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A quantitative review of ecosystem service research in Himalayan Mountainous Region

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ABSTRACT

The Himalayan Mountainous Region (HMR) is one of the important biodiversity hotspots in the world and is highly vulnerable due to anthropogenic activities and climate change. A number of studies were carried out in HMR on ES from multiple perspectives, but no systematic review was carried out. This study aims to assess a systematic review of the trend, pattern and progress of ES research in HMR using SALSA framework, i.e. searching, appraisal, synthesis, and analysis. Initially, 628 literatures were identified after a rigorous review. Finally, 72 literatures met the inclusion criteria. The results showed that (1) the most of the studies were carried out in Nepal (57 %), followed by India (26 %), Bhutan (10 %) and Pakistan (1 %); (2) the most of the studies used primary data (55.84%) and empirical models (56.94 %) to assess ES in HMR; (3) the maximum studies were carried out on provisioning ES (48 %), followed by the regulating ES (28 %), supporting ES (13 %), and cultural ES (11 %); (4) among the provisioning and regulating ES, most of the studies were performed on fuel wood (56 %) and natural hazards regulation (31 %); (5) the maximum number of studies were concentrated in Central Himalayan Region (CHR) (63.47 %), followed by the Western Himalayan Region (WHR) (20.09 %), Assam Himalayan Region (AHR) (15.98 %), and Karakoram Himalayan Region (KHR) (0.46 %). Thus, this review paper can be very helpful to understand the trend of ES research in HMR and find out the research gaps for future research for better management of ecosystems.

Introduction

Ecosystem service (ES) refers to the direct and indirect benefits or services obtained from the ecosystem (Costanza and Kubiszewski, 2012; Wood et al., 2018; Das et al., 2022). The benefits obtained from the ecosystem are essential for the well-being of the people (Dawson and Martin, 2015; Wang et al., 2017; Qiu et al., 2022). The emergence of the term 'ES' has a long history (Mooney et al., 1997) and Daily coined in his book in 1997, and later on, it was extensively mentioned by Costanza et al. (1997). Later on, the ES was widely extended by the Millennium Ecosystem Assessment (MEA, 2005), The Economics of Ecosystem and Biodiversity (TEEB, 2010) and many studies after Coztanza et al. (1997). ES provides various benefits to the people in the form of provisioning ES (such as foods, fiber, and material for house), regulating ES (such as air quality regulation and climate regulation), supporting ES (soil erosion, habitat), and cultural ES (such as recreational, health, social relations) (Baskent, 2020; Mengist et al., 2020). Thus, ES are essential for environmental sustainability and human well-being (Wang et al., 2021; Pinto et al., 2022).

Though ES are essential for the environmental sustainability and well-being of the people, ES are under serious threats due to land use and land cover (LULC) change induced by urbanization (Xiao et al., 2020; Wang et al., 2020), climate change (Zarrineh et al., 2020; Weiskopf et al., 2020). Particularly in the mountainous areas, ES are highly vulnerable due to LULC change and sensitive due to climate change (Belay et al., 2022; Shrestha and Acharya, 2021). Mountainous areas comprise about 33 % of the total earth's surface, and it supports a large proportion of the global biodiversity and cultural diversity (Chaudhary et al., 2016). Mountainous areas are mostly dominated by the forest and grassland ecosystems, and more than 20 % of the total world's population is, directly and indirectly, dependent on the diverse ES provided by mountain ecosystems (Xu et al., 2019). Thus, the mountainous ecosystems are vital sources of various ES and largely support the livelihoods of the people (Bhatta et al., 2015; Cuni-Sanchez et al., 2019). Mountain ecosystem supports biodiversity, and many endemic species provide fresh water for the people residing in mountain and lowland

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areas (Xu et al., 2019). They also provide various provisioning ES such as foods and fodder and protect from various natural hazards (Adhikari et al., 2018; Pritchard et al., 2019). Thus, mountainous ecosystems are essential to understand trend and pattern of ES research for identifying knowledge gaps and understanding future scopes of research.

In this study, Himalayan Mountainous Region (HMR) has been taken into consideration for review and assessment. HMR is the unique and highest mountain ecosystem in the whole world, extending 2500 km from west to east and spreading over 5,95,000 km^2 on earth terrestrial. HMR is considered the storehouse of ES and biodiversity hot spots (Chettri et al., 2008; Xu et al., 2019). HMR provides a wide range of ES provisioning (foods, fiber, fuel), regulating (air quality regulation, climate regulation), supporting (habitat, soil erosion protection), and cultural (tourism, esthetic value) ES (Chettri and Sharma, 2016). This mountain region is also important for energy security, food supply and economic progression in world (Aryal et al., 2018; Kandel et al., 2018; Karki et al., 2018). The mountain ecosystems in this region support the livelihoods of around 53 million people (Kandel et al., 2018), and majority of communities are (about 600 million people) dependent on food production to support livelihoods sustainability (Molden et al., 2016). HMR is a rich source of various ES, but presently HMR faces many challenges due to population growth, LULC change, and climate change (Jha et al., 2022). Thus, this region has experienced dramatic deterioration of ES and loss of species affecting interdependence between ecosystems and dependent communities (Das et al., 2023; Sharma et al., 2019).

Therefore, it is essential to understand pattern and progress of ES research in HMR existing research gaps and inspire researcher to fill research gaps in future. Many research scholars have studied ecosystems with their services in HMR on several issues (Chaudhary et al., 2016; Kandel et al., 2018; Karki et al., 2018). But, no studies were carried out to understand bibliographic review and analysis to assess ES in HMR. This is essential to provide information on ES research in the HMR at the regional scale and find the gaps. This study will be very helpful in

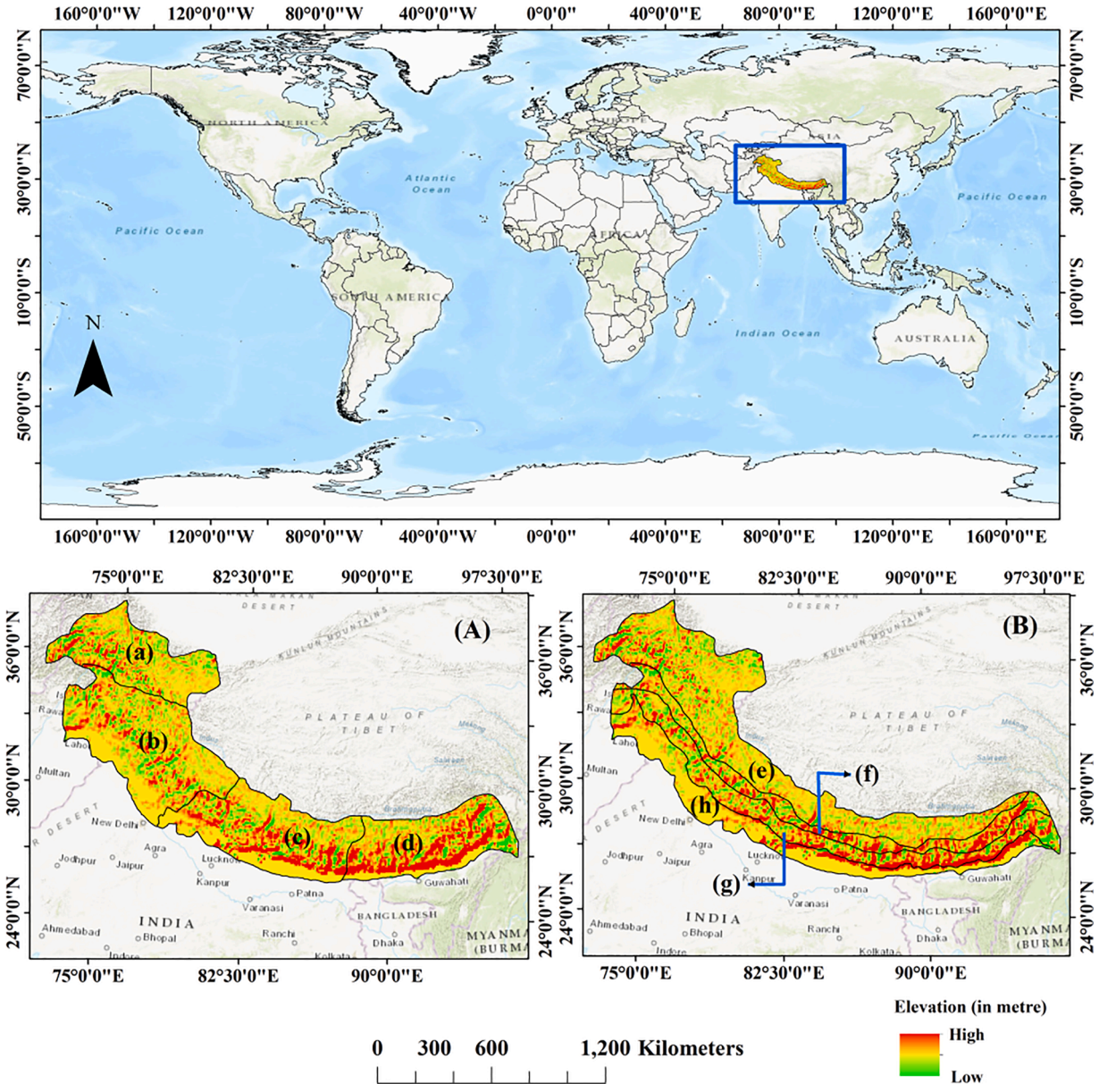


Fig. 1. Spatial focus (A) Latitudinal classification of HMR a. Karakoram Himalayan Region (KHR) b. Western Himalayan Region (WHR) c. Central Himalayan Region (WHR) d. Assam Himalayan Region (AHR) and (B) Longitudinal classification of HMR e. Tythes Himalayan Region (THR) f. Greater Himalayan Region (GHR) g. Himachal Himalayan Region (HHR) h. Siwalik Himalayan Region (SHR).

identifying trend, pattern and progress of ES research for further research in future. The basic objective of this systematic review is to focus on the quantitative research on ES HMR

Materials and methods

Spatial focus

This review research has been carried out in HMR and it is extended over many countries (Such as Nepal. Bhutan, India, and Pakistan). In northern part of Himalayas, there is the Tibetan Plateau, and in southern part, there is an Indo-Gangetic plain. From East to West, mountain ranges of Himalayas are extended over (about 2500 km) Nepal, Bhutan, India, Pakistan and China. Himalayan zones are classified into two broad categories: latitudinal and Longitudinal. The details of location map are presented in Fig. 1.

Designing review framework

The importance of ES in mountainous ecosystems is well recognized, and it is essential for livelihoods of people living in mountainous and downstream (Díaz et al., 2015; Mengist et al., 2020). In spite of this, the contribution of ES in mountainous ecosystems to support livelihoods and environment is well understood and recognized in HMR. Considering this broad research gap of the previous research work, five broad research questions have been formulated. These are:

(a) what are the trends and patterns of ES research in HMR? (b) what is the spatial pattern of ES studies in HMR? (c) what types of data and models have been used in previous literature? (d) what are the regional patterns of ES studies in HMR? and lastly, (e) what are the major issues addressed in the literatures?

Search, Appraisal, Synthesis and Analysis (SALSA) framework has been employed to carry out this systematic review (Mengist et al., 2020). Details of SALSA framework are presented in Fig. 2.

Step I: Protocol

The protocol phase for systematic review is essential for a transparent and replicable review. The application of protocol is not only important to identify research gaps; rather, it helps to formulate research questions to delineate the suitable and useful research method. HMR is spread over a vast area and contains diversified ecosystems and countries with varying research priorities in HMR.

Step II: Search

Search stage of SLR methodology consists of identification of various relevant searching strategies and information sources. This step of SLR is essential to find out appropriate databases and identify proper search string to collect relevant documents (del Amo et al., 2018). In this study, literature was searched from different databases such as Scopus, web of Science and Google Scholar. Multiple search terms such as ES, environmental services, ecological services, ecosystem health, forest services or eco-environmental quality along with Himalayan mountain region were used to find out relevant literature. The relevant literature was searched using a spatial scale such as country (India, Nepal, Bhutan, Pakistan), state (Himachal Pradesh, Uttarakhand, Sikkim, Assam and Arunachal Pradesh) and districts (Darjeeling, Kalimpong).

Step III: Appraisal

In this phase of SLR, the selected literature was evaluated based on objectives of work through screening of selected literature. The literature was evaluated on the basis of inclusion and exclusion criteria, and the literature that fulfilled inclusion criteria were investigated and assessed in detail. The criteria for inclusion and exclusion of selected literatures are shown in Table 1.

Initially, total 628 literatures were screened which included full length research articles, review article, book chapters and letters. After removing gray literature, book chapters, review articles, non-English language literature and inaccessible literature, total 368 literatures were remained for screening. From the selected literature, only 296 literatures were excluded based on the selection criteria. Finally, 72 literatures were selected for further analysis of review. 72 articles among them fulfilled all eligibility criteria of inclusion processes (Table 1).

Step IV: Synthesis

In this SLR, data are extracted and classified from selected literature to gather knowledge and provide conclusions. 72 literatures were selected to identify and extract relevant data. Initially, the relevant and necessary data collected from selected literature were extracted in an

Table 1
Criteria for inclusion and exclusion of selected literatures.

Criteria	Decision
Inclusion	Pre-defined keywords observed in title, abstract and keywords section
	Literatures published in peer review journal
	The literatures must cover ES in HMR
	The literatures should be written in English language
Exclusion	The selected literatures should not review papers
	The inaccessible literatures
	Duplicates research literatures

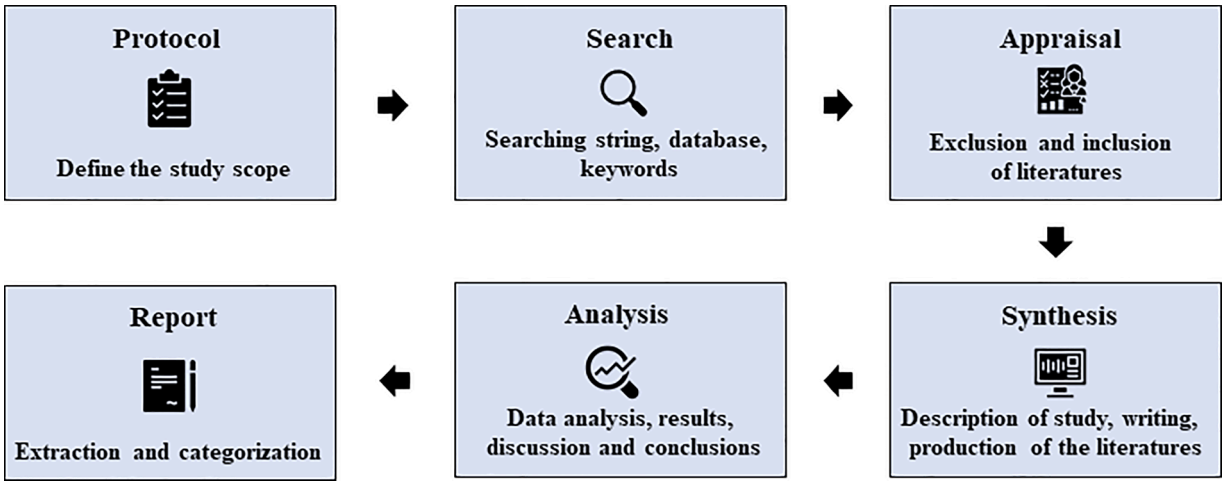


Fig. 2. SALSA framework used for systematic review.

excel sheet for further data processing, and then the extracted data were classified and processed for further analysis. Finally, the final outcomes were presented through various multiple graphs, charts and network analysis.

Step V: Analysis

Synthesis is one of the essential steps of SLR as it encompasses evaluation of data, collection of meaningful information and conclusion of the selected literature. In this SLP, the research questions are answered and formulated. This step includes both a quantitative and qualitative explanation of the outcomes, a discussion, and an indication of the right way for future research directions and conclusions.

A number of numerical analyses are also carried out in this step of the SLR, such as the classification of the publication on the basis of the years, spatial distribution and scale of the literature (such as local, regional, national and global). In addition to this, other information such as the type of ES in the Himalayan region, objective of the study, limitations and future research direction of the studies.

For analysis of the biblio-metric data, an open source software, i.e. VOS-viewer (Version 1.6.7, Leiden University, Leiden, Netherlands), has been used. VOS-viewer is a widely used network tool for the assessment of scholarly network graphs (Aznar-Sánchez et al., 2019; Velasco-Muñoz et al., 2018).

Step VI: Report

This phase of SLR methodology mainly deals with the description of data, the methods followed and the results of the study obtained from the literature reviewed. Mainly two parts are (a) details of the procedures followed and (b) presentation of findings like a scientific journal (Del Amo et al. 2018). In the case of the SLR, this step helps in providing outputs of the research for scientific purposes.

Result

Temporal pattern of ES research

In HMR, exponential growth was observed in ES research. Until 2005, there were only ten research papers and the publications of research papers substantially increased after the Millennium Ecosystem Assessment (MEA) framework in 2005 (Wang et al., 2021). As per the search, it was found that there were 628 research papers published in the last 30 years in HMR. The publication trend has been divided into three classes from 1994 to 2022 (Fig. 4).

(i) **Steady growth (1994 to 2010 (2009)):** In this stage of growth, a total of 27 research papers were published. The average number of publications in this span of time was 1.68/year.
(ii) **Medium growth (2010 to 2019):** From 2010 to 2019, a total of 301 pieces of literature were published within ten years, with an average publication of 30.1 per year. The highest number of publications was observed in 2018, with 61 publications.
(iii) **Booming growth (2020–2022):** After 2020, there were substantial increases in ES research in the HMR. From 2020 to 2022, 300 research papers were published, with an average publication of s 101.33/per year. The highest publication was recorded in 2021, with 133 in this period.

Characteristics of the literature

The sample size of the review work is affected by the objectives and search criteria (Martinez-Harms et al., 2015). The types and size of the databases used for searching the literature also determine sample size. A total of 628 literatures related to ES were screened from various sources (such as Scopus, Web of Science, and Google Scholar). Finally, 72 literatures were selected for further studies after applying the inclusion criteria, encompassing 11.37 % of the total literature. This review work used a larger size sample as compared to other systematic reviews in the previous work, such as Mengist and Soromessa (2019) used 0.3 %, Perevochtchikova et al. (2019) used 0.7 %, Yang et al. (2018) used 2.8 % and Mengist et al. (2020) used 5.9 % of the literature from the database.

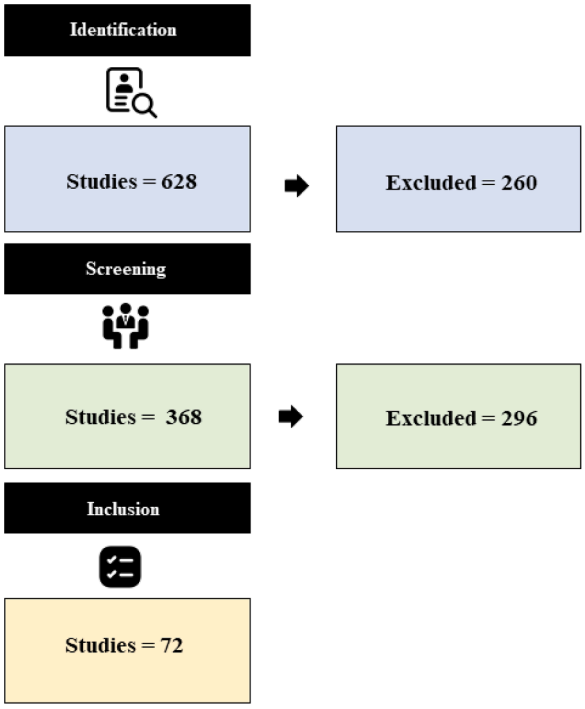


Fig. 3. Methodological framework used for systematic review.

There were spatial variations of ES studies in HMR. For example, among 72 studies, the most of the studies were carried out over five countries. These countries were Nepal (57 % studies), followed by India (26 % studies), Bhutan (10 % studies), and Pakistan (1 % study). Most of the studies were co-authored by India, followed by Nepal, the United States, Australia and China (Supplementary Data Figure S1). Most of the studies used 'Ecosystem service' (about 43 % of the total studies), followed by 'Himalayan', 'Nepal', 'Livelihoods', and 'Forest Management' (Supplementary Data Figure S2).

Data types and models used

Multiple techniques and models are employed to assess the ES of a region. From the 72 literatures reviewed, the data used to assess ES were classified into three categories, these are (a) primary data (data collected through the survey, schedule, questioner, focus group discussion and expert knowledge) (b) secondary data (data collected through various literature, the landsat images, digital elevation model (DEM) and LULC map etc.) and (c) mixed data (both primary and secondary data). Fig. 5 shows the different types of data and models which were used to assess ES. The data used in the selected articles were classified into three different groups. 55.84 % of the total literature used primary data for ES assessment in HMR, 24.72 % of the total literature used secondary data for ES assessment and 19.44% of the total literature employed both primary and secondary data (mixed method) for ES assessment in HMR.

The literature also used multiple models to assess ES in HMR. Broadly, four groups of models were distinguished from the reviewed literature, the Empirical model, the GIS-based model, InVEST model and the mixed model. The results showed that 56.94 % (41 studies) literature employed the empirical model, 22.22 % (16 studies) literature used the mixed model, 19.44 % (14 studies) literature used GIS-based models and 1.39% (1 study) of literature employed InVEST models for the assessment of the ES in HMR (Fig. 6).

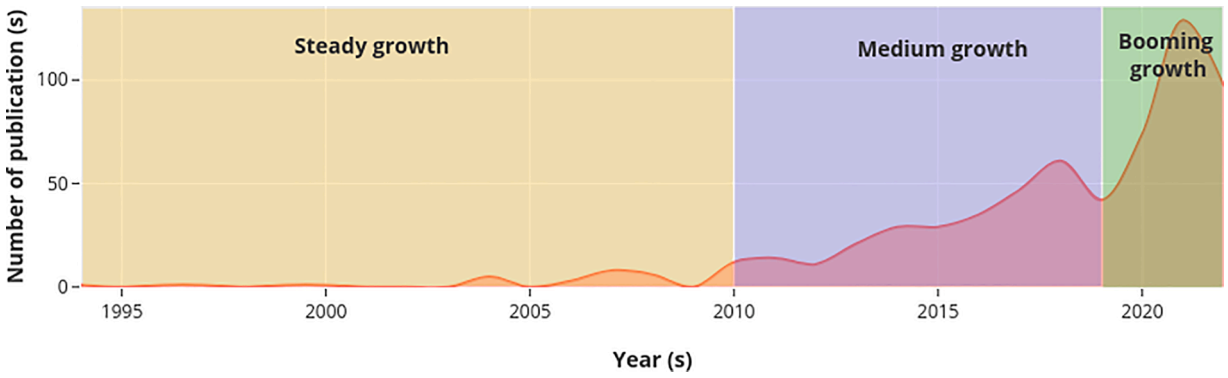


Fig. 4. Number of ES studies per publications in HMR.

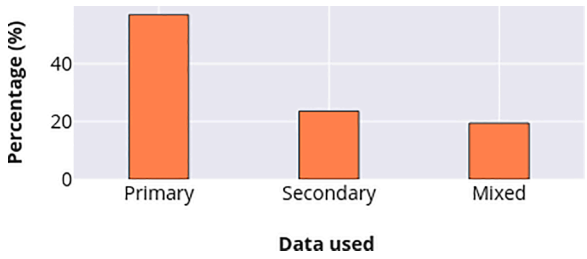


Fig. 5. Data type used to assess ES in HMR.

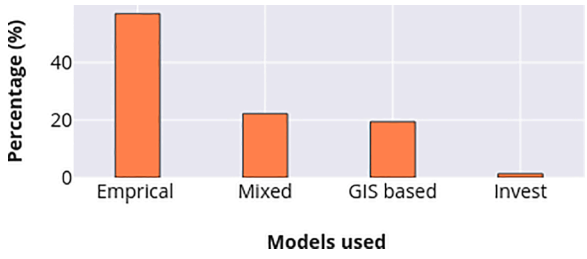


Fig. 6. Models used to assess the ES in HMR.

The empirical models were widely employed from both quantitative and qualitative approaches to assess the ES on the basis of the data field observation and data collection. These models mostly applied surveys and questionnaires to collect ES data based on the perceived value and preference of the ecosystems. From the results of the study, it was found that about 57 % of the total literature used empirical models for the analysis of the ES.

GIS-based models were used to estimate the ES in HMR to a lesser extent as compared to empirical models in the selected previous literature. The results showed that 16 kinds of literature applied (about 19.44 % of the total literature reviewed) various GIS-based models to assess the ES in the HMR. The assessment of the ES based on the GIS-based model requires LULC maps, digital elevation model (DEM), and others datasets based on the research objectives (Haase et al., 2014).

InVEST is one of the widely utilized platforms or software used to integrate different modeling frameworks on the basis of spatial datasets utilizing GIS software (Vihervaara et al., 2019). InVEST models have been used for mapping various ES (Salata et al., 2017; González-García et al., 2020). From the results, it was observed that about 1.39 % of the total literature employed InVEST model for ES assessment. The results also showed that about 22.22 % of the total literature reviewed utilized mixed models to assess ES in the HMR.

ES studied

From the 72 reviewed literature, most of the literature dealt with provisioning ES 47.70 %, followed by regulating ES (28.16 %), supporting ES (13.22 %), and cultural ES (10.92 %), respectively. Fig. 7 represents the major four bundles (single, binary, triple and four) for classifying the ES in HMR. The results showed that about 54.29 % (38) of the total selected literature focused on the assessment of four ES, 18.57 % (13) of the total literature assessed three ES, and the rest literature (21) assessed all the possible binary and single ES. In case of provisioning ES, fuel wood (55.56 %) was the mostly addressed ES, followed by fodder (51.39 %), freshwater (51.39 %), and timber (48.61 %), respectively. In the case of regulating ES, about 30.56 % of the total literature focused on natural hazard regulation, followed by soil erosion control (27.78 %), carbon sequestration (25 %), and climate regulation (23.61 %). Habitat provision (26.39 %) had the highest discuss service in supporting ES, followed by protected biodiversity (22.22 %), soil formation (8.33 %), and nutrient cycle (6.94 %), respectively. It was observed that a total of 34.72 % of the selected literature addressed recreation and ecotourism as cultural ES, followed by the beautiful esthetic landscape (29.17 %), religious site (23.61 %), and spiritual site (20.83 %) (Supplementary Data Figure S3).

Regional variation of ES studies

In HMR, there were also spatial variations of ES studies in case of

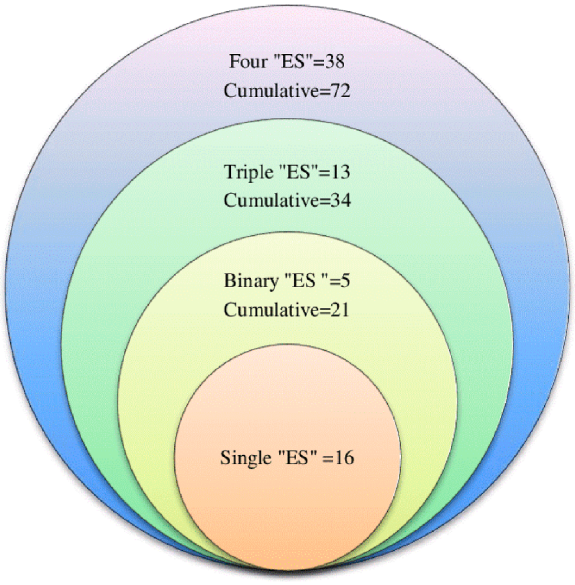


Fig. 7. Number of the studies dealing with ES.

latitudinal distribution, the highest number of studies were carried out in CHR (63.47 %), followed by WHR (20.09 %), AHR (15.98 %), and KHR (less than 1 %). Most studies focused on provisioning of ES (32 %), followed by regulating ES (25.57 %), cultural ES (23.74 %) and supporting ES (19.18 %). Among provisioning and regulating ES, maximum studies were carried out in CHR (59.42 % and 66.07 %) followed by WHR (24.64 % and 17.86 %), AHR (14.49 % and 16.07 %) and KHR (1.45 % and 0 %). Maximum numbers of supporting and cultural ES were also carried out in CHR, followed by WHR, AHR, and KHR (Supplementary Data Figure S4 and Figure S5).

In case of longitudinal distribution, the maximum numbers of ES studies were carried out in HHR (39.07 %), followed by SHR (34.10 %), GHR (26.49 %), and THR. The provisioning ES were widely studied in this region, followed by the regulating ES, cultural ES and supporting ES. The maximum numbers of provisioning, regulating, supporting and cultural ES were carried out in HHR (38.04 %, 41.03 %, 37.70 % and 39.44 %), followed by SHR (32.61 %, 34.62 % 34 0.43 % and 35.21 %), GHR (28.26 %, 24.36 %, 27.87 % and 25.35 %), THR (Supplementary Data Figure S6 and Figure S7).

Discussion

Spatial distribution of ES studies

This study tried to assess the current knowledge and existing research gaps in assessment of ES studies in the HMR. It was well documented that most of the studies were clustered in Nepal, followed by India, and Bhutan. In case of the regional pattern, most of the ES studies were carried out in CHR followed by and WHR. In the case of vertical distribution of ES studies, most of the studies were carried out in HHR followed by SHR. Thus, the findings of the study will be very helpful in understanding trends and spatial patterns of ES studies and identifying the research gaps in HMR.

Categories of ES studies

The most studies focused on the provisioning ES (such as fuel wood, fodder, fresh water, and timber), among regulating ES, natural hazard regulation, followed by soil erosion control, carbon sequestration and climate regulation were the highly studied ES. Among the supporting ES, habitat provision and genetic diversity were highly addressed, and recreation, ecotourism, and esthetic value were the highly studied cultural ES. It was documented that many ES were underrepresented in literature, such as waste treatment, photosynthesis, water purification, sense of peace, social relationship, disease regulation, net primary production (NPP), nutrient cycling, and pollution controls.

The recreation and tourism were mostly focused cultural ES, whereas heritage, sense of place and historical value were the least addressed ES among cultural ES There may be two reasons to study recreational and tourism ES as compared to other ES due to the importance of ES and well-understood methods. Thus, a number of ES studies were undervalued due to a lack of data, methods and barriers in estimating the value of ES.

Major issues addressed

The most of the studies focused on the valuation of ES (Sharma et al., 2019), LULC change and its impact on the ES (Chaudhary et al., 2016; Sharma et al., 2019), the nexus between ES and livelihoods (Bhatta et al., 2015), ES and climate change (Saeed et al., 2022). The details of the findings of some selected literature are shown in Table 2. These findings were similar to the other studies carried out in different parts of world. For example, Qian et al. (2018) carried out a study on Southern Slope of Qilian Mountains (China) and observed that ES value declined due to expansion of mining areas and loss of wetland and grassland. Belay et al. (2022) showed that the ES value in Afroalpine area of Guna Mountain (North-West Ethiopia) declined from 46.97 × 106 USD (1995) to 37.19 × 106 USD (2020). Sharma et al. (2019) carried out a study in Hindu Kush Himalaya, and the findings showed that the ES in mountainous areas were highly susceptible due to climate change. Similar findings were also reported by Moos et al. (2018) in mountainous ecosystems and livelihoods of people are adversely affected by climate change (Xu et al., 2019). Thus, the findings were similar to studies carried out in HMR.

Identification of the research gaps and future scope of research

In the previous piece of the literatures in HMR, a number of issues have been addressed. From overall analysis, few notable research gaps can be highlighted. These are as follows:

Research Gap 1: Inadequate data and methods to assess ES

About 56 % of studies were carried out based on primary survey and rest of the studies were carried out using secondary and primary data. In future studies, more focus should be given on primary data along with large sample sizes.

Research Gap 2: Model based studies needs to be applied

Table 2
Findings of some selected literatures in HMR.

Major issues	Example	Major findings	Spatial focus	Reference
Economic valuation of ES	Literature 1	The economic value of ES obtained from the wetland was 3.91 million USD per year.	Wetland (Nepal)	Thapa et al. (2020)
	Literature 2	The ES value of forest ecosystem was 19.17 billion USD covering 87.16 % of the total ESV in Nepal.	Nepal	Baniya et al. (2019)
LULC change and its impact on ES	Literature 1	ES value from 2000 to 2017 increased by about 1.59×106.	Central Himalaya	Shrestha et al. (2019)
	Literature 2	Food production and carbon storage declined from 1996 to 2016.	Koshi RiverBasin	Rimal et al. (2019)
Livelihoods and ES	Literature 1	ES and livelihoods the village communities are under challenges due to climate change, population growth, urbanization.	Middle Himalayas	Everard et al. (2019)
	Literature 2	About 85 % of the total households are highly dependent on various provisioning ES for their livelihoods and income.	Eastern Himalaya	Kandel et al. (2018)
Climate change and ES	Literature 1	Climate change is a significant threat affecting ES such as crop production, livestock.	Western Himalayan Guruz Valley	Saeed et al. (2022)
Traditional ecological knowledge and ES	Literature 1	Traditionalpracticeswereconsideredasoneoftheimporatantpraciticesforecosystemmanagement	Mai Pokhari (Nepal)	Chaudhary et al. (2019)
	Literature 2	Traditional ecological knowledge plays significant role to conserve local ecosystem.	Eastern Himalayan Region	Thorn et al. (2020)

The most of the studies employed empirical analysis. Spatial modeling based on GIS and InVEST had limited applications.

Research Gap 3: Regional inequality

The most of studies were carried out in CHR and HHR. Therefore, studies should be extended to other areas, such as the AHR and GHR.

Research Gap 4: Limited focus on the spatial mapping of ES

The most of the studies in HMR were carried out based on the primary data and the spatial mapping of various individual ES, such as water yield, carbon sequestration, and habitat quality were undervalued. The mapping of individual ES is important to implement spatial planning for management purposes.

Research Gap 5: Strengthening the on management of ES

In HMR, the most of the studies were carried out to assess valuation of ES and impact of LULC change on ES. Very limited studies were carried out on livelihood sustainability, climate change and traditional ecological knowledge (TEK). In mountainous areas, the livelihoods of people are highly dependent on various ES obtained from ecosystems (Das et al., 2022). Climate change has emerged as one of the serious threats to ES vulnerability (Matthews et al., 2014). Therefore, it is essential to understand the relationship between climate change and ES and impact of climate change on ES. Future studies should be on climate change and ES. The mountainous communities maintain several traditional ecological knowledges, and this TEK is essential to conserving the ecosystems and ES. This TEK can be linked with the management of ES (Das et al., 2021). TEK are associated with the management of ecosystems in the form of taboos and totems (such as no killing and cutting down of animals and trees), customs and rituals (such as traditional medicines), rules and regulations (such as fire belts around farms to control bush fires) and traditional protected areas (such as sacred forests and water bodies) (Boafo et al., 2016; Das et al., 2021)

Limitations

This paper contributes a lot to understanding pattern and trend of ES studies in HMR. Despite this, a few limitations can be highlighted. These are: firstly – the literature published only in the English language have taken into consideration. There were also other languages, such as Nepalese, Chinese, and Hindi. This language barrier can be filled in further studies by considering others sources of non-English and gray pieces of literature. This review work only considered peer reviewed scientific literatures. Reports, book chapters, conference papers were not taken into consideration. Thus, the final number literatures may be underestimated. This review work carried out with 72 scientific studies focusing on ES in HMR. In the previous studies, low number studies related to ES were reviewed (Kosanic and Petzold, 2020). Thus, the number of studies selected for systematic review were valid.

Policy implications for management

HMR has experienced a rapid transformation of ecosystems in the last few decades due to LULC change and climate change (Sharma et al., 2019). The changes and loss of ES have substantially affected climate change and the livelihoods of the people (Everard et al., 2021). Therefore, it is essential to conserve ES in mountainous regions to mitigate climate change and sustain the livelihoods of the people. After the Millennium Ecosystem Assessment (MEA, 2005), ES are being taken into consideration in environmental policies due to their contribution to the economy and human well-being (Bennett et al., 2015). The Convention on Biodiversity (CBD) has implemented new targets for 2020 related to the conservation of biodiversity and ES. For example, targets 14 and 15 mainly deal with the safeguard of ES for livelihoods, well-being and climate regulation (CBD, 2010). The deterioration of ES due to LULC and climate change has multiple impacts on provisioning ES. For example, climate change leads to water scarcity in mountain areas (Rangecroft et al., 2013). For example, the mountainous communities are dependent on the melting water and the disappearance of the glaciers might lead to water scarcity issues. The HMR is famous for tourism and tourism has an impact on climate change, such as carbon emissions (Das et al., 2023). Unplanned urban expansion has brought a series of ecological and environmental problems such as ES, and an increase of temperature in mountainous areas (Uddin et al., 2023). The livelihoods of the mountainous communities are highly dependent on ES such as food, fuel, and raw materials (Huq et al., 2020). Thus, the conservation and protection of ES in mountainous areas is crucial for the diversification of livelihood strategies. The diversification of livelihood strategies can be considered as one of the effective strategies to strengthen livelihood security as well as the resilience of ecosystem-dependent communities in mountainous areas against climate change. In HMR, the communities are highly dependent on ES for their livelihoods (Das et al., 2023). Therefore, it is important to focus on the management of ES in HMR.

TEK plays a significant role in the management of ES in mountainous areas. TEK helps to protect ES in the form of various taboos and totems, customs and rituals, rules and regulations and traditional protected areas (Das et al., 2021). The practices and belief systems of the communities are also essential to ensure sustainable utilization and management of ES (Boafo et al., 2016). In HMR, the local communities, more specifically tribal communities have strong nexus between TEK and ES (Barua and Slowik, 2015). Therefore, planners and policymakers should integrate TEK into formal education systems to promote ecological knowledge and sustainable management of ecosystems in mountainous areas (Fig. 3 and Fig. 8).

Conclusions

The research on ES in HMR substantially increased in last 30 years. Most of the studies were carried out in Nepal Himalayan Region (58 %), followed by Indian Himalayan Region (26 %), and Bhutan Himalayan Region (10 %). Most of the studies focused on the provisioning ES followed by regulating ES. The studies were mostly carried out using primary data, and spatial mapping-based assessment needs to be addressed. Thus, this systematic review will be helpful for future researchers to address the research gaps of the previous studies and improve scientific research.

HMR is one of the important ecological sensitive and rich regions in the world. The HMR not only important from ecological and environmental point of view, rather it supports livelihoods of the mountainous communities and the communities living in other areas. Therefore, this systematic review work will be very helpful improve and study research further ES in future.

Ethical approval

Not applicable

Consent to participate

All participants provided their consent for participating in the interview.

Consent to publish

Not applicable

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Availability of data and materials

The datasets used during the current study are available from the corresponding author on reasonable request.

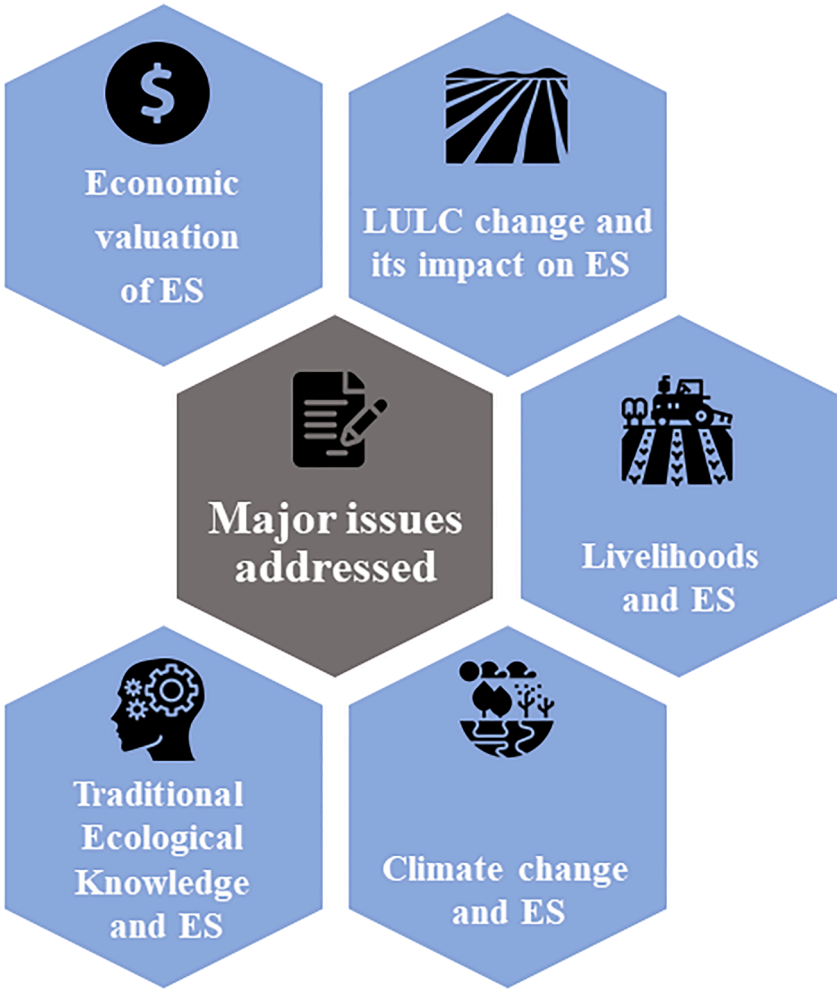


Fig. 8. Major issues addressed in HMR.

Author contribution

AM, MD, and AD conceptualize and designed the study; MD and AR collected and analyzed the data with the support of AD and MD and written the paper; MD, and AM interpreted the analysis. MD, and AD, and PP read and modified the paper. All four have contributed extensively for data interpretation and discussions.

Declaration of Competing Interest

There is no conflict of interest.

Data availability

The authors do not have permission to share data.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2023.100792.

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