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Combating land degradation: Global challenge, local solutions

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ABSTRACT

Land degradation is a critical global challenge that undermines food security and threatens ecosystem services and livelihoods. Driven by unsustainable land use practices, climate change, and natural phenomena, degradation manifests through soil erosion, fertility decline, salinization, acidification and desertification, with drylands regions particularly vulnerable. This review comprehensively analyzes the methods used to assess land degradation, highlighting regional disparities and critical hotspots. Effective mitigation strategies such as conservation agriculture, agroforestry, and soil and water conservation techniques are explored, emphasizing community-based and participatory approaches for combating land degradation. The significance of policy frameworks, including the United Nations Convention to Combat Desertification (UNCCD) and Land Degradation Neutrality (LDN), is underscored in fostering sustainable management to address sustainable development goals (SDGs). Technological advancements, including GIS, remote sensing, and precision agriculture, are pivotal in enhancing monitoring, conservation planning, and management. Despite these advancements, challenges such as socio-economic constraints, climate variability, and policy implementation gaps remain. The paper advocates for integrated, multi-disciplinary strategies that balance short-term actions with long-term sustainability to reverse degradation trends and promote ecosystem resilience, aligning with global sustainability goals.

HIGHLIGHTS

- Land degradation threatens food security, ecosystem services and livelihood.
- SLM is essential to reduce soil erosion and reverse land degradation.
- Adoption of multi-pronged approach in tackling land degradation.
- Reversing land degradation helps in achieving LDN and SDGs

1 | INTRODUCTION

Land degradation is a significant global threat that poses risks to food security, ecosystem services, and biodiversity, with anthropogenic activities like urbanization, deforestation, drastic land use change, improper land management practices, and climate change serving as key contributors (Anālayo *et al*., 2023). This phenomenon involves physical, chemical, and biological processes that lead to the deterioration of soil quality and productivity, with nearly half of the world's cultivated land currently under various stages of degradation (Abdel Rahman, 2023). Various approaches and indicators are utilized to evaluate land degradation, highlighting considerable regional disparities and identifying critical hotspots, particularly in arid and semi-arid regions (Jiang *et al.,* 2024). Mitigation efforts focus on sustainable land management (SLM) or sustainable soil management (SSM) practices, such as conservation agriculture involving no-till / reduced tillage, crop rotation, and residue retention to ensure permanent soil cover, in conjunction with community involvement and global cooperation (Chaudhary, 2024). Addressing land degradation requires the integration of multiple scientific disciplines and using standardized assessment methods to achieve (LDN and support the SDGs (Nedd and Anandhi, 2024).

Combating land degradation is vital for improving food and nutritional security, environmental quality, and socio-economic progress. This issue, driven by unsustainable land use practices (e.g. clearing forest areas, non-adoption of appropriate soil and water conservation measures and non-replenish of soil nutrients, bare soil surface outside the cropping cycle, and low addition of organic manure), climate change, and natural disasters, results in decreased agricultural productivity and biodiversity loss, thereby intensifying poverty and food insecurity on a global scale (Ali *et al.*, 2024). In India, approximately 120.7 M ha are affected by land degradation, primarily due to soil erosion and deforestation (Jinger *et al.*, 2023). Implementing strategies such as agroforestry, sustainable cropping and grazing practices, and integrated land use planning can restore degraded lands, enhance soil quality, and boost carbon sequestration (Chaudhary, 2024). Moreover, tackling land degradation is crucial for achieving the SDGs, as it supports improved living conditions, creates job opportunities, and mitigates the effects of climate change (Gibson, 2022). Therefore, a multidisciplinary approach incorporating community involvement and innovative management techniques is essential to effectively address land degradation and build community resilience to climate change (Badapalli *et al.*, 2023).

This review aims to examine the global extent and impact of land degradation, highlighting its effects on food security, ecosystem services, and livelihoods. It aims to evaluate existing methods and indicators for land degradation, focusing on identifying regional disparities and critical hotspots. Additionally, we identify and analyze effective mitigation strategies, including SLM practices and community-based approaches that have shown success in addressing land degradation (Fig. 1). We also explore the role of policies, technological advancements, and scientific innovations in combating land degradation and achieving LDN. Besides, the scope of this review includes a comprehensive analysis of the forms and drivers of land degradation - both anthropogenic and natural - alongside an assessment of sustainable management practices such as conservation agriculture, regenerative agriculture, agroforestry, soil and water conservation, and integrated land-use planning.

2 | UNDERSTANDING LAND DEGRADATION

2.1 | Definition and Types of Land Degradation

Land degradation refers to the decline in land quality and soil health caused by human activities and natural processes, resulting in reduced soil fertility and biodiversity and disrupted ecological balance (Teng and Zhou, 2020). This phenomenon includes various forms of land degradation, such as soil erosion, desertification, salinization, acidification, contamination, and land destruction, each driven by factors like unsustainable agricultural practices, deforestation, and pollution (Zaitsev *et al.*, 2022; Teng and Zhou, 2020). For example, erosion can be triggered by water and/or wind and accelerated by tillage, while desertification involves the conversion of fertile land into arid regions (Saljnikov *et al.*, 2022). The widespread occurrence of these degradation forms is particularly concerning, with large areas of European agricultural land affected by multiple degradation pathways (Prăvălie *et al.,* 2024). According to Dalal (1996), soil fertility degradation occurs primarily due to soil erosion (via water and wind), overgrazing, intensive cultivation of farmlands using inappropriate practices, poor addition / return of organic residue / manures, loss of soil organic matter from arable lands, nutrient removal via crop produce/residue burning, acidification, salinization, sodification, and flora, fauna and microbial biodiversity loss, and excess accumulation of heavy metal load and pesticides. Therefore, addressing land degradation necessitates a multidisciplinary strategy incorporating SLM practices and effective environmental policies to alleviate its effects.

Soil erosion and the resulting loss of soil fertility / soil fertility degradation are pressing environmental challenges, intensified by both natural factors and human activities such as deforestation, intensive farming, and unregulated construction (Dalal and Bridge, 1996; Dalal, 1998; Barman *et al.*, 2024) (Fig. 2). The physical removal of top- fertile soil leads to nutrient depletion, adversely affecting agricultural productivity and ecosystem health, as key nutrients such as nitrogen,

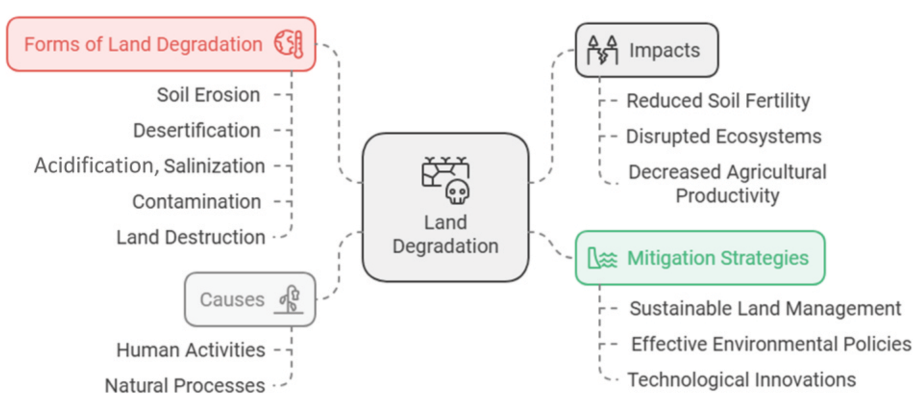

FIGURE 1 Forms of Land degradation and mitigation strategies (Source: Authors)

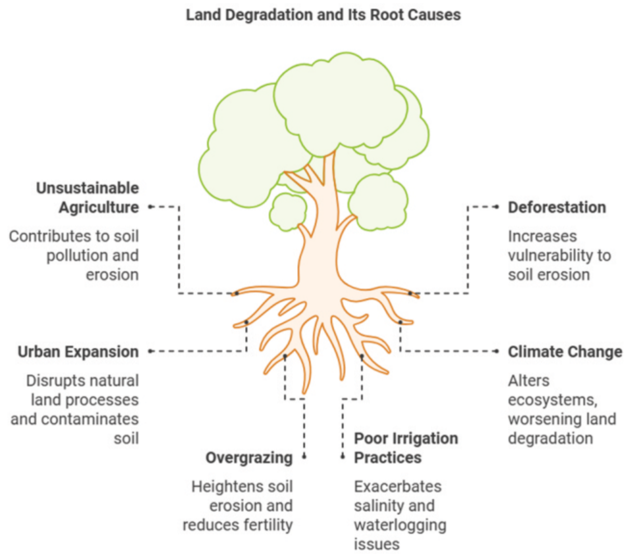

FIGURE 2 Interconnected issues to land degradation (Source: Authors)

phosphorus, and potassium are lost more rapidly than they can be replenished (Musa *et al*., 2024). For example, in Northeast China, soil fertility declined by 4.46% between the 1990s and 2010s, with minimal declines observed in cultivated lands, emphasizing the impact of land-use practices on soil health (Xiong *et al*., 2023). Strategies like cover cropping / green manuring have been shown to improve soil fertility by increasing organic matter and nutrient availability, mitigating some of the adverse effects of erosion. Additionally, specific agricultural activities, such as tuber crops harvesting (e.g., sugar beet, potato), have been recognized as significant but often overlooked contributors to soil erosion and loss, underlining the need for comprehensive soil conservation measures (Saggau *et al.,* 2024). Tackling these interconnected issues requires a multifaceted strategy involving SLM practices and technological innovations (Barman *et al*., 2024).

Long-term salinization and waterlogging severely hinder agricultural productivity in arid regions by adversely affecting crop growth and yields. Salinity stress has been found to decrease the nutritional quality and yield of crops, causing physiological changes that lead to reduced photosynthesis and impaired nutrient uptake, especially in crops like maize and sunflower (Zhang *et al*., 2024). When combined, salinity and waterlogging intensify these adverse effects by osmotic stress, disrupting ion homeostasis and reducing stomatal conductance, further diminishing crop yields (Sachan *et al*., 2022). Poor irrigation practices, such as insufficient drainage, exacerbate soil salinity issues, currently affecting around 952 M ha worldwide (Ashford, 2023). To address these challenges, effective management strategies are crucial, including establishing optimal irrigation-to-drainage ratios to maintain soil health and ensure sustainable agricultural productivity in these susceptible regions (Peng *et al*., 2024).

The primary factors driving desertification and the expansion of arid lands in the 21st century are strongly tied to increasing greenhouse gas (GHG) emissions, thus, global warming and rising atmospheric aridity. Studies have shown that global drylands expanded by approximately 3.67% between 1950 and 2014, with around 4.5% of this growth attributed to GHG emissions, indicating a significant human impact on dryland dynamics (Gu, 2023). As aridity increases, ecosystems transition through various stages of vulnerability, resulting in soil degradation and vegetation loss, which heighten desertification risks, particularly in regions like Africa and East Asia (Sun, 2024). Key factors such as the diversity of vegetation cover and cattle density have been identified as significant predictors of desert expansion, emphasizing the intricate relationship between ecological and socioeconomic factors in driving these changes (Wu *et al*., 2022). Consequently, the interaction between climate change, land use practices, and ecological thresholds plays a critical role in the ongoing process of desertification.

2.2 | Agents of Land Degradation

The primary human activities driving global land degradation involve various practices that significantly impact soil health and ecosystem function. Unsustainable agricultural methods, such as the overuse of pesticides and excessive amounts of fertilizers, contribute to soil pollution and the degradation of agroecosystems, affecting an estimated 33% of global soils (Zalesny *et al*., 2021). Overgrazing and deforestation worsen soil erosion and heighten vulnerability to wind erosion, particularly in arid regions, leading to sand and dust storms (Zucca *et al*., 2022). Urban expansion and industrial activities, including mining and waste disposal, also contribute to soil contamination and disrupt natural land processes (Zalesny *et al*., 2021). Socio-political pressures and climate change create feedback loops that amplify land mismanagement, causing declines in soil productivity and biodiversity (Anālayo *et al*., 2023). These factors highlight the intricate link between human actions and environmental degradation.

Natural factors contributing to global land degradation include climate change (enhanced global warming is human induced, mostly using fossil fuels such as natural gas and coal), soil erosion, and regressive pedogenic processes. Climate change exacerbates land degradation by altering ecosystems and diminishing biological productivity, particularly in vulnerable regions like arid and semi-arid areas. Increased temperatures and shifts in precipitation patterns lead to soil salinization, nutrient imbalances, and erosion driven by wind and water (Roy *et al*., 2022). Soil erosion, primarily caused by natural agents such as water and wind, significantly reduces the topsoil layer critical for agricultural productivity (Farooq *et al*., 2023). Additionally, regressive pedogenic processes, including forming calcium carbonate and subsoil sodicity, impair soil health and crop yields, especially in semi-arid tropical regions (Pal, 2017). These natural factors interact with human activities, complicating efforts to manage and mitigate land degradation effectively.

2.3 | Impact of Land Degradation on Ecosystem and Human Livelihoods

Land degradation significantly affects both ecosystems and human livelihoods, leading to a reduction in essential ecosystem services that support community well-being. For instance, in Majuli, India, the degradation of cultural ecosystem services demonstrates how environmental decline can have irreversible consequences for rural populations, worsening their hardships during natural disasters like floods (Saikia & Goswami, 2024). In Ethiopia, shifts in land use have resulted in considerable economic losses, with degraded watersheds experiencing a decline in ecosystem service values by millions of dollars, primarily due to the loss of arable and grazing lands (Mekuria *et al.,* 2023). Furthermore, intensive agricultural practices contribute to soil degradation, compromising soil health and its ability to support life, thereby threatening food security and public health on a global scale (Sprunger, 2023). In India, land degradation impacts more than 120 M ha, underscoring the urgent need for sustainable practices like agroforestry pasture and perennial crops to restore productivity and enhance ecosystem services critical for food and livelihood security (Pandey, 2023; Jinger *et al*., 2023). Thus, tackling land degradation is vital for the sustainability of both ecosystems and human communities.

3 | GLOBAL PERSPECTIVES ON LAND DEGRADATION

3.1 | Hotspots of Land Degradation Worldwide

Global hotspots of land degradation span various regions and profoundly impact ecosystems and human livelihoods. Approximately 29% of the Earth's land area is estimated to be affected, with approximately 3.2 billion people residing in these regions, highlighting an urgent need for targeted interventions (Le *et al*., 2016). The southern Gobi Desert illustrates severe land degradation caused by climate change and human activities such as unsustainable farming practices and overgrazing, which further accelerate desertification and the formation of sand dunes and dust (Kim *et al*., 2022; Zucca *et al*., 2022). Additionally, soil erosion poses a critical risk, with anticipated increases in erosion rates leading to significant economic losses and challenges to food security, particularly in vulnerable regions like Africa and Asia (Sartori *et al*., 2024). To effectively address ongoing land degradation, it is vital to employ a combination of assessment methods to accurately identify these hotspots and develop informed management strategies (Jiang *et al*., 2024).

3.2 | Policies and Global Initiatives to Combat Land Degradation

Global initiatives and policies aimed at addressing land degradation focus on SLM and restoration practices, which are essential for improving agricultural productivity and enhancing ecosystem services. The United Nations Convention on Combating Desertification (UNCCD) requires signatory nations, including India, to achieve LDN by 2030, underscoring the importance of comprehensive national policies and localized implementation strategies (Sharma and Prakash, 2023; Pricope *et al*., 2022). Numerous programs have been launched to tackle degradation, emphasizing community involvement and incorporating socio-ecological frameworks for effective monitoring (Chaudhary, 2024; Haregeweyn *et al*., 2022). Although challenges persist, including rising rates of land degradation, recent data show a modest increase in forest cover and a decrease in degraded land due to effective policy interventions (Edrisi *et al*., 2022). The collective global efforts highlight the necessity for collaboration, research networks (national and international organizations), and the adoption of innovative practices coupled with informed policy decisions to combat land degradation and foster resilience among vulnerable communities (Pricope *et al*., 2022). The UNCCD (estd in 1994) is regarded as a groundbreaking sustainable development treaty that tackles both environmental and socio-economic issues (Chasek, 1997). It advocates for a Global Governance approach, fostering multi-actor networks and encouraging civil society participation in efforts to combat desertification (Rechkemmer, 2004). The UNCCD emphasizes the importance of public involvement in assessing and rehabilitating land degradation, promoting a bottom-up approach that integrates local insights with scientific expertise (Stringer *et al*., 2007). Nonetheless, the national-level implementation of participatory practices has been challenging, highlighting the necessity for better communication among researchers, practitioners, and policymakers (Stringer *et al*., 2007). Despite these obstacles, the UNCCD continues to be a vital strategic tool for development cooperation, serving as a framework for policies addressing desertification, drought, and SLM (Squires, 2017). In 2015, the 12th session of the Conference of the Parties (COPs) UNCCD COP[12] adopted 35 decisions related to desertification, land degradation, and drought. These included how to pursue UNCCD (LDN) within the framework of the SDGs and how to align UNCCD goals and the actions of Parties with the SDGs.

SDG 15.3 addresses land degradation and encourages land restoration to achieve LDN, which is essential for preserving ecosystem services and biodiversity. This goal holds particular significance in light of the growing global population and economic development, which places increasing demands on land resources for agriculture and livestock production, resulting in environmental harm and loss of biodiversity (Schillaci *et al*., 2022; Fitawek and Hendriks, 2024). The UNCCD has developed an indicator framework to monitor progress, focusing on the ratio of degraded land to the total land area (Schillaci *et al*., 2022).

Recent evaluations have demonstrated that higher spatial resolution data can provide a more precise assessment of land degradation, identifying up to 40% more degraded areas than previously recognized (Schillaci *et al*., 2022). Consequently, achieving SDG 15.3 requires comprehensive approaches that integrate climate-smart agricultural practices and foster community engagement to combat land degradation while ensuring food security (Fitawek and Hendriks, 2024).

The LDN is an essential principle focused on reconciling land degradation with restoration efforts, ensuring no net loss of land-based natural capital, thereby contributing to the fulfillment of SDGs. Introduced under the UNCCD, LDN underscores the need for comprehensive evaluation of land systems that integrate biophysical and socio-economic factors to guide planning and monitoring initiatives (Kust *et al*., 2017; Cowie *et al*., 2018). The framework advocates a hierarchical approach to addressing land degradation, emphasizing the steps of avoid, reduce, and reverse, which encourages the adoption of SLM practices and restoration efforts tailored to specific land types (Cowie *et al*., 2018; Kesavan *et al*., 2022). However, several challenges arise in implementing LDN, including the need for effective indicators, establishing baseline conditions, and addressing technical distinctions between restoration and rehabilitation (Thomas *et al*., 2023; Kesavan *et al*., 2022). Practical applications of LDN are illustrated in case studies from Madagascar and Italy, which highlight the importance of engaging multiple stakeholders and employing adaptive management strategies to achieve successful results (Chasek *et al*., 2019; Kesavan *et al*., 2022) (Fig. 3).

4 | LOCAL SOLUTIONS AND COMMUNITY - BASED APPROACHES

4.1 | Agroecological and Sustainable Farming Practices

Agroecological and sustainable farming techniques play a crucial role in addressing desertification and land degradation, especially in arid and semi-arid areas. Effective strategies encompass agroforestry, conservation agriculture, cover cropping, and sustainable grazing, all of which improve soil health and enhance ecosystem resilience (Ali *et al*., 2024). The significance of soil microbiome is gaining recognition, as they aid in nutrient cycling, carbon sequestration, and soil stabilization, thus boosting land productivity and reducing the impacts of desertification (Islam *et al*., 2024). In Africa, employing participatory methods alongside Indigenous and Local Knowledge (ILK) has proven successful in restoration efforts, resulting in enhanced vegetation and improved livelihoods for communities (Ben-Enukora and Ejem, 2024). In India, a shift from conventional, input-heavy farming to practices like zero-till drilling and the application of biopesticides has shown potential in mitigating land degradation (Chaudhuri *et al*., 2023; Jayaraman *et al*., 2021; Jayaraman and Dalal, 2021). Collectively, these approaches underscore the importance of comprehensive policies and community involvement to promote SLM and effectively tackle desertification (Nwer *et al*., 2021) (Fig. 4).

4.1.1 | *Conservation Agriculture*

Conservation agriculture (CA) is one of the crucial approaches to tackling land degradation while addressing the challenges of environmental sustainability and food security. By utilizing techniques such as minimal soil disturbance, maintaining permanent soil cover, and implementing crop rotation, CA improves soil health, boosts soil organic carbon (SOC) levels, and fosters biodiversity (Jayaraman and Dalal, 2021; Jayaraman *et al.,* 2021; Naorem *et al*., 2023). This helps to alleviate the negative impacts of traditional agricultural practices, which often lead to soil erosion and loss of fertility (Francaviglia *et al*., 2023). Studies suggest that CA can enhance crop productivity by anywhere from 3.8% to 76.2% and significantly improve water productivity, thus contributing to SDGs and efforts to mitigate climate change (Kumawat *et al*., 2023; Francaviglia *et al*., 2023). Additionally, CA practices have demonstrated effectiveness in restoring soil organic matter and enhancing soil structure, both essential for preserving ecosystem services and building resilience to climate change (Mondal *et al*., 2024). Nevertheless, the widespread adoption of CA is hindered by socio-economic and technical challenges, which must be

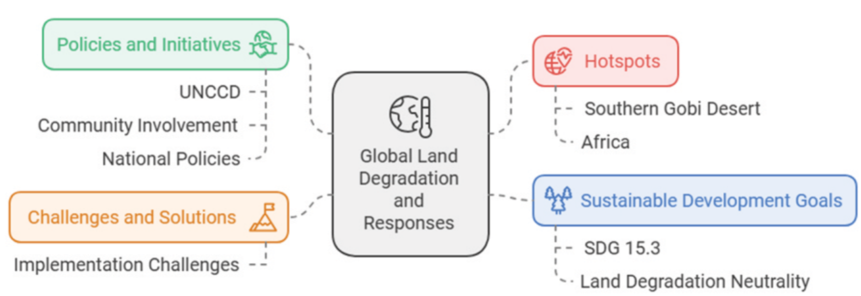

FIGURE 3 Adoption of multi-pronged approach in addressing land degradation (Source: Authors)

addressed through supportive policies and educational initiatives to fully realize its potential for rehabilitating degraded lands (Francaviglia *et al*., 2023).

4.1.2 | *Organic Farming and Permaculture*

Organic farming and permaculture are gaining recognition as effective methods for addressing land degradation while improving soil health and biodiversity. Organic farming focuses on sustainable techniques, including crop rotation, the application of animal manures, and biological pest management. These practices work together to enhance soil structure, fertility, and microbial activity, thereby lessening the negative environmental impacts associated with conventional agriculture (Raj *et al*., 2024). In contrast, permaculture advocates for a comprehensive design framework that incorporates ecological principles, leading to significantly greater soil carbon storage and biodiversity when compared to traditional farming systems (Fiebrig *et al*., 2020). For example, permaculture sites have shown a 27% increase in soil carbon levels and recorded 201% rise in earthworm populations, both indicators of improved soil quality and ecosystem health (Krebs *et al*., 2024). Both approaches not only enhance immediate agricultural yields but also promote long-term sustainability by rehabilitating degraded lands and bolstering resilience to climate change (Pinto *et al*., 2023).

4.2 | Soil and Water Conservation Techniques

4.2.1 | *Contour Farming, Terracing, and Check Dams*

Contour farming, terracing, and the construction of check dams are effective techniques for addressing land degradation, especially in at-risk agricultural areas. Check dams are commonly employed for soil conservation and erosion control; they improve water retention and reduce sediment buildup, ultimately boosting agricultural productivity and ecosystem vitality (Lucas-Borja, 2023). In the Moldavian Plateau, the decline of contour farming practices has intensified soil erosion, underscoring the urgent need for effective soil conservation strategies to combat degradation (Niacsu *et al.,* 2021). Likewise, terracing stabilizes slopes and minimizes runoff, which is vital in regions experiencing significant land degradation (Chaudhary, 2024). In regions with high rainfall, such as the Nilgiris hills of Tamil Nadu, inward bench terracing with a longitudinal gradient of 2.5% to 1% is recommended to ensure safe water disposal (Madhu *et al.,* 2021). It was found that 5% outward sloped bench terraces with rosemary achieved the highest water conservation efficiency (96%), while 10% outward sloped bench terraces with grass (permanent soil cover) and recommended nutrient management practices had the best soil conservation efficiency (98%) and nutrient retention. Therefore, the combination of these practices, along with community involvement and supportive policies, is crucial for effective SLM and restoration efforts. Initiatives in India aimed at achieving LDN by 2030 exemplify this approach (Sharma and Prakash, 2023). These methods enhance soil health, ensure water security, and bolster agricultural resilience in degraded environments.

4.2.2 | *Water Harvesting Structures and Micro-Irrigation*

Water harvesting techniques and micro-irrigation are vital in addressing land degradation, especially in arid and semi-

FIGURE 3 Adoption of multi-pronged approach in addressing land degradation (Source: Authors)

arid areas. In Jordan, micro-catchment water harvesting has been shown to increase soil moisture levels and foster the growth of native plant species, which in turn enhances soil microbial diversity and boosts overall ecosystem health (Tatsumi *et al*., 2021). These systems effectively capture and concentrate rainwater, reducing runoff and erosion while improving water availability for agricultural crops (Thakur and Grendler, 2022). In India, research has highlighted the capacity of water harvesting structures to recharge groundwater, with notable differences in recharge potential influenced by geomorphological and catchment factors (Raskar *et al.,* 2020). Additionally, using low-impact runoff harvesting systems can potentially rehabilitate degraded rangelands by replicating natural hydrological processes, thereby promoting vegetation recovery and enhancing soil stability (Stavi *et al.,* 2020). Together, these strategies help mitigate land degradation and encourage SLM practices.

4.3 | Reforestation and Afforestation Initiatives

Numerous studies have evidenced that reforestation and afforestation efforts are essential strategies in the fight against land degradation. These programs boost agricultural output and enhance environmental health by restoring vital ecosystem services and promoting biodiversity. For example, Greece's Agricultural Land Afforestation Program seeks to combat soil erosion and desertification by providing compensation for income losses during non-productive periods (Grillakis and Christoforidi, 2023). Similarly, Senegal's reducing emissions from deforestation and forest degradation (REDD) initiative focuses on tree planting and agroforestry practices to strengthen ecosystem resilience and encourage community involvement in forest management (Dieng *et al*., 2023). Additionally, global forest restoration initiatives have shown substantial socio-economic advantages, including carbon sequestration and protection of watersheds (Prati and Pomero, 2022). In India, a comprehensive strategy that combines local governance with national policies aims to achieve LDN by 2030, addressing the various factors contributing to land degradation across its diverse agro-climatic regions (Sharma and Prakash, 2023). These initiatives highlight the need to integrate ecological, economic, and social aspects into SLM practices (Chaudhary, 2024).

5 | ROLE OF TECHNOLOGY AND INNOVATION IN COMBATTING LAND DEGRADATION

5.1 | Remote Sensing and GIS Applications

Remote sensing and GIS technologies are vital in the fight against land degradation, offering powerful methods for monitoring and evaluating environmental changes. Research has shown that satellite imagery, including Sentinel-2 and Landsat, is effective in mapping the extent of degradation and identifying signs of agricultural stress, such as soil erosion and crop vitality (Ebrahimi *et al*., 2024). For example, Ebrahimi *et al*. (2024) developed degradation maps using spectral indices, while Al-Mulla *et al*. (2024) demonstrated the rapid assessment capabilities of remote sensing in agricultural monitoring. Furthermore, machine learning algorithms improve the identification of land degradation trends, enabling timely responses and promoting SLM practices (Hediyalad *et al*., 2024). GIS tools also enhance spatial analysis of soil erosion and support planning conservation strategies, emphasizing the importance of integrating these technologies to tackle land degradation issues (Chokshi, 2023). In summary, the synergy of remote sensing, GIS, and machine learning offers a robust framework for effective land management and conservation initiatives.

5.2 | Use of Soil Amendments and Organic Matter Addition

The application of soil amendments and organic matter is an essential approach to address land degradation, improve soil quality, and encourage sustainable agricultural practices. Organic materials such as compost, crop residue, biochar, and manure significantly enhance the physico-chemical properties of soil, including nutrient retention, microbial activity, and organic matter levels, which are crucial for rehabilitating degraded soils (Rani and Kapoor, 2024; Larsen *et al.,* 2024; Matisic *et al*., 2024). For example, incorporating compost and biochar has been found to boost soil dissolved organic carbon while decreasing CO_2 emissions, promoting healthier plant growth and resilience in compromised ecosystems (Larsen *et al*., 2024). Additionally, these organic amendments improve water retention, optimize pH levels, and facilitate carbon sequestration, contributing to the long-term health and productivity of the soil (Matisic *et al*., 2024; Aboukila *et al.,* 2024). Utilizing a range of organic materials, including agricultural and urban waste, not only speeds up soil restoration but also fosters sustainable practices by recycling nutrients and minimizing dependence on chemical fertilizers (Bharti *et al*., 2023). In summary, the thoughtful use of organic amendments is crucial for rehabilitating degraded lands and securing sustainable agricultural futures.

5.3 | Digital Solutions: Precision Agriculture and Monitoring Tools

Digital technologies, especially precision agriculture and monitoring tools, are vital in the fight against land degradation by improving soil health management and maximizing resource utilization. Innovations such as IoT sensors, remote sensing, and machine learning algorithms enable real-time soil condition monitoring, allowing farmers to make well-informed decisions about irrigation and fertilization, which can significantly enhance crop yields and land productivity (Naorem *et al.,* 2024; Levin, 2024). For example, Earth Observing System data analytics (EOS DA) supports effective benchmarking of crop health and monitoring of degraded soils, thereby fostering sustainable farming practices (Oymatov *et al.,* 2023). Furthermore, tools like the Multi-Layered Land Degradation Tracer (ML-LDT) leverage machine learning to predict land degradation patterns, offering valuable insights for implementing effective interventions (Kim, 2023). Overall, these digital advancements signify a significant shift toward sustainable agricultural practices, effectively tackling the issues of declining soil quality and rising environmental challenges (Anshu and Kumar, 2024).

6 | Challenges and Limitations in Addressing Land Degradation

Climate change-driven land degradation and desertification threaten food production systems and ecosystem services. Several challenges arise in the implementation of LDN, including the need for effective indicators, establishing baseline conditions, and addressing technical distinctions between restoration and rehabilitation. Making people and productive landscapes resilient to drought is a core mandate of the UNCCD, which is fully supported by the national and international organization through its strategy, and relevant programs and projects.

Challenges such as poor funding for government-aided projects, socio-economic conditions, climate change-driven land use change, not adopting appropriate soil and water conservation measures / SLM / land use policy, lack of coordination between national and international organizations despite the sincere efforts made by UNCCD in tackling the serious issue of land degradation. Countries / regions / projects need to keep the balance (trade-off) between short-term benefits and long-term sustainability while addressing land degradation.

7 | FUTURE DIRECTIONS AND RECOMMENDATIONS

UNCCD is committed to a bottom-up approach to combating desertification and land degradation, involving the participation of local people and farming communities. This review article highlights the following future directions and the way forward.

- Land degradation comprises physical, chemical, and biological degradation, so a holistic approach is required to tackle this issue (i.e., reduce, reverse, and restore land degradation).
- Multi-dimensional preventive/combating strategies with co-beneficial activities are essential to addressing land degradation vis-à-vis focusing on major land use sectors of the region / country.
- Identifying (areas and degradation processes analysis) and mapping degraded areas using latest tools and techniques, setting target areas and devising 'Sustainable Land Management (SLM) / Landscape Restoration Approach (LRA)' is the need of the hour.
- Restoration efforts should be based on suitable nature-based eco-restoration models with a focus on sustainable natural resource management and livelihood improvement of the farming community (Sometimes, indigenous nature-based local solutions may be tapped for reversing land degradation). Besides, protecting ecologically productive land from other uses via appropriate legal mechanisms (a need for soil law and Governance, national land use policy) (NASS, 2022; Desai, 2023).
- A farmer-centric approach (participatory-public-private partnership, in a PPP mode) is required to address land degradation issues. We need to consider biophysical conditions, different agroclimatic conditions, major soil types, and land use while developing strategic solutions.
- Voluntary targets to achieve LDN involving a multi-ministerial / multi-disciplinary approach- needs priority and funding by each nation / country to safeguard land resources for providing food and nutritional security to growing populations.
- In 2011, the International Union for the Conservation of Nature (IUCN) and the Government of Germany launched the Bonn Challenge, targeting the restoration of 150 M ha of deforested and degraded land by 2020 and 350 M ha by 2030. India took the challenge and pledged to restore 26 M ha of degraded land by 2030. Therefore, our efforts, targets, vision, and actions should be top priorities to achieve the restoration of degraded lands.

5 | CONCLUSIONS

Land degradation and desertification are the major threats to the food production system, economic stability, community viability, and the environment. About 29% of the Earth's land area is affected, with ~ 3.2 billion people residing in these regions, necessitating an urgent need for sustainable interventions. Natural and anthropogenic factors contributing to global land degradation include climate change, soil erosion, and regressive pedogenic processes. Land degradation has been exacerbated by climate change-driven extreme events and human activities such as unsustainable farming practices (deforestation / overgrazing), further accelerating desertification and forming sand dunes and dust. Additionally, soil erosion poses a critical risk, with anticipated increases in erosion rates leading to significant economic losses and challenges to food security, particularly in vulnerable regions such as Africa and Asia. Climate change exacerbates land degradation by altering ecosystems and diminishing biological productivity, particularly in vulnerable regions like arid and semi-arid areas. Increased temperatures and shifts in precipitation patterns lead to soil salinization, soil acidification, nutrient imbalances, and erosion-driven most-fertile topsoil loss by wind and water.

Therefore, SLM is essential to reducing soil erosion, reversing land degradation, and achieving LDN. Moreover, the Sustainable Development Goal (SDG, 15.3) addresses land degradation and encourages land restoration to achieve LDN, which is essential for preserving ecosystem services and biodiversity. Thus, a comprehensive approach is required that integrates climate-smart agricultural practices, ensuring permanent soil cover and fostering community engagement to combat land degradation while ensuring food and nutritional security.

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DATA AVAILABILITY STATEMENT

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR'S CONTRIBUTION

Conceptualization - SJ, AN, RCD; writing - original draft preparation, AN, SJ, RCD, NKS and MM; writing - review and editing, SJ, AN, RCD, NKS and MM, visualization, AN, SJ, RCD and MM. All authors have read and agreed to the published version of the manuscript.

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