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ORIGINAL ARTICLE

Assessing the Realization of Global Land Restoration: A Meta-analysis

Sheikh Adil Edrisi[1,7] · Priyanka Sarkar[2,3] · Jaewon Son[4] · Nagaraja Tejo Prakash[1,5] · Himlal Baral[6]

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Abstract
Restoring degraded land is essential for regaining ecosystem services (ES) and attaining the UN-Sustainable Development Goals by 2030. Unfortunately, 24% of the global lands are degraded, significantly affecting the lives of 3.2 billion people worldwide. Therefore, innovative restoration practices are vital during 'UN-Decade on Ecosystem Restoration.' A meta-analysis of 2093 documents on land degradation and restoration was conducted in this context, and 117 empirical studies were analyzed in detail. These studies were based on the different drivers of land degradation as per the criteria of IPBES and IPCC, respectively. Results suggested that woodland encroachment (18.25%), cropland expansion (18.11%), species loss/compositional shifts (16.06%), climatic factors (14.96%), infrastructure development/urbanization (14.17%), water erosion (13.87%), wind erosion (9.49%) and other demographic pressures (8.66%) were the significant drivers of land degradation. Interestingly, there was a continent-wide change in the critical drivers of land degradation and depleting ES. The infrastructure development/urbanization, demography, and economic attributes were the essential drivers in Asia–Pacific and African regions. In contrast, the fire-regime shift and invasiveness were the significant drivers in Europe, and the climatic attribute was the crucial driver in the Americas. Out of the 117 studies selected worldwide, some ongoing restoration efforts had little emphasis on research-driven on-site restoration for improving different ES. Furthermore, some restoration projects lack proper stakeholder involvement thereby, fail to attract large-scale public acceptance. Moreover, only 12.8% of the studies focused on improving the ES in highly degraded lands. Therefore, this meta-analysis suggests that site-specific, research-driven, and on-site restoration strategies coupled with proper stakeholder engagement are imperative for regaining the ES and functions of the degraded landscape to attain UN-SDG.

Keywords Land degradation drivers · Land restoration · Ecosystem services · Stakeholders' involvement · Policy implications

1 Introduction

Ecosystem services (ES) are the key benefits humans derive from their ecosystems (Hu et al. 2020). Increasing human population and unsustainable exploitation of natural resources have led to the degradation of various ecosystems encompassing the land resources and the ES globally (Edrisi and Abhilash 2021; IPCC 2019; FAO 2015). These ES include biodiversity, infrastructure development, soil formation, carbon sequestration, nutrient, and hydrological cycling, waste treatment, amelioration of potentially toxic elements, and other xenobiotics (Abhilash et al. 2013a,

✉ Sheikh Adil Edrisi
sheikhadil.edrisi@thapar.edu

[1] School of Liberal Arts and Sciences, Thapar Institute of Engineering and Technology, Patiala 147004, Punjab, India

[2] Wetland Ecology Department, Patrick Center for Environmental Research, Academy of Natural Sciences of Drexel University, Philadelphia, PA 19103, USA

[3] Department of Ecology and Environmental Science, Assam University, Silchar 788011, Assam, India

[4] Institute for Technology Assessment and Systems Analysis, Karlsruhe Institute of Technology, Karlstr. 11, 76133 Karlsruhe, Germany

[5] School of Energy and Environment, Thapar Institute of Engineering and Technology, Patiala 147004, Punjab, India

[6] Center for International Forestry Research (CIFOR), Bogor 16115, Indonesia

[7] Commission On Ecosystem Management, IUCN, 1196 Gland, Switzerland

2013b). The shrink in ES globally affects more than 3 billion people (Nkonya et al. 2016) and comes at a degradation cost of 60% of the ES (WHO 2005). Moreover, the land degradation and subsequently diminishing ES have now become a global issue, which is highlighted regularly by various researchers across the world under different timelines (Gonzalez-Redin et al. 2019; Nkonya et al. 2016; Sutton et al. 2016; Gibbs and Salmon 2015; Gisladottir and Stocking 2005; Oldeman et al. 1990). Although different restoration measures were adopted to overcome these issues, there is still a need to assess land degradation thoroughly and monitor the adopted restoration practices. These practices must include the systematic application of appropriate restoration measures for the on-site land restoration according to the land types and climatic conditions to regain the diverse ES.

Various organizations have assessed the land degradation and speculated different estimates of marginal and degraded lands at national and global levels (IPCC 2019; IPBES 2018; Edrisi and Abhilash 2016; Oldeman et al. 1990). The Global Assessment of Soil Degradation (GLASOD) is the pioneer commission of the United Nations Environment Program (UNEP) that mapped the worldwide human-induced degradation and is still utilized today for various interpretations like the studies related to bioenergy production, land-use changes, etc. (Nijsen et al. 2012; Lambin and Meyfroidt 2011). The GLASOD dataset classified the extent of degradation in four classes (i.e., non-degraded, moderately, strongly degraded, and highly degraded lands). According to its assessment, degradation prevailed in an area of around 2 billion ha comprising the forest, agricultural land, pasture, and woodland since the mid-twentieth century. It depicted that most of the degradation occurred in the Asian and African sub-continents, estimating 453 and 321 million ha (Mha) of land. Moreover, the least degradation was found in the Australia and Pacific regions, depicted around 6 Mha of land (Gibbs and Salmon 2015; Oldeman et al. 1990). The direct drivers of such land degradation were deforestation (29.45%), overgrazing (34.54%), agricultural mismanagement (28.08%), over-exploitation (6.77%), bio or industrial activities (i.e., simply the biological or anthropogenic) (1.17%) (Oldeman et al. 1990). Furthermore, the FAO's Global Assessment of Lands Degradation and Improvement project (GLADA) had enumerated Normalized Difference Vegetation Index (NDVI-based) land degradation events between 1981 and 2003 (Gibbs and Salmon 2015). The GLADA project described land degradation as the long-term degeneration in ecosystem functioning. It evaluated a negative trend in the net primary productivity of 2.7 billion ha (21% of global land area) in tropical Africa, Southeast Asia, China, north-central Australia, the Pampas, and swaths of the boreal forest in Siberia and North America (Gibbs and Salmon 2015).

The global economic losses from land degradation are estimated to be US$300 billion year^{-1}. Due to land-use and land-cover change (LUCC) and unsustainable restoration approaches on viable cropland and grazing land. Sub-Saharan Africa (22%) comprises the largest share of the entire global cost of land degradation. Around 46% of the annual global cost of land degradation is due to LUCC, out of which land users (deriving livelihood by working directly in agriculture and/or forest land) exhibit 78%. However, the remaining 54% is carried by the off-farm consumers of ES (Nkonya et al. 2016). Furthermore, land degradation resulted in the loss of around US$6.3 trillion year^{-1} of ES, representing around a 9.2% weighted average decrease in the global annual value of ES (Sutton et al. 2016). Moreover, the degradation of productive land undermines well-being through under-nutrition and malnutrition (Abhilash et al. 2016). Over 800 million people (mostly in low-income countries) suffer from a deficiency in protein, calories, and micronutrients (like vitamin, zinc, and iodine) (WHO 2005). Therefore, land degradation's adverse effects on biodiversity, soil health, water, and other biotic components severely impact human health and well-being.

Though several studies and initiatives are related to the various aspects of land degradation at the local, regional, national, and even global scales, the empirical studies related to the factors mentioned earlier are comparatively lower. Therefore, assessing the trend and the extent of land degradation is highly needed in different regions of the world. It could be addressed by the systematic classification and prediction of the degraded lands as previously done by various researchers (Nkonya et al. 2016; Sutton et al. 2016; Gibbs and Salmon 2015). Moreover, it is necessary to adopt ecosystem-based on-site land restoration to mitigate land degradation. The in situ practice that is employed directly into the field conditions is referred to as on-site land restoration. This strategy has arrived as a science of practice that helps regain these services. It can potentially contribute to developing human well-being (Edrisi and Abhilash 2021).

Furthermore, such strategies can simultaneously address various associated United Nations Sustainable Development Goals (UN-SDG). For example, it targets to conserve biodiversity, which delivers essential services to attain Goal No. 14 of UN-SDG. It also focuses on increasing the contribution of biodiversity to carbon stocks (Abhilash et al. 2012) through the restoration of at least 15% of degraded terrestrial ecosystems (Goal No. 15). The SDG indicator 15.3.1 (Proportion of land that is degraded over the total land area) could play a pivotal role in the estimation based on the assessment of available datasets related to three sub-indicators (Trends in Land Cover, Productivity, and Carbon Stocks) that needs to be reported and validated by national authorities. Besides, ecosystem-based land restoration has various other multiple benefits such as agricultural intensification (Abhilash et al. 2016) land degradation neutrality (LDN) (Keesstra et al. 2018), thereby attaining other UN-SDG such as no poverty, i.e., Goal No. 1, zero hunger (Goal No. 2), good health and well-being (Goal No. 3), gender equality (Goal No. 5), decent work and economic growth (Goal No. 8), responsible consumption and production (Goal No. 12), climate action (Goal No. 13), and peace, justice, and strong institutions (Goal No. 16) (Edrisi et al. 2019).

In this context, the present article was aimed to conduct a meta-analysis to (i) assess the trend in the publications related to land degradation, its processes and restoration strategies; (ii) analyze the severity, global extent, and drivers of land degradation; (iii) suggest the sustainable strategies for the on-site land restoration and regaining ES and approaches to ensure the stakeholders' involvement; (iv) highlight on the challenges of ecosystem-based land restoration approaches coupled with suggestive policy implications.

2 Methodology Employed

2.1 Assessing the Trend on the Publications Related to Land Degradation and Restoration: Literature Search and Selection Criteria

To select research on the restoration of degraded lands, the scientific bibliographic databases were focused on, and a systematic review of the literature was conducted. The search parameters focused on the research associated with land degradation and restoration literature. This study used the PRISMA "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" guideline. It is a widely accepted approach for a systematic review (Moher et al. 2010). The literature search was conducted using the Scopus database (www.scopus.com). The titles, abstracts, and keywords were searched for all peer-reviewed publications. The searched articles were published between the start of 1990 and the end of 2021. The published scientific documents were assessed to get the trends in land degradation and restoration studies. A combination of keywords was used under the '(TITLE-ABS-KEY ("land degradation" OR "land pollution" OR "land contamination" OR "land reclamation" OR "land restoration" OR "restor* land" OR "land development" OR "deforestation" OR "reforestation" OR "forest landscape restoration" OR "ecosystem* servic*" OR "land-use change" OR "soil erosion" OR "land invasion" OR "land rehabilitation" OR "land revitalization" OR "land remediation") AND TITLE-ABS-KEY ("trend*" OR "impact*" OR "strateg*" OR "action*" OR "field" OR "success*" OR "fail*" OR "field implication" OR "field project*" OR "scenario*")),' where "*" denotes a fuzzy search. Further, the search was limited to only English literature. This search resulted in the 89,012 documents and the 'Analyse Results' option was clicked, and 'Publication Years' were closely examined to assess these results. Moreover, the same keywords were searched under 'TITLE-ABS-KEY' AND 'TITLE'-Article search to be more accurate. This search resulted in a total of 3712 document bibliographies.

Considering the framework of the Scopus database, grey literature was unconsciously discounted. Moreover, there is a chance that various land degradation and restoration studies could not be published in peer-reviewed literature. However, they are published as governmental and non-governmental reports and working papers. To target these studies, the first and second search criteria were used in Google Scholar at the end of December 2021. According to the relevance sorting, this search resulted in 19,300 possible documents, which was further limited to the first 1000 records. It was likely that the current search criteria could not capture additional grey literature that did not mention the specific keywords mentioned above. Therefore, it is tedious to develop searching criteria to recognize entire land degradation and restoration studies.

A total of 2093 documents were screened under the first selection (1093 from Scopus and 1000 through Google Scholar) (Fig. 1). The 1093 documents from the Scopus database have been found by filtering as per the Bradford's Law Zone representing the core publications under the bibliometrix package in the R-statistical software. Those publications were only considered, which had the mention of the land degradation, restoration, and/or ES in the Title, Abstract, or Keywords. If the content or context was implicit, only abstracts were focused on identifying those aspects. Furthermore, the final selection considered only those publications published after 2002 until 2021 (last 20 years) that resulted in a total of 117 document records (Fig. 1; Supplementary Information (SI); Table S1).

2.2 Analyzing the Severity, Extent, Drivers, and Processes of Land Degradation

For analyzing the severity of land degradation, a global map was developed using the data products of GLASOD. It was processed under the ArcGIS Desktop 10 (copyright© 2010 ESRI) (Data Source: GLASOD datasets, Available at http://www.isric.org/). The GLASOD datasets were recognized under two broad categories: first, the soil degradation by displacing soil materials, including water and wind erosion. Second, soil degradation by the internal soil physical and chemical deterioration. Finally, by compiling these two broad categories, the parameters were set to the five categories, light, moderate, strong, extreme, and non-degraded types of land degradation.

Moreover, the 117 empirical studies were further categorized under the different land degradation processes per the IPCC (2019). The IPBES (2018) suggested different land

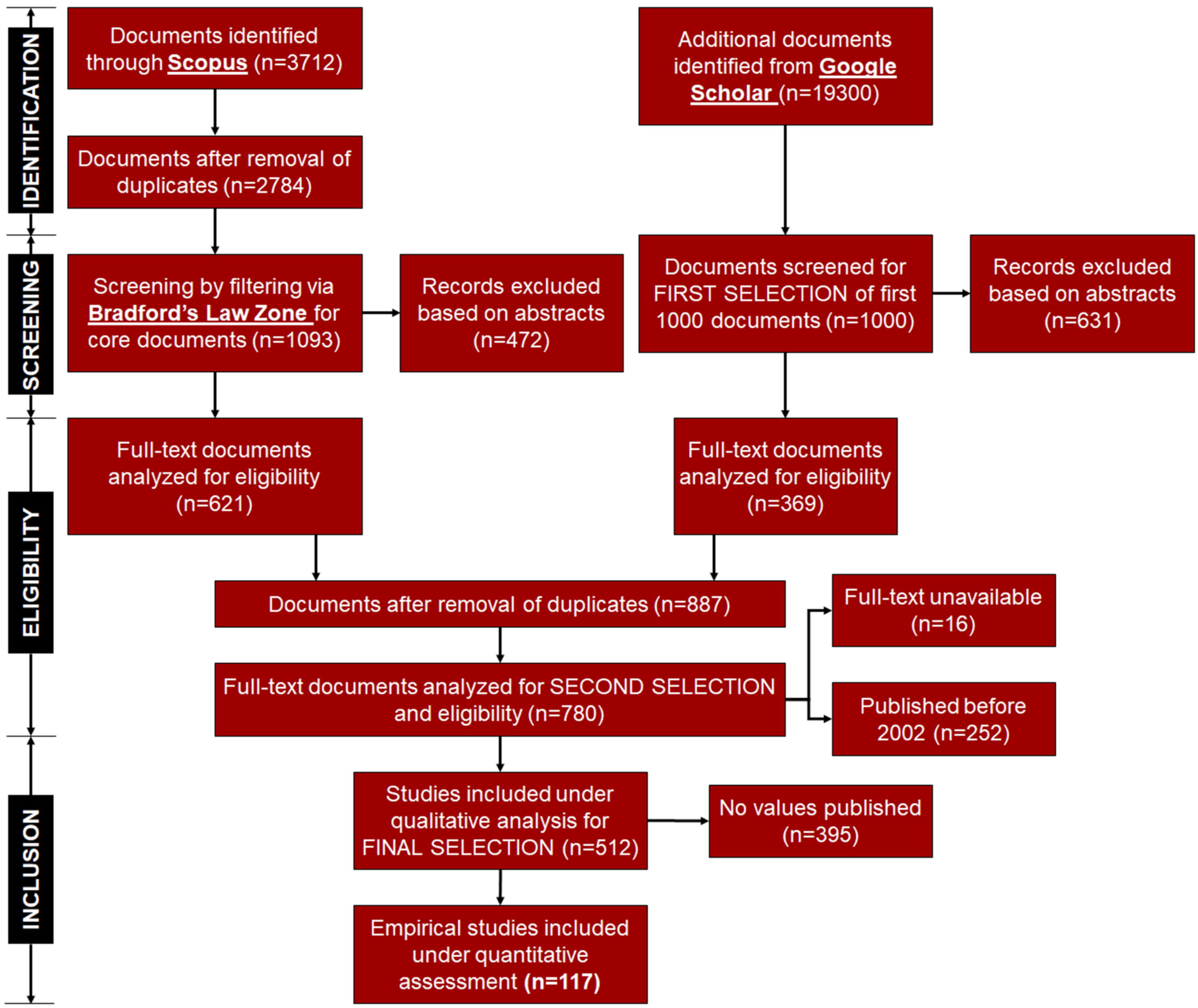

Fig. 1 Search criteria and methodological framework considered under the systematic literature review through a modified version of the PRISMA "preferred reporting items for systematic reviews and meta-analyses" guidelines and rules (Adapted from Moher et al. 2010)

degradation drivers (direct or indirect) were further checked for the explored subset of 117 empirical studies. Each of those empirical studies strictly dealt with the specific drivers of land degradation (Table S1). The drivers of land degradation in these studies were classified as per the IPBES (2018) and land classes (Oldeman et al. 1990). Moreover, these studies were further categorized according to Hobbs and Norton's restoration and conservation principles (1996) and Fischer et al. (2006) to analyze the focus of the studied empirical publications.

2.3 Statistical Analysis

The exported documents (BibTex file format) were analyzed under the bibliometrix package in the R-statistical software (version 3.6.1) copyright© 2019, The R Foundation for Statistical Computing for conducting the trend analysis. The compiled data were subjected to the R-statistical software to develop the heat-map graphs for further assessment according to the methodological framework adapted by IPBES (2018). It was meant to analyze the extent and drivers of land degradation in the different regions and countries.

3 Results

3.1 Trend in the Publications Related to Land Degradation and Restoration

According to the conducted meta-analysis, the primary focus on highlighting the importance of land through these ES mainly was made on biodiversity maintenance, with 20.6%

of the studies across the reviewed empirical research. It was followed by the further emphasis on food, fiber, and fuel provision (19.3%), climate regulation (16.0%), carbon sequestration and nutrient cycling (13.0%), and so on (Fig. 2).

As per the reviewed studies, the processes leading to land degradation were broadly induced by cropping and grazing that has crossed the potential of the land during adverse conditions such as droughts, floods, etc. (Table S1). General documents (89,012 according to Scopus database) on land degradation, restoration, and ES have significantly increased over the years (Fig. 3). The assessed empirical studies included 8 biomes in 46 countries encompassing all

A

B

Ecosystem services provided by land	Percentage (%) of literature (out of 2093 documents) mentioning the particular services in the title
1. Biodiversity maintenance	20.60
2. Provisioning for food, fiber & fuel production	19.30
3. Climate regulation	16.00
4. Carbon sequestration & nutrient cycling	13.00
5. Human habitation & infrastructure development	10.90
6. Hydrological cycling	10.50
7. Cultural heritage	08.00
8. Flood regulation	01.70

Fig. 2 **A** Ecosystem services based on the meta-analysis provided by the land systems (the numbers represent the concerned services mentioned in the table. **B** The number shows the percentage of the studies depicting the concerning ecosystem services

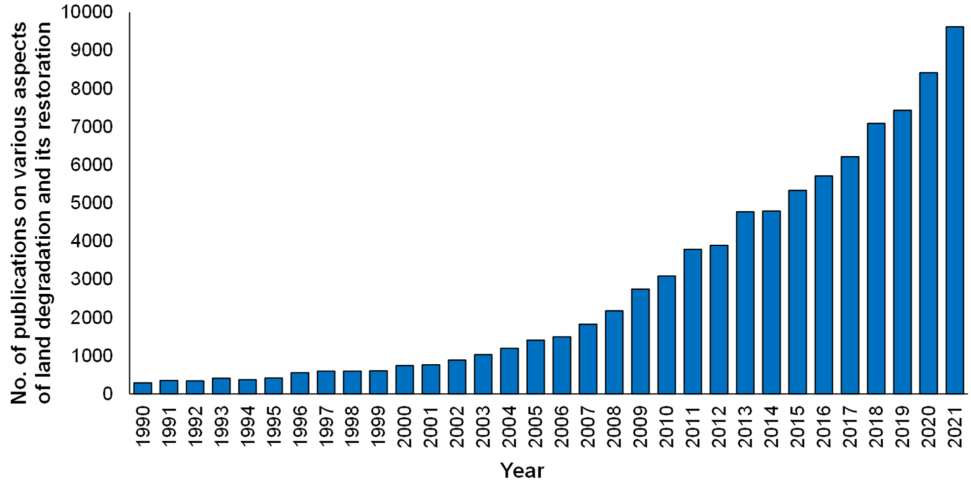

Fig. 3 Number of publications on various aspects of land degradation and its restoration as per the Scopus-based survey (www.scopus.com)

continents except Antarctica. The most frequent countries in the scientific production among the studied keywords were China (19 studies), USA (14), Spain (9), Germany, Sweden (5 each), Brazil (4), Australia, Chile, Ethiopia, Indonesia (3 each), India, Italy, Mexico, Nepal, Portugal, Thailand, Uganda, Zambia (2 each), and rest of the countries have shared single empirical studies (Fig. 4). The most pre-dominating socio-ecological systems were the cultivated systems encompassing the croplands and grazing lands representing (55 studies) followed by forest ecosystems (54), urban systems (20), grassland ecosystems (11), coastal ecosystems (6), dryland ecosystems (5), Karst and mining areas (1 each) (Table S1).

Moreover, the empirical studies also focused on the different land degradation processes classified accordingly based on IPCC-identified land degradation processes. The primary degradation process was found to be soil erosion by water (28.2%), followed by woodland encroachment (25.6%), Species loss/compositional shifts (24.8%), Nutrient depletion (12%), Organic matter decline (6.8%), Invasions/woody encroachments (5.1%), Salinization/Compaction/Hardening (4.3%), Drying of continental waters/wetland/lowlands, Soil microbial and mesofaunal shifts, Soil erosion by wind (3.4% each), Coastal erosion, and Increased burning (2.6% each), Acidification/Over-fertilization/Metal toxicity/Pollution, Biological soil crust destruction, and Flooding (1.7% each), Sodification, Subsidence, and Waterlogging of dry systems (0.8% each) (Fig. 5). Furthermore, these studies utilized various kinds of suggestive restoration or conservation strategies, which included afforestation, reforestation, no-tillage, agroforestry, reduced tillage, integrated ES valuation and management, monitoring studies, nature-based solutions, organic farming practices, urban agriculture, urban settlement management, and various others (Table S1).

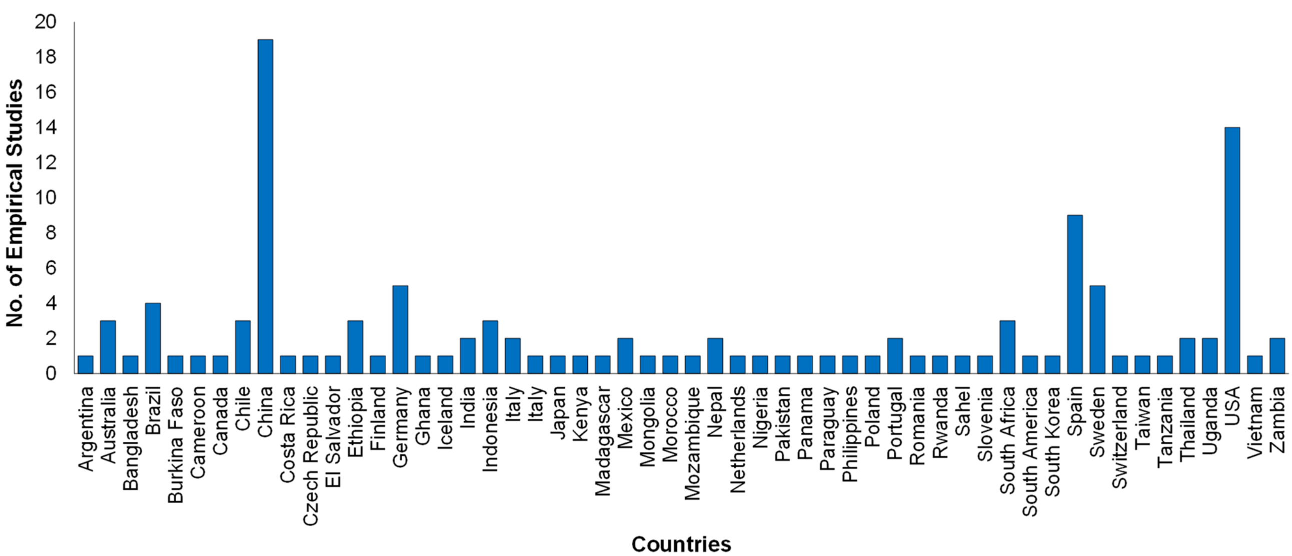

Fig. 4 Country-wise distribution of empirical studies ($n = 117$) on the 'land degradation,' 'land restoration,' and 'ecosystem services'

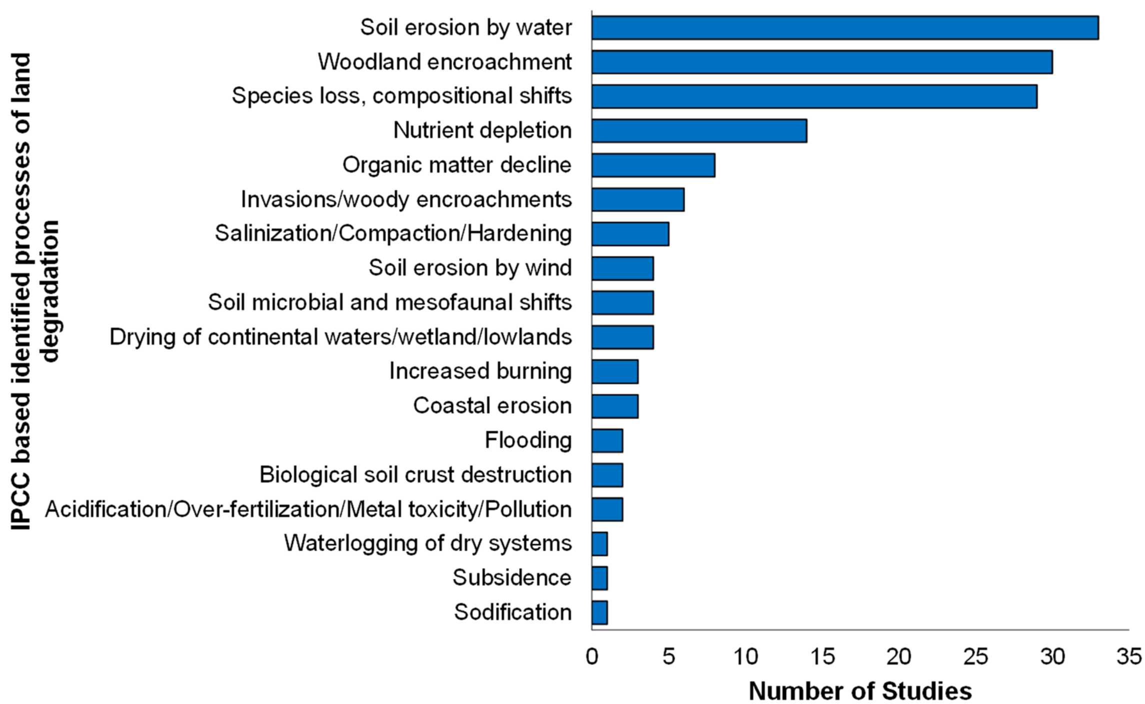

Fig. 5 Empirical 117 studies classified as per the IPCC-based identified land degradation processes after the manual review and assessment

3.2 Drivers, Severity, and Extent of Land Degradation

Drivers are the factors that trigger land degradation processes (IPBES 2018). These drivers can be direct (natural and anthropogenic) or indirect. The significant drivers of degradation documented in the explored empirical publications were grouped according to the categories described by the IPBES (2018). These drivers were the Cropland expansion (31 studies), Infrastructure development and urbanization (28), Climatic (26), Socio-economic (24), Demography (20), Non-timber natural resource extraction (11), Grazing land mismanagement (8), Cultural (7), Energy production and extractive industrialization (7), Fire regime change (5), Institution and governance (5), Invasion occurrences (3), Lifestyle (3), and Science, knowledge, and technology (2) (Table S1). The extent and the severity of global land degradation have been depicted in Fig. 6 as per the datasets accessed from http://www.isric.org/. According to Fig. 6 majority of the land area was moderately degraded, followed by light, strong and extreme. Moreover, from the empirical studies, it was also found that most of them were moderately degraded (47%), followed by light (27.4%), strong (2.6%) (Table S1).

Furthermore, from the reviewed empirical studies, a heat-map graph was prepared as per the methodological framework of IPBES (2018), shown in Fig. 7. According to the results obtained, it was anticipated that there was a more significant impact of land degradation in the Asia–Pacific and African regions than that of the American and European nations. The critical drivers in Asia–Pacific and African regions were infrastructure development/urbanization, demography, economic attributes depicting the extreme decrease in land viability, and ES. However, the fire-regime shift and invasiveness were the significant drivers in European countries. In contrast, the climate attribute was the emerging driver in the American context. Moreover, essential drivers among all reviewed studies were the cropland expansion (18.11%) followed by climatic (14.96%), infrastructure development and urbanization (14.17%), and demography (8.66%), contributing for more than 55% among the enlisted and identified land degradation drivers. Also, these drivers were affected from moderate to extreme strength and depicted an increasing trend in many regions of the world (Fig. 7a–d).

4 Discussion

4.1 International Initiatives Related to Significant Land Restoration Projects

Ecosystem restoration is a process that currently encompasses the basic science of revitalizing the disturbed ecosystem (Edrisi and Abhilash 2021). Agencies worldwide

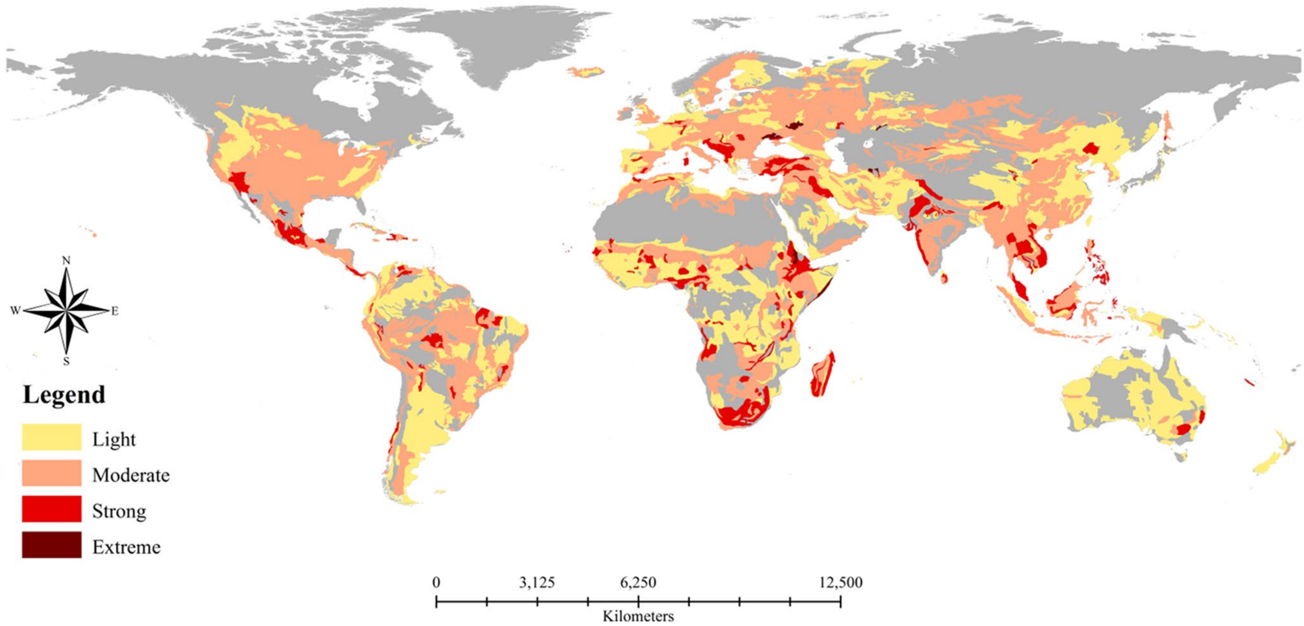

Fig. 6 Extent and severity of global land degradation: the class with 'light' terrain degradation shows slightly reduced suitability for the agricultural practices but is still suitable for utilization in the local farming systems. The 'moderate' deterioration depicts the considerably declined agricultural productivity but can be utilized under local farming systems. Furthermore, the class 'strong' degradation shows the terrain cannot be reclaimed at the farm level practices. It requires significant engineering works for its restoration. The 'extreme' type of category indicates that the terrain is irreclaimable. (Data source: http://www.isric.org/)

are undertaking various initiatives to restore degraded ecosystems. For example, a UNEP report suggests that restoring 350 Mha of degraded land during the years 2019 to 2030 could generate ES worth US$9 trillion in and capture an additional 13 to 26 Gt of GHGs from the atmosphere (UNEP: www.unep.org). Currently, 57 countries, several governmental bodies, and private agencies have a consensus to convoy more than 170 Mha of the restoration program (Chazdon et al. 2017). This target has developed from regional efforts such as the Initiative 20 × 20 in Latin America to restore 20 Mha of degraded lands by 2020. Besides, the AFR100 African Forest Landscape Restoration Initiative targets the restoration of 100 Mha of degraded lands by 2030. Moreover, 20 Mha of degraded forests was targeted to be restored by 2020 across different Central and South American countries. This initiative has been supported by US$365 million from the investors (World Resources Institute: www.wri.org).

Similarly, some efforts have been emphasized to combat desertification—a mosaic of forest plantings across Africa. This initiative is partnered by more than 20 countries with several NGOs as well as industry partners that funded around US$ 1.1 billion from the investors (The World Bank: www.worldbank.org). Currently, a global target is to restore around 150 Mha of disturbed and degraded land ecosystems, under priority of the United Nations Rio + 20 Conference on Sustainable Development (IUCN: www.iucn.org). In addition, the Global Land Project (GLP) has currently endorsed the HERCULES Project that deals with the Sustainable futures for Europe's heritage in cultural landscapes. Findings of this project could help in developing tools for understanding, managing, and protecting landscape functions and values.

Moreover, the REDD-PAC project is under the GLP that indulges in land-use modeling at the global and regional scales to support national and regional REDD + policies. There are several other projects of GLP such as 'Impacts of Reducing Emissions from Deforestation Degradation and Enhancing Carbon Stocks (I-REDD +),' 'Ecosystem Services, Well-being, and Justice: Developing Tools for Research and Development Practice' and 'Agricultural Landscapes under Global Climate Change: Processes and Feedbacks on a Regional Scale.' Similarly, Global Environmental Facility (GEF), in association with Society for Ecosystem Restoration (SER), promotes several other land restoration initiatives. The Global Soil Biodiversity Initiative (GSBI) has also been associated with revitalizing degraded soil resources.

Moreover, various landscape-level implications have been undertaken to restore different marginal and degraded lands worldwide (Fig. 8), supported by multiple governmental and non-governmental organizations such as the World Bank, Initiatives 20 × 20, Plant It 2020, Capital Region Land-keepers Trust, etc. These international initiatives aim to restore

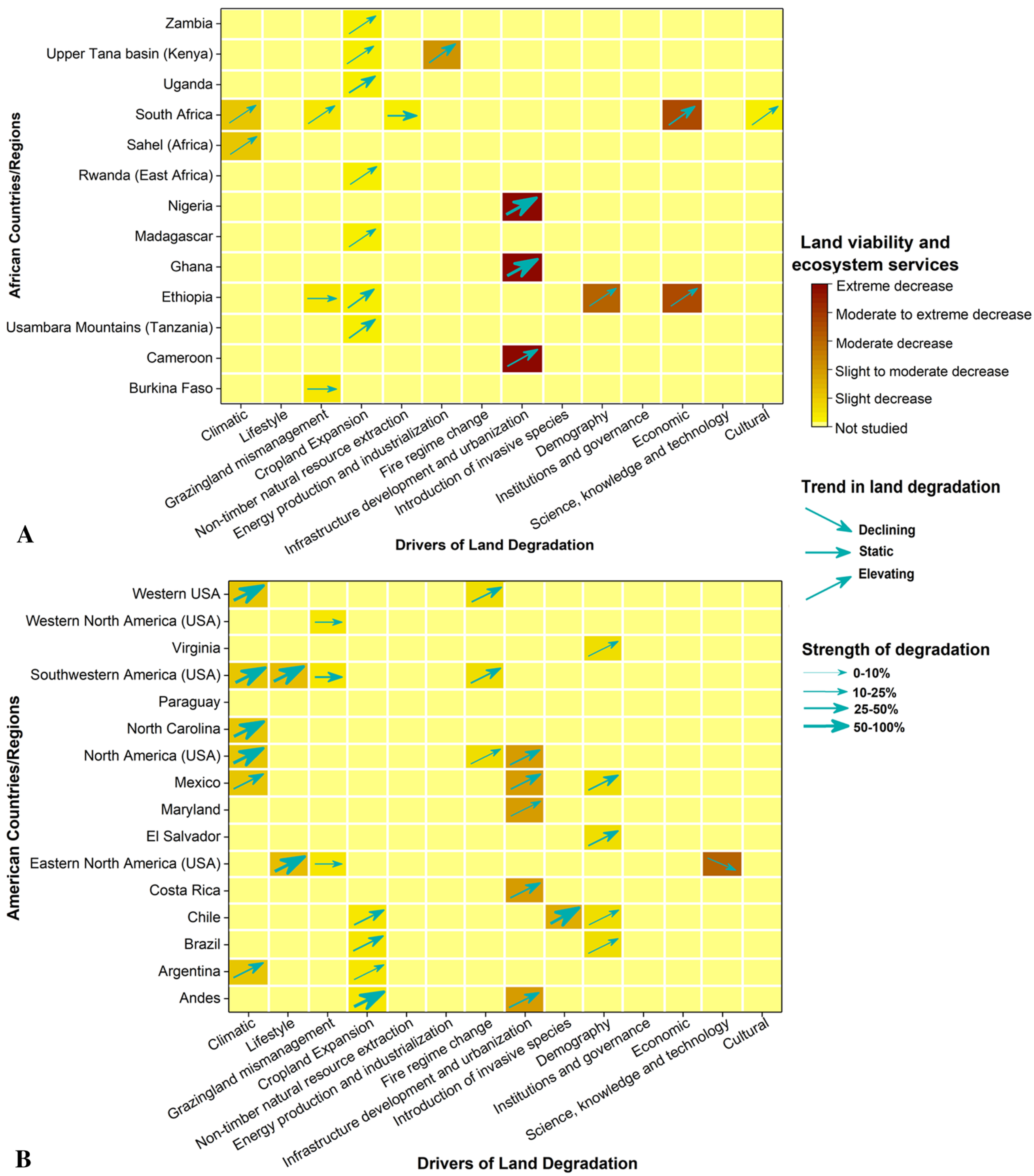

Fig. 7 Trend and strength of land degradation and its subsequent impact on the land viability and ES in different countries and regions: the 117 empirical studies were digitized to develop a heat map in the R-Statistical software. The IPBES 2018, has already prescribed the land degradation drivers. (Detailed data has been provided in Table S1)

the degraded lands with specific timeline targets. Such a restoration program often depends on the complexities of ecosystems, land-use scenarios, and ongoing degradation.

However, some restoration programs face various critical difficulties in their accomplishments. Since around 30% of the restoration scenario usually fails, and another 35% do

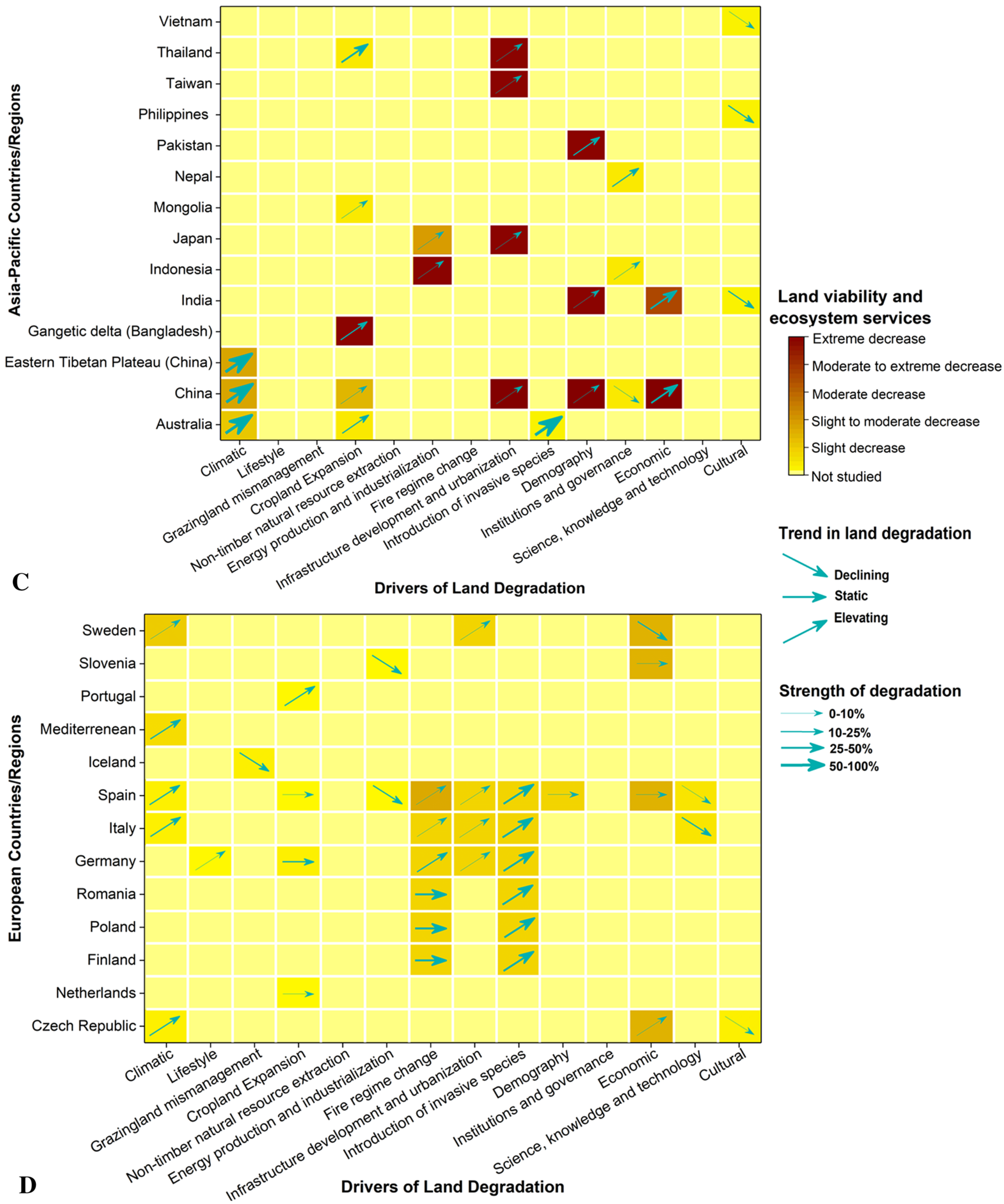

Fig. 7 (continued)

not accomplish properly, there are possible failures in some restoration programs (Brasser and Ferwerda 2015). Similarly, as shown in Fig. 8, most restoration projects are in their mid-way of accomplishments, and some are getting completed with certain shortcomings in line with obtaining the diverse ES. Therefore, it is necessary to focus on the aims of

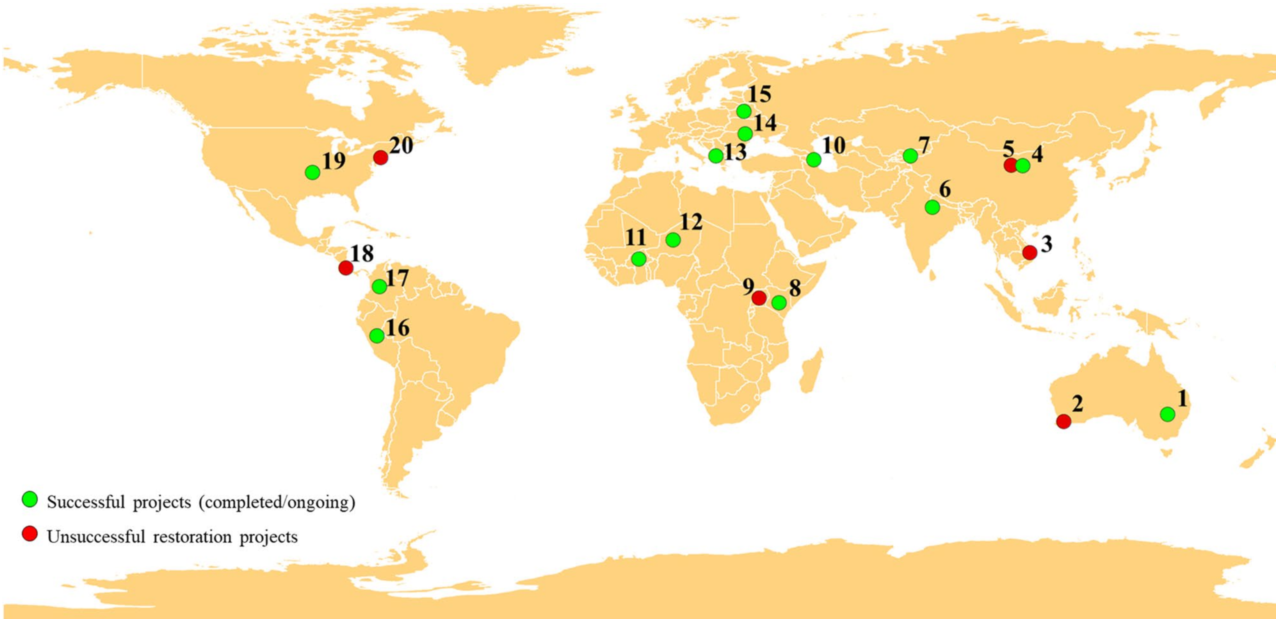

Fig. 8 Field level major restoration initiatives undertaken all across the world: (1) Restoration of Temperate Grassy Woodland in South eastern Australia[a]; (2) Eco-restoration of degraded landscapes of Gondwana Link, Australia[b]; (3) Single species approach in Vietnam[c]; (4) Desertification control and ecological protection in Ningxia, China[d]; (5) Three-North forest shelterbelt 'green wall of China'[e], (6) Sodic lands reclamation in Uttar Pradesh, India[d]; (7) Integrated forest ecosystem restoration in Kyrgyz Republic[d]; (8) Climate adaptation in arid and semi-arid lands of Kenya[d]; (9) Restoration beyond carbon in Uganda[c]; (10) Integrated biodiversity conservation in Azerbaijan[f]; (11) Decentralised forest and woodland restoration in Burkina Faso[d]; (12) Acacia-based carbon sequestration for restoring degraded lands of Niger[d]; (13) Afforestation and reforestation of abandoned lands in Albania[d]; (14) Soil and non-renewable natural resources conservation in the Moldova of Europe[d]; (15) Silvicultural management practices in the degraded forest of Belarus, Europe[d]; (16) Reforestation program in Peru by PlantIt 2020 g; (17) Reforestation in the grazing land of Colombia[d]; (18) Widespread reforestation in Costa Rica[h]; (19) Ecosystem restoration of Ozark Highlands in USA, (20) New York's million tree initiative[e]. [[a]www.landkeepers.org.au, [b]Moreno-Mateos et al. 2012; [c]Brasser and Ferwerda 2015, [d]www.projects.worldbank.org, [e]David et al. 2016, [f]UNCCD 2017, [g]www.plantit2020.org, [h]Andam et al. 2018]

LDN and UN-SDG with an approach toward transdisciplinary research (Edrisi and Abhilash 2021). Consequently, it must be mediated through ecosystem-based land restoration under holistic and on-site restoration of degraded lands for regaining diverse ES.

4.2 Strategies for Land Restoration and Regaining ES

From the reviewed studies, it was observed that several approaches were utilized to restore the degraded lands. The current research classified these approaches as per the guiding principles for the restoration and conservation strategies proposed by Hobbs and Norton (1996) and Fischer et al. (2006) (Fig. 9). Most of the studies (43.6%) aimed to enhance the restoration/conservation values in the degraded/protected/productive landscapes. Only 14.5% of the studies (17 studies) emphasized the "improvement of the reproductive potential in the degraded production lands," and 12.8% (15 studies) targeted the "restoration of the highly degraded lands." Therefore, it is suggested that more focus should be made on the studies related to guiding principles highlighted above for land restoration, which could ensure the success of the restoration projects.

Moreover, it has been observed from the reviewed studies that the adoption of appropriate on-site restoration practices in the degraded land systems enhanced the biodiversity and ES. Contrastingly, various off-site restoration measures have significantly improved the soil quality but failed under field conditions (Benayas et al. 2009). Hence, an emphasis must be delivered frequently on bridging the gap between science and the practice of restoration (Menz et al. 2013). Since the associated ES are directly related to human well-being, the on-site land restoration will have a high impact.

Literature provides ample shreds of evidence related to the various on-site land restoration measures. A study from the Indian Himalayas suggests that stubble retention under conservation tillage enhances the yield and fodder production from the crops like wheat and rice. It also results in the carbon sequestration potential over the control by 0.61 Mg ha^{-1} year^{-1} (Bhattacharyya et al. 2015). Moreover, the measures that reduce the soil organic matter

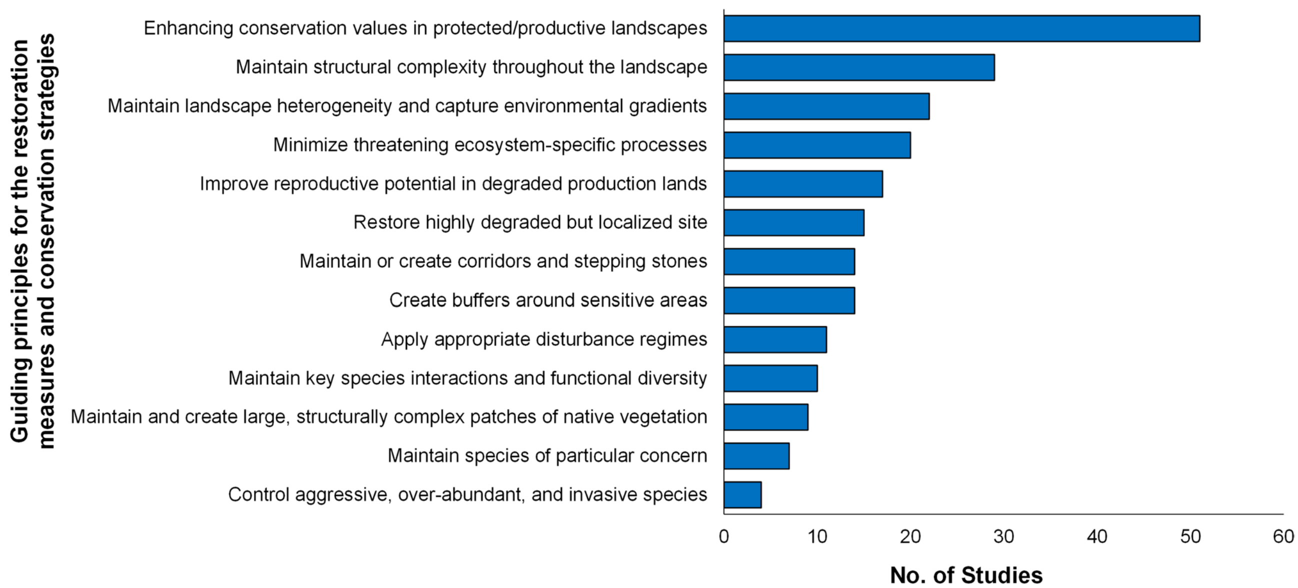

Fig. 9 Guiding principles for the restoration measures and conservation strategies on the degraded lands from the reviewed empirical studies

loss are usually the conservation tillage, crop residue management, and integrated crop-livestock-forestry systems (Cowie et al. 2011). The technical sink potential through these management practices is estimated to be 0.3–0.5 Pg C year^{-1} as compared to the desertification control (Lal et al. 1999). Moreover, it varied from 0.4 to 1.0 Pg C year^{-1} for restoring the salt-affected soils (Lal et al. 2010). Introducing cover crops leads to sequestering the carbon between 0.1 and 1 t C ha^{-1} year^{-1} (Smith et al. 2008). Furthermore, it has been estimated that 0.12 Pg C year^{-1} could be captured globally through highly efficient restoration practice. It would compensate for 8% of the direct annual GHG emissions from agriculture in the arid regions (Poeplau and Don 2015).

Green manure crops, particularly *Sesbania aculeata,* accumulate 133 kg N ha^{-1} with the dry matter production of 23.2 t ha^{-1}. Similarly, other crops such as Sunnhemp, cowpea, and *Pillipesara* sp. are known to assimilate 134, 74 and 102 kg N ha^{-1}, and dry matter production of 30.6, 23.2, and 25.0 t ha^{-1}, respectively, thereby suggesting an efficient technology and economically viable strategy to conserve and enhance soil organic carbon (SOC) and nutrients, especially nitrogen (Kumar et al. 2013). Moreover, an organic carbon input of around 1.5 Mg C ha^{-1} year^{-1} has been observed in the Green manure legume-based cropping system compared to the bare fallow systems with an average carbon capture potential of 0.55 Mg ha^{-1} year^{-1} (Dabin et al. 2015).

Furthermore, compost application via ‘scoop and dump technique’ is also one of the novel approaches utilized by Sax et al. (2017), under which the urban marginal lands are restored. They reported that various soil quality indicators such as bulk density, water holding capacity, and organic matter improved significantly to 0.89 g cm^{-3}, 0.22%, and 8.43%, respectively, in the compost treated lands as compared to the degraded control with values 1.47 g cm^{-3}, 0.15%, and 3.23%, respectively, during the 12 years of the study period. Conservation tillage (CT) is another practical technique for crop residues utilization to enhance and maintain the soil carbon pool. Carbon sequestration potential by 4913 Tg C if 417 Mha enhances the land area under CT. It represents the global carbon sequestration rate of 0.125 Pg C year^{-1}, resulting in a worldwide increase of SOC content by 0.002% year^{-1} (Lal 1997). However, effective water utilization is one of the critical challenges in the dryland and barren areas raised due to excessive water harvesting. Around 130,000 ha of abandoned and degraded lands in central Burkina Faso have been restored by adopting an indigenous practice—tassas and zaï. Cereal yields in these regions rarely achieved 300 kg ha^{-1}. However, the improved lands resulted in cereal production ranging from 700 to 1000 kg ha^{-1} (Pretty et al. 2003).

All the strategies described above and approaches have been directed towards restoring or remediation of specific soil attributes or contaminants, uplifting mostly the single type of ES such as food, fodder, or fiber yield, above- or below-ground biodiversity, etc. However, sustainable integrative technologies (Upadhyay and Edrisi 2021) can ensure efficient restoration processes. Therefore, we propose that local knowledge systems should be coupled with an appropriate validation measure. This would support sustainable restoration depending on the type of degradation and regaining multiple ES. Development of marginal and degraded lands for regaining diverse ES could also provide value-added bioproducts, including bioplastics, biocomposites, biofuels, biosurfactants, pharmacologically active products, industrially important solvents, and many others. This would undoubtedly enhance the viability of the land ecosystems and develop resistance towards ecological perturbations. Land restoration thus could help to mitigate further land degradation, ultimately contributing towards LDN and UN-SDG.

4.3 Strategies to Ensure the Stakeholders' Involvement

One of the challenges for managing and remediating degraded lands is to include all the concerned stakeholders in the process actively (Okpara et al. 2020). For remediation and containment of degraded land resources, we have to involve different stakeholders, including landowners, financiers, environmental or engineering consultants. Besides, we also must focus on other stakeholders like pressure groups, local councils, residential associations, etc. Currently, there is a lack of insight into how to facilitate the learning between these multiple stakeholders involved in the restoration and management of degraded lands. Intensive and frequent interaction is required between the stakeholders involved in restoring and managing degraded land resources (Hou and Al-Tabbaa 2014). Active involvement of the restoration technology experts and policymakers would support the involvements of the owners/managers of degraded land. It could also enhance the social acceptability of new technologies and policies (Hou and Al-Tabbaa 2014). Rapid land degradation over the years has aroused the demand for economically sustainable remediation initiatives; hence, it requires various financial and regulatory incentives to ensure stakeholders' involvement (Hou and Al-Tabbaa 2014). As degraded land is too a valuable asset, site owners often require rapid and sustainable restoration practices (Abhilash et al. 2016). According to the United States Environmental Protection Agency (USEPA), remediation with current remediation practices such as bioremediation of already contaminated sites may require 100–200 years (USEPA 2004). However, even slow technologies like bioremediation and phytoremediation could help in generating a green economy. It would be possible to utilize the generated biomass as a substrate for food, feed, producing biofuels, biosurfactants, platform chemicals, etc. (Edrisi et al. 2019; Edrisi and Abhilash 2015a). It will also offer socio-economic benefits by diversifying the regional manufacturing into newer products that may provide local labor employment, helping enhance participation of the involved stakeholders (Hou and Al-Tabbaa 2014; Edrisi and Abhilash 2015b).

Continuously increasing land degradation also demands a reconsideration of strategies making land restoration a joint-learning process. It should target different stakeholders taking account of local traditions, knowledge, mindsets, and the microclimatic conditions. De Pina Tavares et al. (2014) described a hybrid combination to solve the desertification problem in the Cape Verde archipelago. This approach considered the experiences and skills of the local people with the scientific knowledge of external stakeholders. The active involvement of stakeholders also requires initiatives from government agencies by making policies and regulatory guidelines and providing a technology toolkit to promote sustainable practices in contaminated site clean-up (Manero et al. 2020). For example, a traditional technique of fire ban adopted by the Portuguese government agencies and integrated restoration of rangeland areas by improved incorporation of scientific and technological knowledge has helped stakeholders' involvement in designing effective strategies to reduce fire risk, thus offering increased safety and sustainable restoration of land resources (Carreiras et al. 2014).

4.4 Challenges in Ecosystem-Based Land Restoration and Way Forward

It is observed that globally several restoration projects at a landscape level suffer from various shortcomings and failures due to the lack of communication and unawareness to bridge the gap between science and practice (David et al. 2016). For instance, New York's million tree initiative aimed to restore 809 ha of lands failed due to the lack of guidelines for species selection, placement, and monitoring (Cabin et al. 2010). Similarly, the four-forest restoration initiative in the Arizona National Forest targeted around 121,406 ha of lands, and the well-known mangrove restoration project, including 44,000 ha of lands in the Philippines, failed due to the lack of scientific recommendations. The later project faced the problem of more than 90% of seedlings death or dismally stunted within a year of planting (David et al. 2016). Therefore, more holistic approaches are required to overcome these failures, and other issues like stakeholders' involvement must be emphasized. Apart from the ecosystem point of view, these issues could be the cost–benefit analysis of the process, societal justice, cumulative social impacts, stakeholders' involvement, certification, and marketing of the products produced to achieve the large-scale utilization of degraded ecosystems (Fig. 10). Globally, the emphases are made to re-establish the concurrent restoration practices to achieve the goal of sustainability. This perspective also becomes much more intense in developing nations since the technologically deprived countries cannot afford upgraded technologies for such restoration programs. Hence, these local and regional frameworks usually influence the socio-economic considerations of the concerned nations. It also includes the educational level, cultural aspects, and policies, including environmental and social targets (Liu et al. 2019).

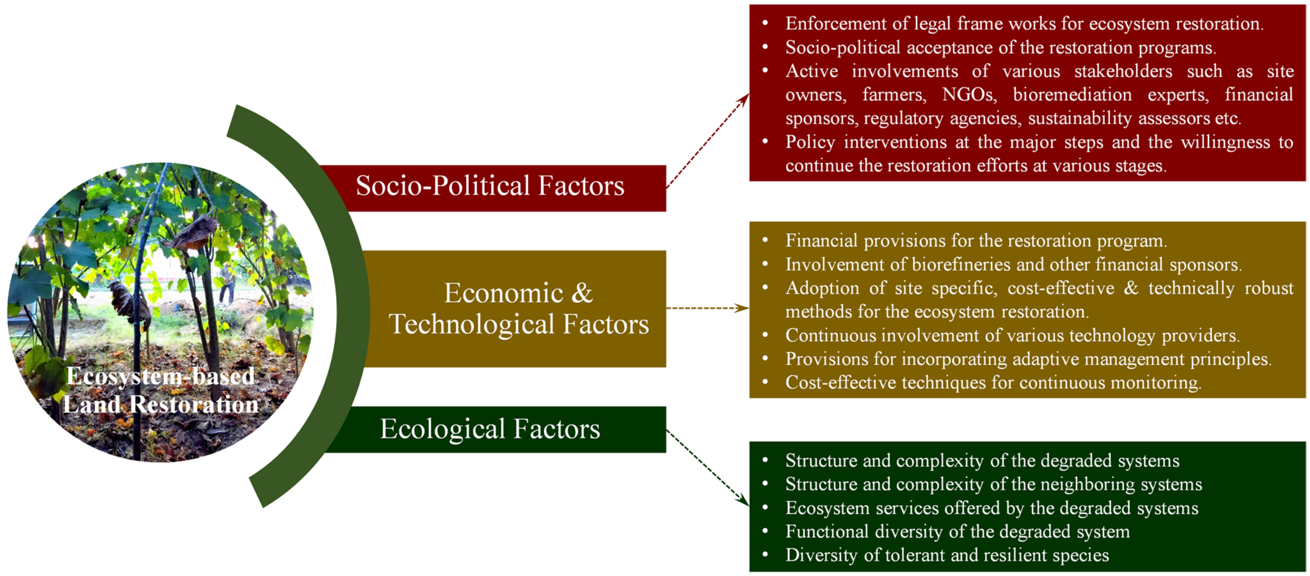

Fig. 10 Critical factors to be undertaken for sustainable ecosystem-based land restoration

5 Concluding Remarks and Policy Implications

The study suggested that most of the restoration works have focused on enhancing the conservation or restoration values, which is necessary to conserve productive lands and restore already degraded lands. However, the studies related to restoring the highly degraded land or improving its productivity are still not meeting the demands. Therefore, it is highly needed to adopt the systematic science of ex situ restoration into the field for successful on-site land restoration for regaining ES and meeting UN-SDG.

It is pertinent to identify the critical issues of the degraded landscape to achieve sustainable restoration. Furthermore, integrative technologies with the coupled local knowledge need promotion under proper validation approaches. It could offer successful restoration of ES and provide additional benefits to people. As per the meta-analysis, though the process had several success stories, still cautious learning is required from the concurrent shortcomings. Hence, field-oriented implementations and restoration should be empirically adopted under long-term projects.

Moreover, several factors such as local people's perceptions, stakeholders' involvement, and youth engagements need to be undertaken during action plan development for restoring the degraded lands successfully. These factors could be the holistic approaches encompassing the whole framework of sustainable restoration (i.e., ecological, socio-political and economical, and technological factors). However, various factors are yet to be explored and monitored while adopting the restoration practices for harnessing the multiple benefits of LDN and attaining UN-SDG.

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Data Availability All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Declarations

Conflict of Interest The authors declare no conflict of interest.

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