastructure conservation including wading off threats from deforestation to meet growing local and international economic needs for logs varies across different contexts and regions. For instance, the interconnectedness of the global economy can pose difficulties for Indigenous communities in regulating the use of their natural infrastructure because multinational corporations frequently function beyond the jurisdiction of local and Indigenous regulations in their quest to cater to the unprecedented increasing global demand for natural resources. Indigenous communities often face significant pressures for resource extraction, such as mining, logging, and agriculture, due to economic development priorities (Gilberthorpe and Hilson, 2016; Altamirano-Jiménez, 2021). These pressures can override Indigenous and traditional governance structures and rights in part through accumulation by dispossession. Notwithstanding, the world is witnessing resistance from the grassroots in some cases, such as protests, blockades, and other forms of direct action can draw attention to unsustainable natural resource extraction to disrupt the operations of local and multinational corporation (e.g., see Gedicks, 2015; Altamirano-Jiménez, 2021). These actions can garner support from environmental activists and sympathetic allies, which together with the power of the media, is amplifying the voices of Indigenous peoples and preventing local and multinational corporations from completely having their way. It is worth pointing out that land titling may be a viable way Indigenous communities are harnessing to combat the infiltration of Indigenous land to illegally harvest their natural infrastructure including catalyzing deforestation as it can significantly reduce land disturbance particularly in the short term. For example, in the Peruvian Amazon, deforestation was reduced by 81% in the year that followed titling (Viswanathan, 2023).

3.3 Theme 3 (green cluster)—Collective action to protect natural infrastructure

Indigenous people in developing countries often rely on collective action as a fundamental strategy to build adaptive capacity and resilience to protect and sustain their natural infrastructure in the face of climatic and non-climatic challenges (Mavhura et al., 2013; Ebhuoma and Simatele, 2017; Chanza and Musakwa, 2022). Collective action refers to the coordinated efforts by community members working together to address specific goals and challenges. As studies show, through collective action, Indigenous communities vehemently advocate for their rights to sovereignty over their land and resources (Gedicks, 2015; Altamirano-Jiménez, 2021). These efforts are crucial for securing legal recognition and protections, allowing them to manage their natural infrastructure sustainably. Indigenous knowledge is often embedded in communal decision-making processes. Indigenous communities foster collective action by sharing their traditional ecological knowledge and practices. Indigenous communities engage in discussions and consultations to collectively determine resource use, conservation strategies, and adaptation measures. This promotes ownership of decisions and ensures that diverse perspectives are considered, and their cultural identity is protected (Koot and Hitchcock, 2019). Collaborative management, where Indigenous communities are active participants, helps ensure the sustainability of natural infrastructure. Seeking collective input in issues pertaining to their welfare, including protecting and conserving their natural infrastructure, leads to locally grounded policies and practices that are more likely to be accepted and successful. As Whyte (2017) acknowledged, elders and community leaders play a vital role in leading and coordinating the collective

TABLE 1 Indigenous guidelines used to protect natural Infrastructure in developing countries.

Title of article	Study area/ country	Indigenous guidelines employed to govern natural infrastructure	References
Challenges and opportunities in the protection and preservation of Indigenous knowledge in Africa	Northern Tanzania	For many generations, the Masai herders have been utilizing a localized uniform strategy of moving their livestock around to access a variety of vegetation that is wildly dispersed. This not only ensures that their animals' access nutritional pastures from different areas but increases the seasonal capacity of the land to always cater to the nutritional needs of their livestock.	Msuya, 2007
The role of traditional laws and taboos in wildlife conservation in the Oban hill sector of Cross River national park, Nigeria.	Ejagham community, Oban Hill, Cross River State, Nigeria	The Ejagham community has a sacred forest Indigenously referred to as *Mgbe* forests. The rich flora and fauna in the communities are protected by traditional norms and taboos, which prohibit people who have not been initiated into the Mgbe cult from entering the forests. This restriction helps to regulate the extraction of forest resources.	Jimoh et al., 2012
Community conserved areas in South America	Southern Chile	Chile's coastal temperate rainforest stands as a distinct and endangered forest complex, representing one of the world's last remaining temperate rainforests. This region serves as the ancestral territory of the Mapuche-Huilliche Indigenous people, who have protected extensive portions of the native forest. For the Mapuche-Huilliche, the forest is inhabited by *ngens*, the spiritual guardians of nature responsible for overseeing various elements of the universe. The preservation of the mountain forests, considered the homeland of these spirits, is crucial for the flourishing of community members. Consequently, the Huilliche established six Indigenous protected areas over 1,000 hectares, interconnected by a 52-kilometer belt of forests that encompasses vital ecosystems in the area. These areas are protected by an Indigenous organization called the *Mapu Lahual* ("Land of Alerce") Network of Indigenous Parks. Partly due to the meticulous stewardship of the Indigenousorganization, the Alerce, *Fitzroya cupressoides*, a native tree which holds important cultural significance in the area, is recorded to have lived for over 3,000 years.	Oviedo, 2006
Role of traditional beliefs of Baima Tibetans in biodiversity conservation in China	Baima, China	The giant panda is considered a spirit among the Baima Tibetans; therefore, they are prohibited by tradition from annihilating the animal. Baima Tibetan consider killing of animal generally as a sin.	Luo et al., 2009
The potential of Amazon indigenous agroforestry practices and ontologies for rethinking global forest governance	Nonuya, Andoque, and Ceima Chacivera communities in northwestern Colombian Amazon	Certain Chagra practices are essential to consistently maintain the biophysical, human, and spiritual components of the natural environment. Chagra is described as an integrated system of several Indigenous (agro)forest(ry) activities, refer to a forest as an ever-changing dynamic system. For instance, elders practice what is referred to as traditional management of energy balance. This refers to the ceremonies they create to request permission to use certain areas of the natural environment from sacred spirits, sometimes known as spiritual tree owners. This intervention is crucial to consistently maintaining these (agro)forest(ry) areas since it is believed to simultaneously reduce accident risk and increases soil fertility.	González and Kröger, 2020
Influence of Indigenous spiritual beliefs on natural resource management and ecological conservation in Thailand	Ban Don Daen village, Thailand	The people of Ban Don Daeng worship the Pu Ta spirit, which they believe managed the natural resources in the Nongchaiwan wetland. For instance, for good fishing, they pray to Pu Ta spirit by saying "Pu Ta, I ask for fish for dinner, please". The Indigenous people used the resources for sustenance only and did not use more than what they needed as they were cautious of the spirit that protected the wetland.	Chunhabunyatip et al., 2018
In the sacred forest: landscape, livelihood, and spirit beliefs among the Katu of Vietnam	Co-Tu villages, Vietnam	For instance, the Co Tu people regard untouched areas as potentially dangerous because they may be inhabited by spirits. When a family wishes to clear a previously untouched forested area, the village leader and senior community members must carry out various ceremonies and assessments before determining whether it is suitable for cultivation or should be left untouched.	Arhem, 2009
Sacred Groves: Myths, Beliefs, and Biodiversity Conservation—A Case Study from Western Himalaya, India	Uttarakhand, India	Numerous plants, animals, as well as lakes and rivers hold sacred status, and consequently, no cutting down or utilization activities are permitted. This consecration leads to the preservation of various tree and animal species, some of which possess economic significance or face endangerment in other regions. Consequently, they serve as a genetic reservoir and a protective barrier against the extinction of these species.	Singh et al., 2017
The role of Indigenous knowledge systems in the management of forest resources in Mugabe area, Masvingo, Zimbabwe	Mugabe area, Masvingo, Zimbabwe	All respondents argued that the *Muchakata* tree species is one of the trees preserved through Indigenous knowledge. Key informants, who were interviewed, shared that the *Muchakata* tree was believed to serve as the dwelling place for ancestral spirits. *The key informants emphasized that the conservation of the Muchakata* tree is rooted in its vital role within their traditional beliefs. To harm this tree would signify a disturbance to the habitat of their ancestors, who both protect and fulfill their needs.	Tanyanyiwa and Chikwanha, 2011
Indigenous knowledge and management of *Araucaria araucana* forest in the Chilean Andes: implications for native forest conservation	Data was obtained fom the Mapuche people residing in central southern part of Chile, and in the central- western part of Argentina	According to Mapuche Pewenche culture, every element of nature possesses a being, referred to as a *ngen*, who possesses unique powers. As a result of this belief system, the Mapuche Pewenche are required to ask for permission before using any natural resource, incldluing the Araucaria tree, which is sacred. The tree was created by *ngünemapun* to provide food for his sons, the *mongewe*. The tree is believed to enable the existence of the Pewenche. Failure to seek permission before utilizing some of nature's resources could result in incurring the anger of the *ngen*.	Hermann, 2006

(Continued)

TABLE 1 (Continued)

Title of article	Study area/ country	Indigenous guidelines employed to govern natural infrastructure	References
From sacrilege to sustainability: the role of Indigenous knowledge systems in biodiversity conservation in the Upper West Region of Ghana	Vogoni in the Nadowli- Kaleo District, Upper West Region, Ghana	*Vogoni* possesses a natural sacred palm grove known as "Kore", which includes ponds and serves as a habitat for fish and crocodiles. This grove is a sanctuary for numerous animal and plant species, as well as the deities of the land. Notably, none of the trees within the grove, including the palm trees, can be felled unless it is for sacrificial purposes. Conversations with respondents revealed that the grove is unquestionably a place of refuge that provides them with spiritual protection. People enter the grove to seek solace for their problems, to pour out their concerns to the deities, and the deities respond to their pleas.	Kosoe et al., 2020
Indigenous ways of environmental protection in Gedeo community, Southern Ethiopia: A socioecological perspective	Gedeo zone (Gedeo community), Ethiopia	*Songo* holds a spiritual significance and functions as an indigenous institution for enforcing various local regulations and traditions. As a result, numerous ceremonial rituals are conducted in the sanctified areas to invoke rain, ensure the wellbeing of livestock, boost agricultural yields, and safeguard the village from potential disasters and calamities. The *songo* sacred sites are meticulously maintained, with their surfaces kept flat and adorned with clean, lush green grass known locally as *Qorichissa*. According to the elders, owing to the sanctity of these *songo* locations, actions like theft within their vicinity, acts of infidelity, tree-cutting in their surroundings, and dishonest behavior are strictly prohibited and are subject to societal norms. Violating these rules and regulations associated with *songo* is considered taboo and is believed to bring about misfortune and adverse consequences in the lives of transgressors, including sudden death, infertility, disobedience among children, infertility, curses, and increased violence within the village.	Maru et al., 2020
Role of Indigenous knowledge systems in the conservation of the bio-physical environment among the Teso community in Busia County-Kenya	Teso district of Busai county, Kenya	There were certain tree species that were never felled due to some beliefs that such were associated with water sources, having medicinal properties, associated with bad omen, ancestor or were associated with luck and wealth. The fig tree locally known as Ebule and Edodoi for instance was associated with spirituality and where traditionally community members used to worship under could never be tampered with.	Ayaa and Waswa, 2016

decision-making process in Indigenous communities. By pooling their collective knowledge, Indigenous communities adapt their practices to changing weather conditions to protect and conserve their natural infrastructure (Fariss et al., 2023).

An important attribute of collective action lies in its contribution to preserving cultural traditions and practices that are closely linked to the effective management of natural infrastructure. By upholding cultural values and practices, Indigenous communities maintain a sense of identity and resilience in the face of climate change to protect their natural infrastructure (Ebhuoma and Simatele, 2019; Lawal et al., 2022). Indigenous people often establish community-based natural infrastructure management systems emphasizing shared responsibility for natural resources. By collectively managing forests, water sources, and other ecosystems, Indigenous peoples ensure sustainable practices that prevent overexploitation and degradation. It is noteworthy to mention that many Indigenous communities assert their territorial rights through collective stewardship of nature, which includes mapping and protecting the boundaries of their ancestral lands (Sletto, 2009; Wainwright and Bryan, 2009; Bryan, 2019). As highlighted in Section 3.2, Indigenous communities establish customary rules and norms that guide resource use and interactions with the environment. These rules are partly underpinned by collective efforts, which play a crucial role in maintaining the integrity of ecosystems (Dar et al., 2019; Maru et al., 2023).

Collective action supports disaster preparedness and response efforts to protect and conserve their natural infrastructure. Indigenous communities have historically developed strategies to deal with natural and anthropogenic-induced extreme weather conditions such as flooding and droughts. Through coordinated efforts, they share resources, information and support one another during times of crisis (Mavhura et al., 2013; Ebhuoma and Simatele, 2017). Another way through which Indigenous people use collective action to protect and conserve their natural infrastructure is by forming networks and alliances with other communities, NGOs, and governmental bodies to amplify their collective voice and influence policy decisions (Gedicks, 2015; Altamirano-Jiménez, 2021; Viswanathan, 2023).

An essential ingredient of collective action is trust-building, hinged on social capital. Studies highlight that trust-building activities in Indigenous communities such as folklore tales stories, among others, which are crucial to concretize the ideology of shared identity and purpose, have contributed to increased cooperation and willingness to use natural infrastructure sustainably (Fariss et al., 2023). These findings suggest that increased attention to collective action can help scale up the effective management of natural infrastructure (Fariss et al., 2023). Overall, collective action is a cornerstone of Indigenous community resilience, enabling them to adapt to changing circumstances while maintaining the balance between their cultural traditions and the management of their natural infrastructure. It empowers communities to shape their future and ensures the continuation of their unique ways of life.

4 Discussion and conclusion

IKS plays a fundamental role in protecting and conserving natural infrastructure in developing countries. By conducting a bibliometric analysis, this study sought to unpack the literature to explore how Indigenous knowledge has facilitated the protection and conservation of natural infrastructure necessary for the continuity of livelihood activities in developing countries. Themes

that emerged include the conservation and management of natural infrastructure, Indigenous governance to mitigate deforestation and climate change, and collective action to protect natural infrastructure. It can be asserted that the themes that emerged in the bibliometric analysis regarding the mechanisms through which Indigenous people protect their natural infrastructure may not occur in isolation in practice but may be interconnected in some Indigenous communities. An important economic consequence of all three themes lies in their ability to improve the livelihood of Indigenous peoples. For example, the effective conservation of their natural infrastructure, including the mitigation of climate change through reforestation and sustainable forest management through collective action by Indigenous peoples in countries like Mexico, Columbia, and Cambodia has been acknowledged to create new economic opportunities by receiving payment for ecosystem services (PES), which scaled up Indigenous livelihood (Clements et al., 2010; Lliso et al., 2020; Rodríguez-Robayo). Also, through reforestation and sustainable forest management, Indigenous peoples in developing countries have become key players in the carbon markets, which has resulted in increased revenue generation through the sale of carbon credits (Aguilar-Støen et al., 2016; Aguilar-Støen, 2017). A drawback, however, of Indigenous peoples' participation in carbon markets and other carbon mitigation projects is that it can expose them to market fluctuations, thereby compromising the stability of their income, which can have enormous ramifications for their economic wellbeing and personal welfare. Notwithstanding, the ability to increase their revenue has morphed into enabling Indigenous people to protect their culture and intellectual property rights.

It is argued that Indigenous communities place significant importance on equity considerations associated with PES that extend beyond mere financial gains. These considerations encompass their ability to actively shape the design of PES initiatives and determine the most just and equitable methods for distributing payments (Lliso et al., 2020). This finding corroborates the importance of collective action for Indigenous people in guiding their affairs. Also, the literature acknowledges that Indigenous peoples are keen to protect and preserve their cultural richness and identity while participating in PES programs. As Rodríguez-Robayo et al. (2016) highlight, the PES program may not achieve its desired objectives if it fails to consider the cultural richness of Indigenous communities because Indigenous households may not understand the program. Thus, it is recommended that while policy developers and government officials seek to ensure Indigenous people benefit from PES, they must not replace the intrinsic motivations—deep-rooted spiritual connection with their land, cultural practices, place-based knowledge, and sacred sites—that serve as the primary driver motivating Indigenous people to protect and conserve their natural infrastructure.

Although PES schemes are increasingly heralded as a means of promoting conservation and reducing poverty in developing nations, a growing body of literature acknowledges that conservation policies, underpinned by epistemologies from the developed North and framed by neoliberal logic, are likely going to undermine environmental management practices already in place by Indigenous communities. This is because Indigenous use and conservation strategies of natural resources may conflict with state conservation agendas, which could result in the disenfranchisement of Indigenous peoples and communities (de Francisco et al., 2013; Kull et al., 2015). PES projects and policies are deemed neoliberal due to the notion that market-based management would produce the best results. This is because it is more efficient for markets to distribute limited conservation resources than for states and governments to dictate their use and distribution. PES are also neoliberal by expanding commodity relations into domains previously considered separate from the economy by framing elements of nature as commodities that can be traded (McAfee and Shapiro, 2010). Studies show that neoliberal lens has altered Indigenous natural resources conservation practices, creating internal conflicts among community members and recalibrating local development goals in Indigenous communities (de Francisco et al., 2013; Nguyen et al., 2022). Thus, to ensure that PES achieve its desired goal, it is recommended that PES schemes situate its lens beyond conservation to critically examine how Indigenous communities manage and distribute their local resources among community members (Rodríguez-Robayo et al., 2020).

It is also important to highlight that Indigenous cosmovision—which sees nature and Mother Earth as a sacred living being, which depend on all other living beings, including stones, water, air, earth and all the creatures that inhabit Earth, and must be defended due to Mother earth's right to life (GARN, 2014)—may be at odds with the commodification of nature through PES schemes. For instance, an Ecuadorian study reveals that PES fundamentally alters traditional resource management and land use practices while aggressively erasing Indigenous cosmovision (McBurney, 2021). Additionally, because PES schemes may promote the adoption of individual land rights, which runs counter to the collective and communal approach to land ownership adopted by many Indigenous communities, Indigenous cosmovision may be compromised (Barnes and Quail, 2011; Knox et al., 2011). Furthermore, it is argued that PES schemes in Indigenous communities operate within a broader social, political, economic, and cultural context that has historically devalued Indigenous cosmovision and land use (McBurney, 2021). Thus, to ensure that PES achieve its desired goal, it is recommended that PES schemes situate its lens beyond conservation to critically examine the cultural and intrinsic values Indigenous peoples attribute to their land and how Indigenous communities manage and distribute their local resources among its members (Rodríguez-Robayo et al., 2020).

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Also, research has demonstrated that another important economic advantage stemming from the capacity of Indigenous people to safeguard and preserve their natural infrastructure is the creation of opportunities to derive economic value from their culturally rich heritage. This is achieved through activities such as cultural and eco-tourism, and revenue generation from visitor fees and the sale of traditional items (Hashim et al., 2015; Qian, 2022; Suacana et al., 2022). Additionally, another crucial economic benefit arising from the effective protection and conservation of natural infrastructure, especially through collective endeavors, is the ability of Indigenous peoples to leverage their intellectual property rights. This entails negotiating agreements with interested parties or organizations for the utilization of their knowledge and other cultural assets, resulting in enhanced economic gains (Agrawal, 2006; Jain, 2009). It is important to acknowledge, however, that the economic implications of climate change and deforestation mitigation for Indigenous communities are intricate, multifaceted, and context specific. To ensure that these communities experience more favorable economic outcomes and are not adversely impacted by mitigation initiatives, it is imperative to establish effective and inclusive governance mechanisms that prioritize Indigenous rights, traditional knowledge, and equitable distribution of benefits.

To conclude, Indigenous knowledge serves as a vital foundation for sustainable land-use and the conservation of natural infrastructure in developing countries. Thus, the voices of Indigenous people must play a crucial role in dictating the use and strategies to conserve natural infrastructure so that the intrinsic value which they hold precious are not eroded and lost, which can have huge ramifications for the continuity of their rich cultural heritage and identity for future generations.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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