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Synthesizing strategies and innovations in combating land degradation: a global perspective on sustainability and resilience

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ABSTRACT

This paper presents a comprehensive examination of land degradation, a critical environmental challenge with far-reaching implications for agricultural productivity, ecosystem sustainability, and socio-economic stability worldwide. With the backdrop of escalating human population pressures and the exacerbating impact of climate change. It delves into the causes and consequences of soil erosion, desertification, salinization, and biodiversity loss, highlighting the interplay between natural processes and anthropogenic activities. Through a detailed review of literature spanning various remediation technologies, conservation practices, and policy frameworks, the paper critically assesses the effectiveness of current land management approaches, including the utilization of biosurfactants, remote sensing technologies, and agroforestry systems. Furthermore, it identifies significant research gaps and future directions, emphasizing the need for quantitative assessments, exploration of socio-economic impacts, and evaluation of restoration techniques. By offering evidence-based recommendations for policymakers and practitioners, this paper contributes to the global dialogue on sustainable land management and aims to catalyze action towards halting the advance of land degradation, ensuring food security, and preserving biodiversity for future generations. This work not only advances our understanding of land degradation challenges but also outlines a path forward for research, policy, and practice in the pursuit of environmental sustainability and resilience.

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1. INTRODUCTION

It is thought that land degradation, a serious worldwide environmental issue brought on by a variety of natural and human-caused factors, may be triggered by climate change [1], [2], these variables include erosion, the loss of organic matter, decreased soil fertility, and the effects of hazardous chemicals. On the other hand, it may result from inadequate management techniques pertaining to our natural resources, such as plants, water, and soils. More and more evidence points to the negative short- and long-term effects that land degradation has on nearby landowners, land users, society, and communities. The growing number of people on the planet and the resulting increase in food consumption have led to a greater need for easily accessible agricultural land. As such, it is critical to stop more land degradation and repair already-damaged regions. Degraded or marginal soils must be restored and conserved, and sustainable land use techniques must be put in place to provide food security for an expanding population. A variety of remediation techniques are employed in the effort to restore natural resources, albeit it should be noted that the majority of them have unintended consequences and are not considered ecologically safe. As a result, approaches for improving agricultural yields and protecting plants sustainably are of great interest to people all over the world. Investigating green technologies for the repair of troublesome soils is also a priority.

The main sources of amphiphilic chemicals, such biosurfactants, are microbes and plants. However, biosurfactants made by microbes work better than surfactants derived from plants because of their multifunctional qualities, quick synthesis, and capacity for large-scale manufacturing. When produced on an industrial scale, plant-based biosurfactants are expensive to produce but have excellent emulsification qualities. In [3], [4] have brought attention to the hydrophobic nature and solubility problems of plant-based surfactants, which pose additional obstacles. Hydrophobic chemicals usually have a lower water repellence, which increases their bioavailability [5]. It has been noted that biosurfactants have two different effects: they can either promote or hinder certain processes. These impacts rely on a number of variables, including the pollutants involved, the chemical makeup of the biosurfactants, and the physiological traits of the microorganisms. In addition to aiding in the swarming movement of microbes, biosurfactants also have a role in the physiological processes of signaling and growth within cells as well as improving the solubility and bioavailability of hydrophobic compounds [6]. The biosurfactants contribute to the production of biofilms by interacting with different bacteria proteins. This activity might lead to the alteration of the conformational shape of the enzyme. The breakdown of chemical contaminants will increase as a result of this alteration. According to Chen *et al.* [7], it accomplishes this via changing the specificity, activity, and functions of the enzyme. Because biosurfactants function as antibacterial agents and lower the incidence of disease, they may be able to support sustainable agriculture.

Deforestation is the main cause of land degradation, which has significant side effects such soil erosion, floods, and the loss of fertile soil. Over the course of several millennia, humans have cleared, grazed, and burned an enormous area in the aforementioned locations. Consequently, there has been significant soil erosion in these places due to the significant reduction of natural vegetation. But there are a lot of big challenges to overcome, such the possible effects of climate change and the quickly evolving social and economic landscape. The majority of the talk that is now being said about land degradation centers on the several facets related to water availability, distribution, and consumption. A large number of forest fires that started in the early 1990s led to runoff, flooding, and soil erosion. The public's opinion of land degradation was significantly impacted by the incidence of these fires. As a result, the known spring water sources' and streams' base flows' soil water retention capacity has dropped. The sources indicated above are essential to managing soil moisture levels and guaranteeing water supply for household use. Conversely, desertification usually happens after a protracted period of land deterioration. Because there is so little water in a desert, life cannot survive there for very long [8].

For human survival and societal advancement, land resources must be available [9]. Due to ecological deterioration, rising food demand brought on by population increase, fast urbanization, industrialization, and uncontrolled use of land resources, land degradation has worsened and accelerated over the 20th century [10], [11] states that the large proportion of land-roughly 60%-that is thought to be degraded is a major obstacle to the transformation of the world's land regions to sustainable usage. Accelerated land deterioration is said to pose a serious threat to soil health. An estimated 24 billion tonnes (BT) of soil are lost annually due to water erosion, with 75 BT of soil erosion occurring annually on agricultural land globally. An estimated $400 billion in financial damages result from every year global soil partnership (GSP), 2017. There have been different types of soil degradation on over 120.7 million hectares (ha) of land in India, according to the National Academy of Agricultural Sciences (NAAS), 2010. Soil erosion brought on by wind and water erosion is the main factor contributing to land deterioration. Approximately 71% of the country's degraded land, or 85.7 million hectares, is caused by this sort of erosion [12]. The majority of soil erosion-roughly 60.7%, or 73.3 million hectares—is the result of the phenomena of soil erosion, particularly due to water. However, of the total erosion, wind erosion accounts for around 10.3% (12.4 million hectares). Physical deterioration from mining and water logging, as well as chemical degradation from salinity, alkalinity, and acidity, are the main causes of the depletion of land resources. The deterioration of land is made worse by a number of important reasons. Among these include deforestation, or the loss of tree cover, which, according to global forest watch 2022, totaled 2.07 million hectares between 2001 and 2021 [13]. The Fertilizer Association of India (FAI), 2021 reports that the indiscriminate use of fertilizers totaling 32 million metric tons annually, intense rainfall exceeding 7.5 millimeters per hectare, uncontrolled grazing on

5.65 million hectares, and shifting cultivation on 7.6 million hectares are all contributing factors. The statistical area classification (SAC), 2021 study states that as of right now, 29.7% of the nation's land is degraded, or 97.8 million hectares (Mha). With a combined 23.7% of the total geographic area (TGA) made up of degraded areas, the states of Rajasthan, Maharashtra, Gujarat, Karnataka, Ladakh Union Territory, Jharkhand, Odisha, Madhya Pradesh, and Telangana have the highest percentage of land under these conditions. This amounts to more than two thirds of the country's whole degraded area.

Because to their lack of organic matter and soil nutrients, the degraded lands are not appropriate for the establishment of any kind of flora. If not effectively managed or maintained, these circumstances have the potential to last indefinitely and diminish output, with serious ecological and societal repercussions. Improving land productivity through the restoration of damaged soils is seen to be one of the most feasible approaches. Agronomic, mechanical, and biological techniques can be used to rehabilitate degraded fields [14]. One simple and economical method for implementing biological remedies is to cultivate crops, herbs, trees, and shrubs. The strain on forests and conventionally cultivated lands may be lessened by these measures. It is well acknowledged that agroforestry is a very successful biological strategy for raising agricultural yield and fostering environmental and economic sustainability. The ecosystem services provided by the agroforestry system include supplying, regulating, sustaining, and cultural services. These services either directly or indirectly support the rehabilitation of land [15]. The goal of the pro-people and pro-environment life movement, also known as lifestyle for environment, is to shift society's perspective from careless and wasteful consumption to intentional and sustainable use of natural resources, India made this effort a top priority. In addition, India has made an effort to uphold its dedication to tackling global environmental issues in order to protect Earth, the home of mankind. India uses a combination of national programs and international collaboration to show its dedication to combating climate change.

The motivation for this survey paper is to critically examine the pervasive issue of land degradation—a global environmental crisis with profound implications for ecological integrity, agricultural productivity, and human livelihoods. Acknowledging the escalating threat posed by the loss of fertile soil, desertification, and the degradation of natural resources due to anthropogenic activities and climate change, this paper aims to synthesize current knowledge, identify gaps, and explore sustainable solutions. With an understanding that land degradation affects not just the environment but also the socio-economic fabric of societies worldwide, the paper seeks to catalyze a more informed and integrated approach to land management. By evaluating various remediation technologies and conservation strategies, including the role of biosurfactants, remote sensing, agroforestry, and indigenous practices, this survey endeavors to contribute to the global dialogue on reversing land degradation trends, thereby ensuring food security, biodiversity conservation, and the well-being of future generations. The contributions are given below:

– Comprehensive synthesis of existing knowledge: it aggregates and synthesizes current research findings, technologies, and strategies addressing land degradation, providing a consolidated resource that highlights the scale of the issue, its multifaceted impacts, and the various efforts underway globally to mitigate these effects. By examining both the causes and solutions to land degradation, including innovative approaches like the use of biosurfactants, remote sensing technologies, and sustainable farming practices, the paper offers a broad perspective on the state of land health and conservation efforts.
– Identification of research gaps and future directions: through a meticulous review of the literature, this paper identifies critical research gaps and areas needing further investigation, such as the quantification of land degradation, the socio-economic impacts on affected communities, and the long-term effectiveness of restoration techniques. By highlighting these gaps, the paper sets the agenda for future research efforts and encourages the development of new methodologies and technologies to better understand, monitor, and address land degradation.
– Policy and practice recommendations: by analyzing the effectiveness of current land management policies and practices, this paper provides evidence-based recommendations for policymakers, land managers, and practitioners. It emphasizes the importance of integrated, multi-disciplinary approaches that combine traditional knowledge with modern conservation techniques, underscoring the role of international cooperation and community engagement in achieving sustainable land management and combating land degradation. This contribution is aimed at fostering a more coherent and effective global response to one of the most pressing environmental challenges of our time.

2. METHOD

Land resources are the non-renewable resources that are essential to human society's survival and advancement. Ensuring sustainable land use and efficient resource exploitation are vital concerns for humankind. There has been a noticeable change in the ways that people use land since the turn of the twenty-first century. This shift is explained by the global population growth's more negative effects as well as the rising need for quick economic development. The dynamics of resources, the natural environment, and the economy have all been greatly impacted by the aforementioned issues. One of the main drivers of human society and economic development has always been the use of land. The ongoing progress in science, technology, and production has created hitherto unheard-of opportunities for the growth of human society. Due to a number of issues, including overuse of resources, loss of vegetation, deteriorating land quality, pollution of the environment, ecological degradation, natural catastrophes, extinction of species, and more, the potential poses a substantial challenge.

Initially, information about degraded lands in India was derived by using aerial photographs [16]. With the launch of the ERTS-1/Landsat-1, Landsat-TM, SPOT, and IRS Satellites, the use of remote sensing data in the mapping of degraded regions has become increasingly important. Due to the use of disparate criteria and methodologies for identifying degraded lands, the estimates of land degradation supplied by different groups varied significantly. According to SAARC's 2011 report, the estimates range from around 53.3 million hectares to 187.7 million hectares. The Ministry of Rural Development and the Department of Land Resources (DOLR) used remote sensing methods to map the barren regions. 53.3 million hectares of waste land were estimated in 1985 using 1:1 million scale satellite photography [17], [18]. According to the author, one aspect of the process known as desertification is the deterioration of land in dry places. It is well established that over grazing, over cultivation, and over clearing are human actions that exacerbate the current problem. The end effect is that the area's plants, water, and soil are impacted, which lowers the ecosystem's capacity to support human requirements and ultimately leads to a deterioration in the ecosystem's general health. The concerns stated above are not new, but they have become more important because of irrigation, urbanization, and significant population expansion [19].

In [20], [21] this article looks at the mechanisms that turn arable land into non-arable land, the causes that contribute to the reduction in arable land, and the effects of using arable land improperly. Bangladesh's agricultural land is steadily declining, even though the bulk of the country's population lives in rural regions. The main causes of this problem are poverty, outmoded irrigation methods, population increase that is happening too quickly, the exploitation and abuse of land, and a lack of enthusiasm and competence in agriculture. In addition, the effects of natural catastrophes brought on by climate change, such as floods, droughts, and salt rises, diminish soil fertility and agricultural output, which in turn jeopardizes food security. Denis and Edwin [22] discusses user experiences and expectations with relation to mapping conservation areas and assessing land degradation using geographic information systems (GIS) and remote sensing technology. It is vital to take into account a number of variables, including the climate, soil composition, flora, physiography, land use, socioeconomic situation, and other pertinent local characteristics, in order to create an extensive database with information on natural resources. GIS and remote sensing techniques [23] are needed for the integration of these datasets as well as for the detection, analysis, extrapolation, monitoring, and calculation of the region. Monitoring the temporal and geographical changes in land cover and usage, as well as identifying regions of land degradation, are the main goals of remote sensing and GIS. This article [24], [25] offers a thorough framework for evaluating different types of soil, along with techniques for conserving soil and recognizing signs of soil degradation. It is possible to identify the physiographic area by superimposing several data layers for various map units. Making a link between geographical data and non-spatial data—which has more precise attribute information—allows for the assessment of a territory's size. Table 1 summarizes key methods for addressing land degradation, outlining their main advantages and disadvantages.

2.1. Land degradation and vulnerability

The land degradation and vulnerability index (LDVI) are more than just an assessment tool—it serves as a predictive model for identifying future risks and degradation-prone areas. By integrating physical, biological, and socio-economic indicators, LDVI provides a comprehensive view of land health, considering factors like soil erosion, biodiversity loss, water quality, and human land-use impacts. This holistic approach helps stakeholders understand the dynamic interplay between natural processes and human activities driving land degradation. Its applications are diverse: land managers and farmers can leverage LDVI to implement sustainable practices that enhance soil fertility, improve water conservation, and boost agricultural productivity. Environmental organizations can use it to prioritize conservation efforts, allocate resources efficiently, and engage communities in restoration initiatives. The global importance of the LDVI is profound. As land degradation threatens food security, water availability, and climate regulation, LDVI plays a crucial role in global efforts to achieve the United Nations sustainable development goals (SDGs), particularly SDG 15 (life on land), SDG 6 (clean water and sanitation), and SDG 13 (climate action). By identifying degradation hotspots and trends, LDVI supports international collaboration and investment in land restoration and sustainable management initiatives.

However, the effectiveness of LDVI hinges on addressing key challenges. Reliable, up-to-date data are critical for accurate assessments, yet data gaps persist in many regions. Additionally, selecting and weighting indicators appropriately is essential to ensure the index reflects local conditions and priorities. Regular updates incorporating the latest scientific insights are necessary to keep LDVI responsive to evolving environmental and socio-economic dynamics. Ultimately, LDVI is a powerful tool in the fight against land degradation. By providing a comprehensive assessment of land health and vulnerability, it informs decision-making, supports sustainable land management, and enhances ecosystem and community resilience. Its ongoing development and application are vital for safeguarding the planet's land resources for future generations. Figure 1 illustrates the key factors influencing land degradation.

Table 1. Comparative overview of methods for land degradation assessment and management

Method	Advantages	Disadvantages
Biosurfactants	– Enhance bioavailability of hydrophobic compounds, aiding in their degradation. – Can act as antimicrobial agents, contributing to agricultural sustainability.	– Microbially produced biosurfactants can be rapidly produced but may face scale-up challenges. – Plant-based biosurfactants, while having excellent emulsification properties, are expensive to produce on an industrial scale and have solubility issues.
Remote sensing for land degradation mapping	– Provides large-scale, comprehensive data on land degradation. – Facilitates monitoring changes over time and can identify hotspots for targeted intervention.	– Estimates of land degradation can vary widely due to different methodologies. – Requires sophisticated technology not always available in all regions.
Agroforestry	– Enhances land productivity and provides ecological and economic benefits. – Offers numerous ecosystem services, helping in land restoration.	– Implementation can be complex and requires understanding of local ecosystems. – May require significant changes to traditional farming practices.
GISandRemotes in land degradation assessment	– Integrates various data sets for comprehensive assessment. – Supports soil conservation and degradation assessment, identifying suitable areas for intervention.	– Requires access to advanced technology and expertise. – Data integration and interpretation can be challenging.

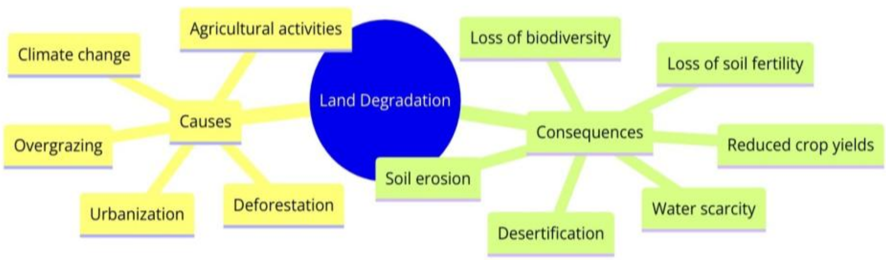

Figure 1. Factors affecting land degradation

2.2. Factors affecting land degradation

Land degradation is a complex and multifaceted process influenced by a wide range of natural and anthropogenic factors. Climatic elements such as reduced rainfall, increasing temperatures, and prolonged droughts directly affect soil moisture, vegetation cover, and land productivity. Topographic features like slope and elevation contribute to erosion and runoff patterns, accelerating degradation in vulnerable areas. Human activities, including deforestation, overgrazing, unsustainable agricultural practices, urban expansion, and industrialization, further intensify the stress on ecosystems. Additionally, poor land management and inadequate policy interventions often exacerbate the degradation process. Understanding these contributing factors is essential for developing targeted strategies to mitigate land degradation and promote sustainable land use.

– Soil depth: soil depth, the thickness of the solum above the parent material or bedrock, determines plant rooting depth and the soil's capacity to retain water and nutrients. It reflects the balance between soil formation and erosion. A reduction in solum depth due to topsoil loss from sheet erosion, selective removal of finer particles, and surface accumulation of coarse grains and gravels indicates ongoing land degradation.

- Soil texture: regarding land degradation, the soil texture of the surface horizon, particularly gravelliness, was a key factor. Rainfall influences this by eroding finer particles, affecting infiltration and percolation. The loss of finer particles through erosion leads to the development of coarse-textured soils in upland areas.
- Soil drainage and erosion: soil drainage is primarily determined by surface texture. Heavy-textured soils allow better water infiltration, while poor drainage increases erosion risk. In the study area, sheet erosion is predominant, especially in undulating granite regions, where large amounts of silt and clay particles are washed away from the topsoil.
- Soil reaction: in the study area, soil profiles range from strongly to moderately acidic, primarily due to high rainfall and leaching of bases. This acidification leads to deficiencies in calcium, magnesium, and micronutrients such as boron (B) and zinc (Zn), a common issue in highly leached lateritic soils of coastal districts.

2.3. Suggested management measures

To effectively address the pressing issue of land degradation and ensure the sustainable management of land resources, it is essential to implement a multi-faceted and coordinated approach. This involves not only the integration of scientific research and technological innovation but also the active participation of stakeholders at all levels—from policymakers to local communities. The following strategic directions outline key actions required to build a comprehensive framework for sustainable land management and the rehabilitation of degraded lands:

- Development of land resource information systems for land management: a scientific community has to be identified and mobilized to initiate and mount an integrated program for methods, standards, data collection and research networks for assessment and monitoring of soil and land degradation. Based on the information, hot spots can be identified for monitoring the extent of degradation, the factors causing land degradation and its impact assessment.
- Enhance the research and development in degraded lands: high priorities are to be given to promote public investment in research and development aimed at identifying the root cause of land degradation and developing soil resources conserving, yield enhancing low-cost technology for problematic lands.
- Developing suitable land use planning and policies: the land use planning has to be developed by considering or identifying the models which incorporate the factors (natural and human induced) that contribute to land degradation. Strong land use polices have to be identified, which encourage sustainable land use and management and should arrest the conversion of prime agricultural land into non-agricultural purposes.
- Encourage participatory land use planning involving local organization arrangements have to be made for collaboration between public research institutions, non-governmental organization (NGOs) and local organizations for developing land use plan using locally available inputs and training should be given for effective adaptation of resource conserving and yield enhancing technologies.

2.4. Challenges encountered

Addressing land degradation presents numerous challenges that span ecological, social, and economic dimensions. These challenges are complex and multifaceted, making the task of halting and reversing land degradation daunting for stakeholders at all levels. Some of the key challenges encountered include:

- Data availability and quality: one of the fundamental challenges is the lack of high-quality, accessible, and up-to-date data on land conditions. Monitoring land degradation over large and often remote areas requires sophisticated technologies like remote sensing and ground-based observations, which may not be readily available in many regions. Furthermore, data collection is expensive and time-consuming, and there may be inconsistencies in methodology across different regions or countries, making it difficult to compare or aggregate data.
- Diverse causes and indirect drivers: land degradation is caused by a complex interplay of direct factors such as deforestation, agricultural expansion, overgrazing, and inappropriate irrigation practices. However, these are often fuelled by indirect drivers including demographic changes, economic pressures, land tenure issues, and policy frameworks that do not adequately support sustainable land management. Addressing these root causes requires integrated approaches that span beyond environmental policies to encompass economic and social dimensions.
- Climate change: climate change exacerbates land degradation through increased frequency and intensity of extreme weather events such as droughts, floods, and storms. These events can lead to immediate and severe degradation of land and water resources. Moreover, the feedback loop between land degradation

and climate change, where degraded lands emit more greenhouse gases, further complicating efforts to combat both crises.
- Socio-economic constraints: in many regions, especially in developing countries, communities' dependent on land for their livelihoods face socio-economic constraints that limit their ability to implement sustainable land management practices. Poverty, lack of access to knowledge, technology, and financial resources, and insecure land tenure are significant barriers that hinder the adoption of practices that could prevent degradation or restore degraded lands.
- Policy and governance challenges: effective governance and policy frameworks are crucial for addressing land degradation. However, policies are often fragmented across different sectors and levels of government, leading to inconsistent or conflicting objectives. There is also a need for greater international cooperation, as land degradation and its effects, such as dust storms and migration, can transcend national boundaries.
- Public awareness and engagement: raising public awareness about the importance of land and its vulnerability to degradation is challenging. Engaging communities and stakeholders in land management decisions is critical for the success of any intervention. However, there is often a lack of understanding or interest in land degradation issues among the general public and decision-makers, which can lead to a lack of political will and community support for necessary actions.
- Technological and methodological limitations: while advances in technology have improved the ability to monitor and manage land degradation, there remain significant technological and methodological limitations in predicting degradation trends, assessing the effectiveness of interventions, and restoring degraded lands. Innovations in technology and methodology are needed to enhance our understanding and management of land degradation processes. Overcoming these challenges requires integrated, multi-disciplinary approaches that combine technological innovations, policy reforms, enhanced governance, and active participation from local communities and international stakeholders. Such efforts are crucial for achieving sustainable land management and mitigating the impacts of land degradation on ecosystems, economies, and societies globally.

2.5. Research gap

Identifying and addressing research gaps related to land degradation is crucial for advancing our comprehension of its processes and implementing more effective mitigation strategies. By focusing on areas such as the socio-economic impacts of degradation, the long-term effectiveness of restoration techniques, and the role of indigenous knowledge, we can develop comprehensive approaches to sustainable land management. Closing these gaps not only enhances environmental conservation but also ensures the resilience and well-being of communities reliant on healthy land ecosystems.
- Quantitative assessment of land degradation: there's a need for more quantitative studies that measure the extent, rate, and severity of land degradation in various ecosystems, employing uniform methodologies to enable comparative analysis.
- Impact of climate change on land degradation dynamics: while the link between climate change and land degradation is recognized, detailed studies on how changing climate patterns specifically influence land degradation processes in different regions are lacking.
- Socio-economic impacts of land degradation: research is needed on the direct and indirect socio-economic impacts of land degradation on communities, including livelihoods, migration patterns, and economic stability, with a focus on developing countries.
- Effectiveness of land restoration techniques: there's a gap in comprehensive evaluations of the long-term effectiveness and sustainability of different land restoration techniques across various environmental conditions and land uses.
- Role of indigenous knowledge and practices: integrating and assessing the role of indigenous knowledge and practices in preventing and mitigating land degradation remains an underexplored area.
- Technology adoption and land management: understanding barriers to the adoption of sustainable land management technologies among smallholder farmers and other land users is crucial for designing effective interventions.
- Policy and governance mechanisms: research is needed on the effectiveness of existing policy and governance mechanisms in addressing land degradation and promoting sustainable land management, including case studies of successful and failed policies.
- Biodiversity loss due to land degradation: the impact of land degradation on biodiversity, especially in terms of species extinction rates, habitat loss, and ecosystem function, requires further investigation.
- Economic valuation of land degradation: there's a scarcity of studies on the economic valuation of land degradation, including the cost of inaction versus the benefits of restoration and sustainable management.

– Remote sensing and big data analytics: exploiting the potential of remote sensing technologies and big data analytics for real-time monitoring and predictive modelling of land degradation trends and restoration success is an emerging field that needs more attention.

3. RESULT

The survey findings reveal significant challenges in addressing land degradation, encompassing data availability, diverse causal factors, and socio-economic constraints. Climate change exacerbates degradation, posing additional hurdles to effective mitigation efforts. Governance issues and fragmented policies hinder cohesive action, while limited public awareness presents an obstacle to garnering support for necessary interventions. Overcoming these challenges demands integrated approaches that bridge ecological, social, and economic dimensions, emphasizing the importance of international cooperation and community engagement. Addressing these obstacles is paramount to achieving sustainable land management and safeguarding ecosystems for future generations.

4. CONCLUSION

This survey paper underscores the critical and escalating issue of land degradation, a global environmental challenge with profound implications for food security, biodiversity conservation, and human well-being. Through an exhaustive review of existing literature, this study has illuminated the complex interplay between anthropogenic activities, climate change, and the natural processes leading to land degradation, offering a nuanced understanding of its causes, impacts, and the current efforts to mitigate these effects. The synthesis of remediation technologies, conservation strategies, and policy interventions highlights both the progress made and the substantial challenges that remain in reversing degradation trends. Significantly, this paper has identified crucial research gaps, such as the need for more quantitative assessments of land degradation, deeper exploration of its socio-economic impacts, and the long-term evaluation of land restoration techniques. These gaps represent pivotal areas for future investigation, promising to refine our understanding and enhance our response to land degradation. Furthermore, the paper provides actionable recommendations for policymakers, land managers, and practitioners, advocating for integrated, multi-disciplinary approaches that leverage both traditional knowledge and modern scientific advancements. It emphasizes the importance of international cooperation, community engagement, and evidence-based policy making in achieving sustainable land management and combating land degradation.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest related to this work.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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