Exploring Methodologies for Assessing Land Degradation: A Comprehensive Review with Insights from Namibia

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Abstract

Land degradation represents a significant global environmental challenge, posing threats to ecosystem integrity, food security, and sustainable development. In this comprehensive review, we examine the methodologies employed for assessing land degradation, drawing insights from studies conducted in various regions, with a particular focus on Namibia. The study conducted a systematic literature search to gather information on land degradation assessment methods applied, 159 publications were reviewed. Utilizing the Mann-Kendall trend test, the study discerns notable trends in the publication landscape, providing valuable insights into the evolving research trajectories within this field. A prominent finding of this review is the dominance of remote sensing as the primary method utilized for assessing land degradation. In conclusion, this review underscores the imperative for future research endeavors to prioritize an in-depth exploration of land degradation processes, mechanisms, and impacts as well as advocates for the adoption of innovative technologies and monitoring methods, the advancement of theoretical frameworks, and the promotion of multidisciplinary integrated system research. By embracing these recommendations, stakeholders can effectively address the multifaceted challenges posed by land degradation and advance toward sustainable land management practices.

Keywords: *Land degradation, Methodologies, Remote sensing, Mann-Kendall trend test, Namibia, Sustainable development*

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1. Introduction

Land degradation is the process that reduces land quality, health, primary productivity, and ecosystems. It presents a formidable challenge globally, exerting adverse impacts on ecosystems, and livelihoods, and posing challenges to sustainable land management (Qadir et al., 2014; Sofia Kapalanga, 2008). Land degradation undermines the land's capacity to provide ecosystem services crucial for human existence, including the production of crops, forage, fuel, and wood, as well as the availability and quality of water resources, with climate change anticipated to exacerbate the situation by intensifying droughts, increasing evapotranspiration, and even decreasing mean annual rainfall in certain regions, the outlook is dire (Vogt et al., 2011). The repercussions of permitting land degradation to persist are increasingly recognized as costly, at different levels, ranging from farmers but also for society at large, both in the short and long term (Trucost, 2013). Moreover, it stands out as one of humanity's most pressing issues, given its propensity to permanently diminish the biological productivity of land, resulting in economic losses, yield reductions, and subsequently hunger (Keyserlingk et al., 2023). Presently, land degradation adversely affects the well-being of approximately 3.2 billion people worldwide and results in a loss of about 10% of the annual gross domestic product. Alarmingly, the Millennium Ecosystem Assessment revealed that around the year 2000, 60% of examined ecosystem services were either degraded or used unsustainably. By 2050 this may grow to 90% or more (Kust et al., 2023).

Land degradation has garnered significant attention as a major environmental and socio-economic challenge addressed by international conventions such as the United Nations Convention to Combat Desertification (UNCCD) and the Convention on Biological Diversity (CBD) (Mitri et al., 2019). For instance, Target 15.3 under Goal 15 focuses on combatting desertification, restoring degraded land and soil, including land affected by desertification, drought, and floods, and striving to achieve a land degradation-neutral (LDN) world by 2030. Various methods have been developed by researchers to assess land degradation, encompassing field observations/measurements, expert/land manager knowledge, and remote sensing (Omuto et al., 2014).

Land degradation is driven by multiple natural and ecological factors such as drought, climatic variability, fires, changes in the water table, flooding, volcanic activity, and insect invasions like locusts. Human-induced factors exacerbating degradation involve soil erosion, fertility loss, salinization, soil compaction, excessive grazing, deforestation, agrochemical contamination, unsustainable agro-pastoral practices, water logging, the introduction of alien species, poverty, and urbanization (Imbamba, n.d.). In Namibia, Klintenberg and Seely (2004) attribute land degradation to population growth, livestock impact, rainfall, climate change, erosion, and unsustainable land management practices. Increased human density leads to smaller cultivation fields, heightened wood use, intense grazing due to overstocking, and constrained animal movement. The country's semi-arid climate and fragile ecosystems make it particularly vulnerable to desertification and soil erosion (Ministry of Environment, 2015). Therefore, understanding the causes, impacts, degree, and associated climate, soil, water, land cover, and socio-economic factors of land degradation is imperative for addressing this challenge effectively. Timely detection of degradation processes is essential to prevent the continued deterioration of land conditions. Nevertheless, the absence of authenticated evidence on the scale of desertification has raised doubts about the existence of a global degradation problem, with large-scale studies often conflicting with plot and field-scale studies (Higginbottom & Symeonakis, 2014).

Considering the effect of land degradation on society and nature, there is an urgent need for accessible and accurate measurements to assess the extent of degradation and desertification, catering to policy, natural resource management, and scientific research requirements (Verón et al., 2006). Given the temporal dynamics of land degradation, measurements must adhere to the principles of repetitiveness, objectivity, and consistency (Hill et al., 2008). Taking into account the vastness of semi-arid regions and the developmental status of many vulnerable nations, Earth Observation (EO)-based systems emerge as a viable option for establishing monitoring networks (Bai et al., 2008). Thus far, trend analysis of vegetation index data, notably the Normalised Difference Vegetation Index (NDVI), has been the most widely employed method using EO datasets as a proxy for Net Primary Production (NPP).

Namibia's semi-arid climate, characterized by low rainfall, high temperatures, and prolonged droughts, plays a central role in driving land degradation, as these climatic conditions lead to soil erosion, vegetation loss, and desertification. Furthermore, socio-economic pressures, such as overgrazing and bush encroachment, exacerbate these impacts. Overgrazing, fueled by

Namibia's reliance on livestock farming, depletes soil nutrients and vegetation, leaving the land susceptible to invasive species that further compromise its productivity. In northern Namibia, bush encroachment worsens rangeland degradation, reducing its carrying capacity and threatening both agriculture and biodiversity. Additionally, Namibia's agricultural sector is characterized by low and highly variable productivity, heavily reliant on subsistence farming and extensive livestock grazing (Fortunato & Enciso, 2023).

Adding to this complexity, Namibia's diverse landscapes and ecosystems, which include arid and semi-arid regions, are especially vulnerable to degradation due to the interplay of natural and anthropogenic factors. Socio-economic challenges, such as population growth, poverty, and ineffective land management policies, further amplify land degradation pressures. Rapid rural population growth intensifies resource exploitation, leading to unsustainable land use practices. Simultaneously, poverty and limited alternative livelihoods drive communities to overexploit natural resources, accelerating degradation. These interwoven climatic, environmental, and socio-economic factors highlight the multifaceted challenges Namibia faces in combating land degradation, underscoring the importance of localized strategies to address these issues effectively (Abdrabo et al., 2014).

Understanding the state and extent of land degradation in Namibia is imperative for devising effective conservation and restoration strategies. Furthermore, the assessment of land degradation methodologies is essential for understanding the extent of this issue and formulating effective strategies for mitigation and restoration. This review synthesizes existing literature, evaluates methodological approaches, and identifies gaps in current practices. The specific objectives for this review were to (1) evaluate various methods used for the quantitative and qualitative assessment of land degradation in Namibia, (2) identify associated challenges and limitations, and (3) propose recommendations for advancing and standardizing assessment methodologies. By delving into the diverse techniques applied to land degradation assessment, this paper aims to contribute to the refinement of methodologies and the enhancement of our understanding of the dynamic processes shaping Namibia's landscapes.

2. Methodology

2.1.1. *Study area*

Namibia is a large country with an approximate land area of about 825,615 square kilometers (Kaseke et al., 2016). Its coastline stretches over 1,570 kilometers along the Atlantic Ocean. Namibia shares borders with Angola to the north, Zambia and Botswana to the northeast, South Africa to the south and southeast, and the Atlantic Ocean to the west. Namibia boasts a plethora of geographic elements, comprising deserts, grasslands, elevated areas, and coastal lowlands (Song et al., 2023).

2.1.2. *Climate*

Namibia experiences a predominantly arid to semi-arid climate. The western coastal region is dominated by the Namib Desert, renowned as one of the planet's oldest and driest deserts, spanning around 2,000 kilometers along the Atlantic shoreline, characterized by extremely low rainfall and high temperatures. Moving inland, the terrain evolves into semi-arid savannahs and grasslands, while the Kalahari Desert dominates the eastern expanse of the nation. Namibia's climate fluctuations and arid environment intensify land degradation processes, heightening the nation's susceptibility to desertification and soil erosion (Nyong et al., 2007).

Namibia experiences diverse climatic conditions, including high temperatures, low humidity, and high evaporation rates inland. Along the Atlantic coast, the Namib Desert presents low precipitation, cool temperatures, and moist air. In the northeast, high temperatures and frequent floods are common, while the central-north region experiences alternating floods and droughts. These conditions result in increased evaporation and transpiration, leading to meteorological droughts, soil water deficiency, and plant water stress. Agricultural productivity may suffer as a consequence, and prolonged droughts can cause hydrological impacts such as reduced streamflow and wildlife habitat (A. Kgabi et al., 2016).

2.1.3. *Rainfall*

Rainfall distribution is erratic, with the bulk of precipitation falling between November and April during the summer season. Rainfall increases from west to east, with the western coastal areas receiving less than 50 millimetres annually, while the north-eastern regions receive up to 800 millimetres in some areas. In central and northeastern Namibia, where rainfall is relatively higher, savannah and woodland ecosystems are found. These areas support a mix of grasses, shrubs, and trees, including acacia species and mopane trees (Wingate et al., 2014). Temperature differentials are notable, with daytime highs surpassing 30°C during summers and notable declines at night (Fig. 1).

2.1.4. *Vegetation*

The Namib Desert is characterized by sparse vegetation, such as drought-resistant shrubs, succulents, and unique desert-adapted plants like the Welwitschia mirabilis. The Caprivi Strip and other areas with higher rainfall and proximity to rivers exhibit floodplains and wetland vegetation, including riverine forests, papyrus swamps, and grasslands (Fig. 1).

Despite its dry climate, Namibia boasts a diverse array of plant and animal life, well-suited to its challenging environmental circumstances. The nation hosts a variety of iconic wildlife species, such as desert-adapted elephants, lions, rhinoceroses, and giraffes, all of which have developed specialized traits to flourish in arid habitats (Song et al., 2023).

2.1.5. *Population*

Namibia has a population estimated at around 2.5 million people (Namibia Statistics Agency, 2013). The population density of Namibia is relatively low, with around 3 people per square kilometre due to its large land area and sparse population distribution. Population density exhibits significant regional variation within Namibia, with certain regions, including Ohangwena, Omusati, and Khomas, characterized by higher population densities, while others, such as Omaheke, Kunene, and Hardap, exhibit lower population densities (Fig. 1).

In Namibia, livestock farming is a significant component of the economy and plays a crucial role in the livelihoods of many rural communities (MEFT/NACSO, 2021). Livestock, including cattle, sheep, and goats, are an important source of income, food, and employment for a large portion of the population, particularly in rural areas. Livestock farming is closely linked to the population, as it provides livelihood opportunities for many Namibians, especially in rural areas where agriculture is a primary economic activity.

Livestock farming also has implications for land use and environmental sustainability in Namibia. The expansion of livestock farming can lead to overgrazing and land degradation, particularly in semi-arid and arid regions where vegetation cover is sparse (Strohbach, 2018). This can have negative impacts on biodiversity, soil quality, and ecosystem services. Therefore, sustainable management of livestock and rangelands is essential to ensure the long-term viability of both the livestock industry and the environment in Namibia.

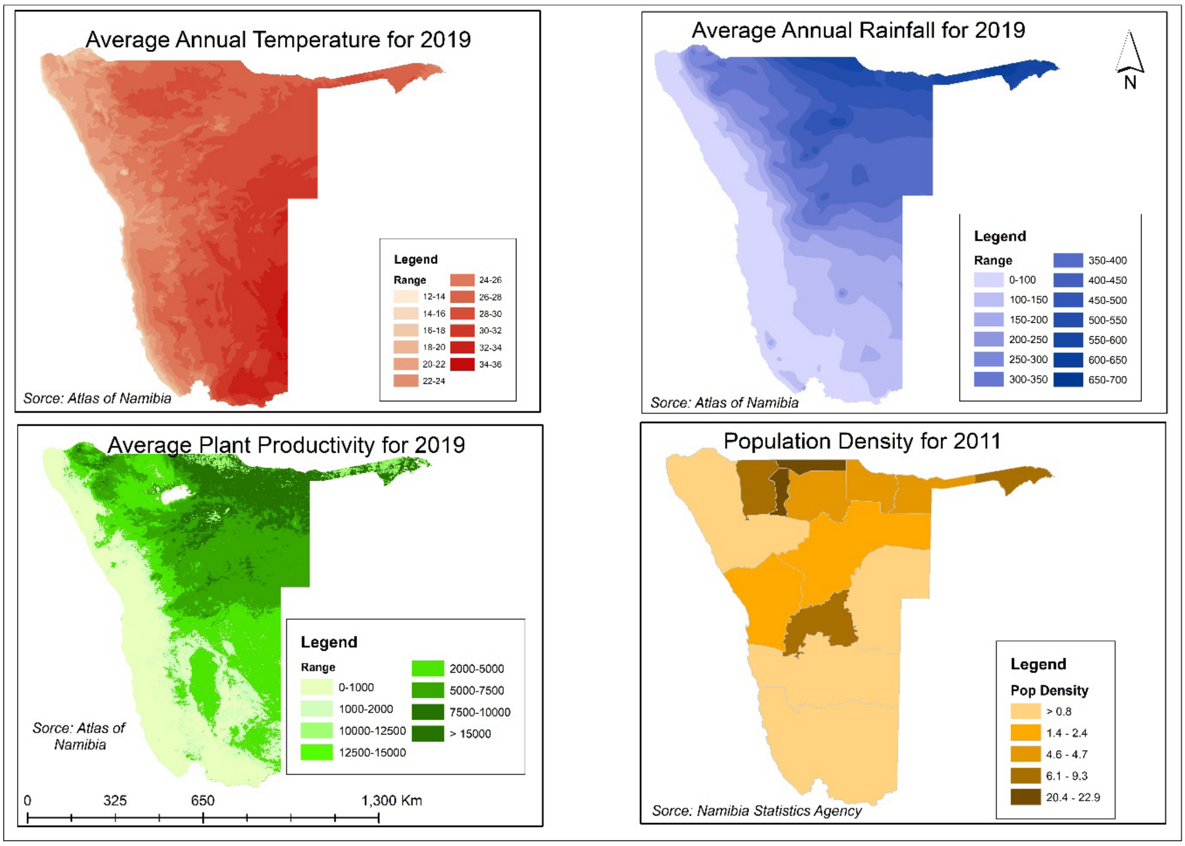

Figure 1: Namibia's climatic and demographic variables

2.1.5. *Socio-demographic correlates of land degradation in Namibia*

According to Klintenberg & Seely, 2004, these are some of the land degradation drivers in Namibia: population pressure, land cover change, total grazing pressure, soil erosion, human poverty index, rainfall index, normalized difference vegetation index, water consumption by resource type, routine monitoring of water levels in non-strategic regional aquifers, value added to water, water quality within water resources, economic diversification, GDP spent on environmental resource research, capacity to do regional and local land use planning. They were presented and discussed at a workshop, where participants ranked them according to their perceived relevance to the monitoring of land degradation in Namibia.

The map (Fig. 2) illustrates the status of land degradation in Namibia, generated using Trends.Earth. It categorizes the land into three distinct classes: high, low, and very low, each representing specific levels of land degradation risk. The 'high' class denotes regions at significant risk of land degradation, while the 'low' and 'very low' classes indicate areas demonstrating improvement in land condition.

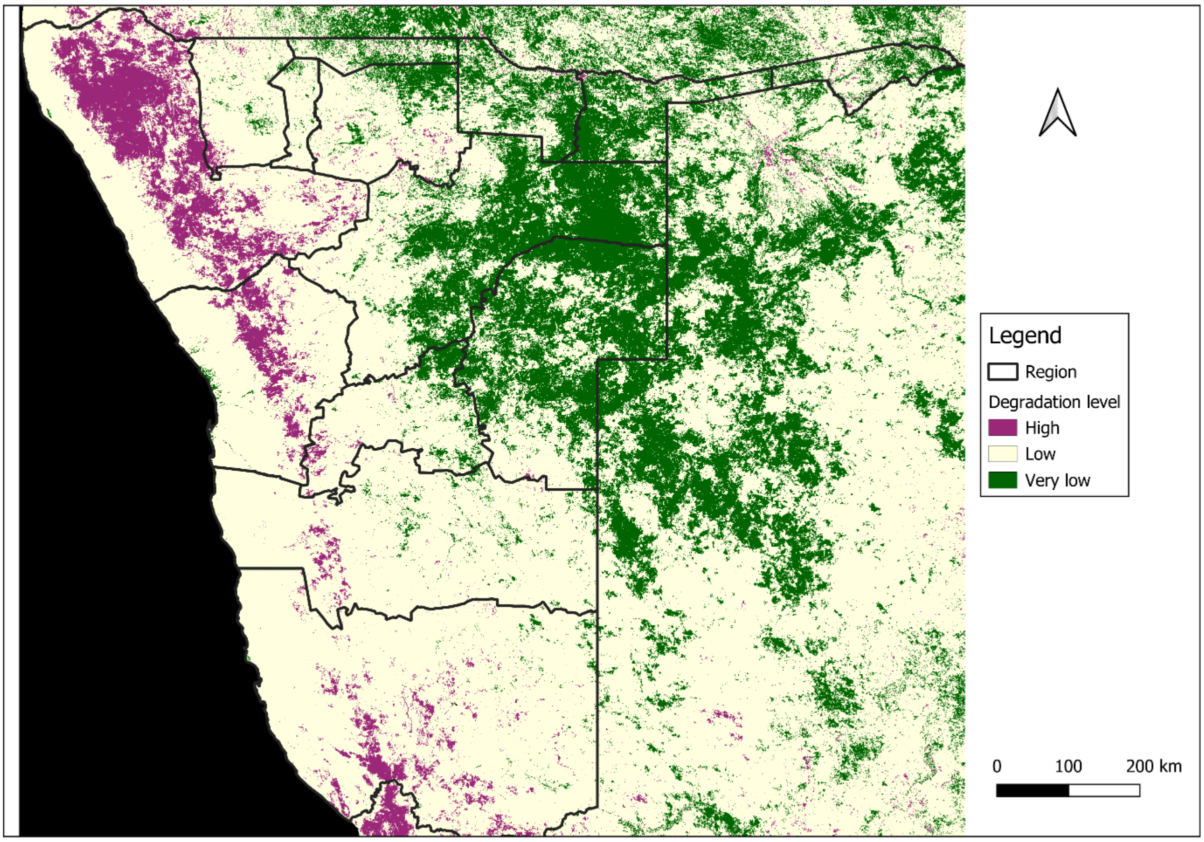

Figure 2: Status of land degradation in Namibia

2.2. Data collection

We conducted a systematic literature search to retrieve studies on land degradation assessment methods applied in Namibia up until the end of 2023. This search was conducted using the Google Scholar and Web of Science search engines between November 10, 2023, and February 28, 2024. The search strings utilized were "land degradation assessment methods", and "assessments of land degradation methods". Due to the limited number of publications from Namibia, the study scope was expanded to include Africa and other continents. The selected articles were analyzed to extract information such as the title, author, date of publication, aim, and objectives of the study, study area, methods used, definition of land degradation, findings, and main conclusion. This information was meticulously recorded in a Microsoft Excel spreadsheet. The study was limited to peer-reviewed literature on land degradation assessments to ensure the reliability and credibility of the sources utilized. This selection criterion was implemented to maintain a high standard of scientific rigor and to mitigate the risk of incorporating potentially biased or unreliable information. Consequently, the findings and conclusions drawn from this study are based on a robust foundation of scholarly research, enhancing the validity and credibility of the results obtained.

2.3. Statistical analysis

The information was categorized into three main sub-headings: method, challenges, and recommendations. We used the Mann-Kendall two-sided test to determine the trends in the publication in R studio. A Chi-Square was used to compare frequencies among categories (i.e., methods, definitions of land degradation, challenges, and recommendations).

The Mann-Kendall trend test was selected for analyzing the temporal trends in land degradation-related research publications due to its robustness and flexibility. Unlike linear regression, which assumes a linear relationship and data normality, the MK test identifies monotonic trends without these constraints, making it suitable for bibliometric data often characterized by non-linear patterns and irregularities (Wang et al., 2020). Its resistance to outliers further strengthens its applicability for publication frequency data. The assumptions of the MK test, such as independent observations, were assessed and found to align with the characteristics of the dataset.

The methodologies employed in this study can be further enhanced by drawing insights from region-specific research conducted in Namibia and its neighboring countries. For example, studies in southern Africa have emphasized the utility of satellite-based indices, such as NDVI, to monitor vegetation trends in semi-arid regions. However, these approaches face challenges, including data gaps and limited accessibility in rural settings. Furthermore, Namibia's socio-political landscape significantly impacts land degradation processes. While aiming to secure land tenure, the Communal Land Reform Act has unintentionally created pressure on communal lands, accelerating overgrazing and bush encroachment (Abdrabo et al., 2014). Integrating these contextualized perspectives enriches the analysis by aligning methodologies with Namibia's unique ecological, economic, and policy environment.

3. Results

3.1. *Publications*

From 1999 to 2023, a total of 159 publications related to land degradation assessments were identified. Over these 24 years, three distinct periods of increment were discerned (Fig. 2). The first period, spanning from 1999 to 2007, registered 19 publications. The second period spanned between 2008 and 2016, with a notable increase in publications to 33. The percentage increase between these two periods was 73.68%. The most substantial surge occurred between 2017 and 2023, during which 107 publications were observed, constituting 224.24% of the total number of publications between the second and third periods. The overall percentage increase between the years was 463.2%.

The Mann-Kendall trend test revealed a significant trend ($\tau = 0.604$, $p < 0.005$) indicating a moderate to strong positive trend association between the number of publications and years in this subject. These results underscore a discernible upward trajectory in publication frequency, highlighting a significant trend indicative of heightened scholarly activity within the field over the examined timeframe (Fig. 3).

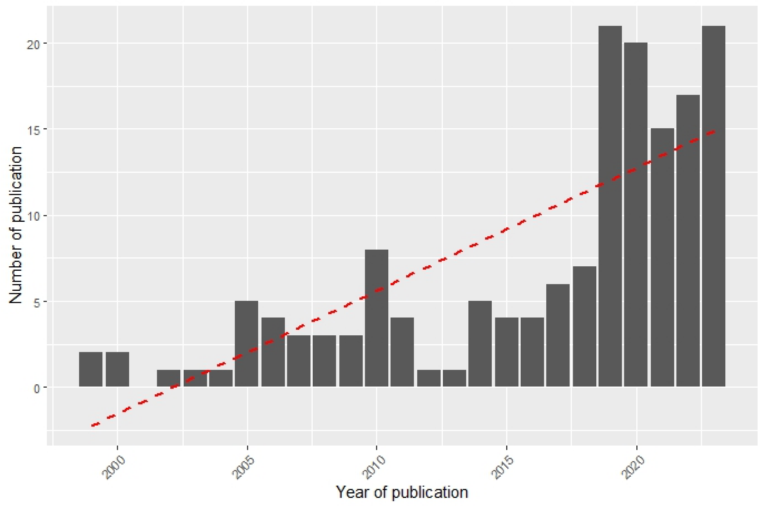

Figure 3: Number of publications by years on land degradation published between 1999 and 2023 (n= 159) globally.

3.2. *Distribution of studies across the globe*

The 159 reviewed studies originated from assessments conducted in 57 countries spread across the five continents (Fig. 4).

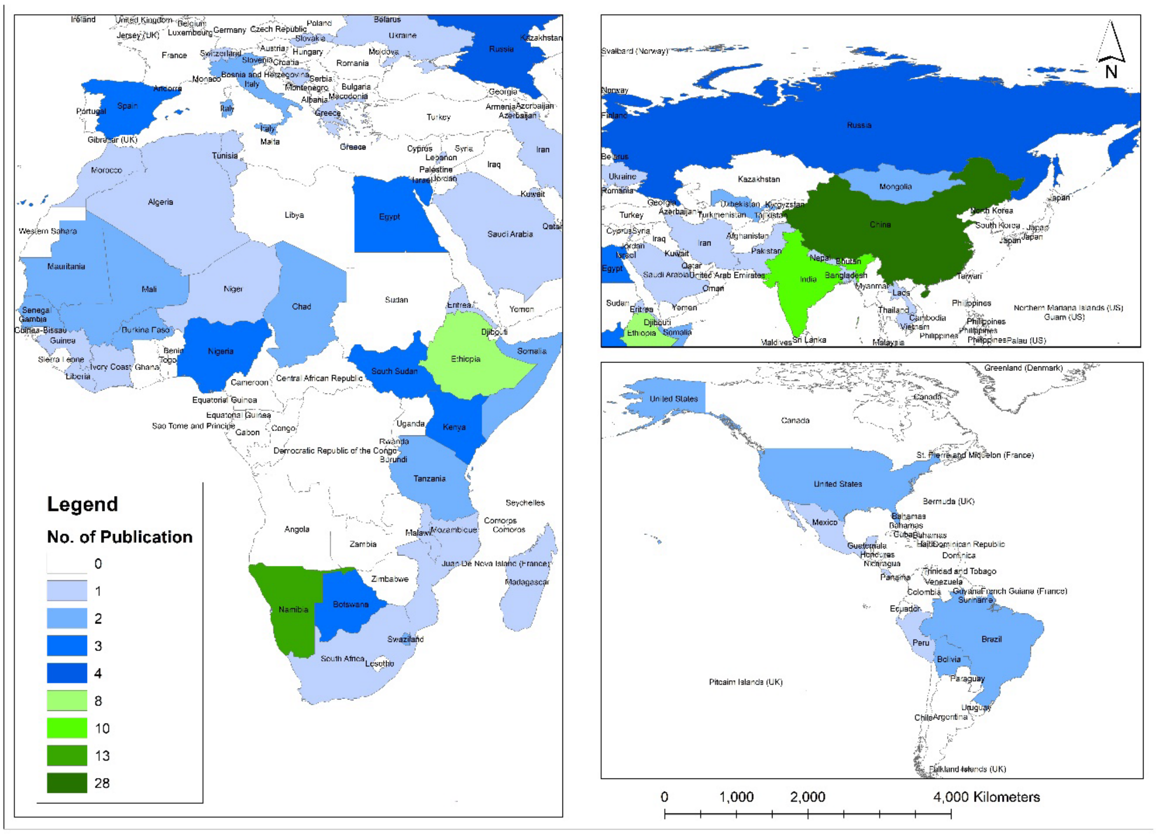

Figure 4: Number of publications on land degradation assessment per country and continental levels conducted from 1999 to 2023.

In terms of countries, China was the country with the highest number of studies, totaling 28. This was followed by Namibia and India, with 13 and 10 studies, respectively, representing a percentage difference of approximately 53.57% between China and Namibia, and 64.29% between China and India. The difference between Namibia and India was about 23.08%. Ethiopia followed with eight studies, and Russia had four assessments. Countries such as Kenya, Egypt, Botswana, Nigeria, Sudan, and Spain had three studies each. Seventeen countries, including Cambodia, Bolivia, Italy, Mali, and Chad, had two studies each. Finally, 29 countries, such as Ukraine, Algeria, Iran, Iceland, Nepal, and Mozambique, had only one published paper each.

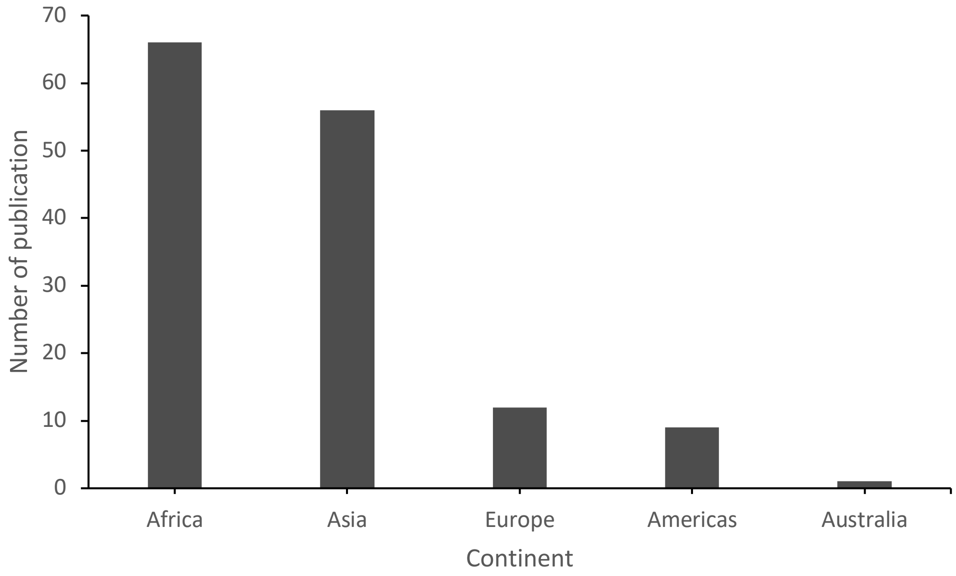

Figure 5: The number of publications on land degradation assessment per continent.

When data is aggregated at the continental level, Africa emerged with the highest number of publications (n = 66), followed by Asia (n = 56) and Europe (n =12), whilst South and North America exhibited 9 publications each. Conversely, a single publication was retrieved from Australia. This distribution underscores the varied research focus on land degradation across different geographical regions, with Africa and Asia notably garnering more scholarly attention in this domain compared to Europe.

3.3. *Methods used to assess land degradation*

The review revealed that eight methodologies have been employed either as a stand-alone or in combination to conduct land degradation assessments at the global and Namibia levels (Fig. 6).

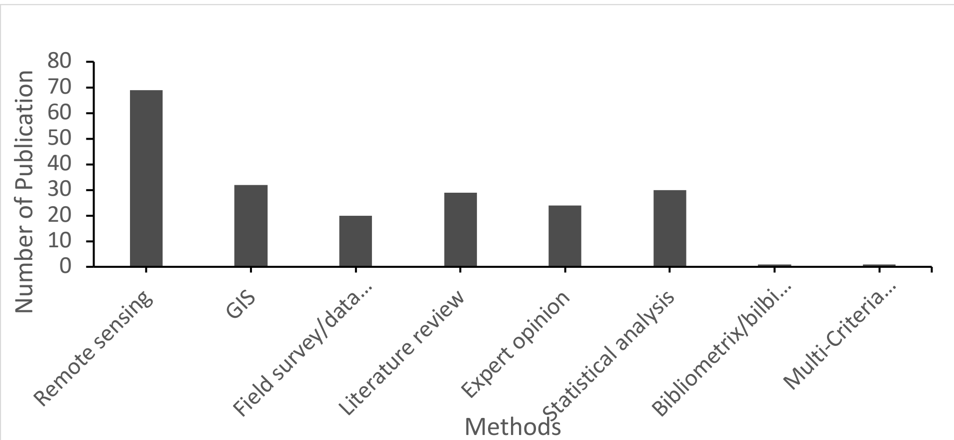

Figure 6: Various methods used to assess land degradation.

The predominant method employed for assessing land degradation was remote sensing, featured in approximately 33.5% of the publications. Followed by GIS at 15.5%, with a 53.6% difference compared to remote sensing. Statistical analysis accounts for 14.6%, differing by 56.5% from remote sensing. Literature review methods appear in 14.1% of the publications, showing a 58.0% difference. Expert opinions and field surveys are utilized in 11.7% and 9.7% of publications, with differences of 65.2% and 71.0%, respectively. Both Bibliometrix/Biblioshiny software and Multi-Criteria Evaluation are the least employed methods, each featured in only 0.5% of publications, exhibiting a 98.6% difference from remote sensing.

Table 1 presents a summary of land degradation assessment methods. The methods were systematically grouped based on their similarities before being presented in Figure 6. This classification facilitates a concise understanding of the diverse methodologies used to assess land degradation.

Land Degradation Assessment Method	Description
Remote sensing, earth observation, RESTREND methods (e.g., Aynekulu et al., 2017; Klintenberg & Seely, 2004b; Ogorodnikov, 2022)	Utilizes satellite imagery (Landsat and Sentinel) and aerial photography to monitor temporal changes in land cover and vegetation.
Geographic Information System (Han et al., 2019; Masoudi & Jokar, 2022; K. Zhang et al., 2007)	Integrates spatial data layers e.g. land cover to construct predictive models and analyze degradation phenomena.
Mann Kendall test, Shannon wiener/species richness. (de Araújo et al., 2015; Kang et al., 2020; Roy et al., 2022)	These are statistical techniques used to analyze data related to land use, land cover, and environmental variables.
Experts' opinions, stakeholder consultation, land user's opinions, local community knowledge (Lanckriet et al., 2015; Nyong et al., 2007; Omuto et al., 2014)	Involves soliciting input from experts and stakeholders across relevant disciplines.
Field observation and measurement, data collection, field monitoring (Assefa & Hans-Rudolf, 2016; Bekele et al., 2021; Inman et al., 2020)	Involve direct observation and measurement of various land-related parameters in the field to evaluate the extent, severity, and drivers of degradation processes.
Literature review (Dubovyk, 2017; Jnr, 2014; Pacheco et al., 2018)	Involves systematically gathering, analyzing, and synthesizing existing knowledge, research findings, and scholarly literature related to land degradation processes.

Table 1: Summary of assessment methods used in the study.

3.4. *Definition of land degradation*

We documented seven definitions of land degradation across the 159 studies. Twenty-seven publications adhered to a definition characterizing land degradation as the "reduction or loss of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns." (Aynekulu et al., 2017). The emphasis here is on the reduction or loss of economic productivity highlighting the tangible impacts on ecosystems and livelihoods.

In turn, 21 publications adopted the definition of land degradation to be "the decline or loss in ecosystem functions and services of a given territory that cannot fully recover unaided within decadal time scales." (Montfort et al., 2021). This definition emphasizes the broader ecological consequences of degradation, underscoring the long-term impairment of ecosystem resilience and services critical for human well-being.

Furthermore, 11 publications articulated land degradation as "the reduction in the capability of the land to produce benefits from a particular land use under a specified form of land management." (Pricope et al., 2023). This definition emphasizes the context-specific nature of degradation, acknowledging the influence of land management decisions on land productivity. This is in line with Aynekulu et al. (2017) which clearly highlights the role of anthropogenic drivers of land degradation during the process of assessment.

Moreover, six publications defined land degradation as "the deterioration or total loss of the productive capacity in soil properties related to crop production, infrastructure maintenance, and natural resource quality for present or future use" (Abdul Rahaman & Solavagounder, 2020). From this definition, the emphasis is on the degradation of soil properties that are critical for supporting various aspects of human activities, particularly crop production, infrastructure maintenance, and the quality of natural resources.

Omuto et al., (2014) and Angaman et al., (2024) interpreted land degradation as "a form of land cover modification resulting from human impacts under climatic variations." Here, the focus is on the interaction between human activities and climatic factors in driving changes to land cover, highlighting the interconnectedness of social and environmental processes.

Vasu et al., (2018) and Kiunsi & Meadows, (2006) defined land degradation as the processes and results of both vegetation and soil degradation due to natural and/or anthropological factors. From this definition, the emphasis is on the holistic view of land degradation because of both vegetation and soil degradation, resulting from a combination of natural and anthropogenic factors.

Lastly, Kust et al., (2023) defined land degradation as "the proportion of land that is degraded over the total land area." This definition provides a quantitative metric for assessing the extent of degradation, offering a standardized measure to track changes over time.

Across the various definitions of land degradation documented, several common themes emerge. Primarily, most definitions emphasize the reduction or loss of productivity and the deterioration of land quality. This includes the biological, economic, and ecological aspects of land productivity and the services that ecosystems provide. For instance, definitions by Aynekulu et al. (2017), Pricope et al. (2023), and Abdul Rahaman and Solavagounder, (2020) highlight the tangible impacts on ecosystems and human livelihoods, focusing on the loss of productive capacity. Another commonality is the recognition of human activities and natural processes as drivers of land degradation. Definitions by Omuto et al. (2014) and Angaman et al. (2024) explicitly mention the interplay between anthropogenic factors and climatic variations. Additionally, the idea of long-term consequences and irreversible changes is present in several definitions, such as those by Montfort et al. (2021), which stress the broader ecological impacts and the inability of ecosystems to recover unaided over decadal time scales.

While the definitions share common themes, they also exhibit notable differences in emphasis and scope. For example, Aynekulu et al. (2017) and Pricope et al. (2023) focus on the economic and productivity aspects of land degradation, making them particularly relevant for agricultural and land management contexts. In contrast, Montfort et al. (2021) places greater emphasis on ecosystem functions and services, highlighting the ecological and environmental implications of degradation. Definitions by Abdul Rahaman and Solavagounder (2020) are more specific to soil properties and their relevance to crop production and infrastructure, underlining the importance of soil health in land productivity. Omuto et al. (2014) and Angaman et al. (2024) highlight the interaction between human impacts and climatic variations, bringing a more integrated perspective on how land cover is modified. Lastly, Kust et al. (2023) provides a quantitative metric, focusing on the proportion of degraded land, which offers a more standardized measure for assessing and tracking land degradation over time.

4. Discussion

Land degradation represents one of the most significant global environmental challenges, necessitating concerted efforts to mitigate and address its impacts. As such, initiatives aimed at reducing land degradation are crucial for promoting sustainable development and environmental resilience. The analysis revealed a consistent increase in the number of publications in recent years, indicating growing interest and research activity in the field of land degradation. In addition, Africa and China emerged as the continent and country with the highest number of publications, respectively. In terms of assessment techniques, remote sensing emerged as the predominant method. Finally, the predominant definition of land degradation, as observed in the reviewed literature, encapsulates the concept as the "reduction or loss of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or a process or combination of processes, including processes arising from human activities and habitation patterns."

4.1. *Publications*

The rise in publications on land degradation between 1999 and 2023 can be attributed to a confluence of factors. Heightened global awareness of the adverse effects of land degradation on ecosystems, food security, and livelihoods has spurred increased research interest in the topic. Advances in research methods and technologies, particularly in remote sensing and geographic information systems, have arguably enabled more accurate assessments of land degradation, further driving research output. In a review by Kawy & Darwish, (2019), the authors attributed the growth to advancements in remote sensing technology and geographic information systems, to have facilitated an increase in studies focusing on methodologies for assessing land degradation. This trend underscores the rising utilization of remote sensing data and spatial analysis tools in the realm of land degradation research.

Additionally, international agreements and initiatives, such as the UNCCD and SDGs, have provided a framework for collaborative research efforts and policy action on land degradation (Akhtar-Schuster et al., 2011). Pressing environmental challenges, including climate change and loss of biodiversity, have purportedly underscored the urgency of addressing land degradation, prompting interdisciplinary research efforts. Moreover, increased funding and support from governments, NGOs, and international agencies have incentivized research on land degradation, contributing to the proliferation of publications in this field (Gebreselassie et al., 2015). For instance, the German Federal Ministry for Economic Cooperation and Development (BMZ), has provided financial support for the research by Gebreselassie et al. (2015).

Xie et al., (2020) conducted a study investigating the trends of research publications focused on land degradation assessment methods between 1990 and 2019. Employing bibliometric analysis on data sourced from diverse databases, the researchers observed a consistent increase in the volume of about 157 articles about this subject matter.

Similarly, Masoudi & Jokar, (2022) conducted a study employing bibliometric techniques to explore the evolution of research on land degradation assessment. Their analysis of publication records from various databases revealed a notable surge in articles dedicated to land degradation assessment methods, particularly within the past five years. This progressive pattern indicates an escalating acknowledgment of the significance of land degradation concerns and underscores the imperative for robust assessment approaches, highlighting the growing emphasis on advancing methodologies for evaluating and monitoring land degradation and indicating heightened research endeavors in this domain.

4.2. *Spatial distribution of land degradation assessment*

The prevalence of research on land degradation in Africa at the continental level and in China at the national level can be attributed to several key factors. Firstly, Africa is particularly susceptible to land degradation due to a combination of environmental, socio-economic, and climatic factors, such as rapid population growth, widespread poverty, unsustainable land management practices, and variable weather patterns (Kiage, 2013; Reynolds et al., 2007). Considering the continent's diverse range of ecosystems, which range from arid and semi-arid regions prone to desertification to tropical forests and savannahs that are vulnerable to deforestation and soil erosion, Africa faces significant challenges related to land degradation. Consequently, there is an urgent need for research to improve our understanding of the underlying drivers, impacts, and potential mitigation strategies for addressing land degradation across the continent.

Similarly, China's prominence in research on land degradation can be attributed to its rapid industrialization, urbanization, and intensive agricultural practices, which have placed significant pressure on its land resources (Chen et al., 2007). As a result, the country faces numerous challenges related to land degradation, including soil erosion, desertification, deforestation, and pollution, exacerbated by factors such as the overexploitation of natural resources, changes in land use, and inadequate land management policies for instance in Amudarya River delta (Jiang et al., 2019). Given China's status as one of the world's largest economies and most populous countries, addressing land degradation is imperative for the nation's sustainable development and environmental conservation efforts (Huang et al., 2023; L. Zhang & Schwärzel, 2017).

Moreover, both Africa and China have seen a growing acknowledgment of the significance of addressing land degradation on both national and global scales. Governments, academic institutions, and non-governmental organizations in these areas such as the Economics of Land Degradation Initiative Secretariat, European Commission, GIZ, and UNCCD have allocated resources toward conducting research, executing conservation initiatives, and devising policies aimed at mitigating land degradation and fostering sustainable land management practices (Gebreselassie et al., 2015). Furthermore, international partnerships, funding avenues, and platforms for sharing knowledge have played a pivotal role in facilitating research endeavors on land degradation in these regions, thereby fostering an increase in the number of studies conducted.

Namibia, India, and Ethiopia also emerged as notable focal points. This concentration of research highlights Namibia's significance as a case study for understanding land degradation processes which may be attributed to its unique environmental characteristics and socio-economic dynamics (Abdrabo et al., 2014). Likewise, with India and Ethiopia, it is most likely due to their diverse ecological landscapes and socio-economic contexts, which likely offer valuable insights into the drivers and impacts of land degradation within different regional contexts (Kirui et al., 2021; Prakash et al., 2016).

Finally, it is noteworthy that the majority of countries were represented by one to four published papers. While these individual studies may provide valuable insights into localized issues or specific research questions, the limited representation of these countries underscores potential gaps in our understanding of land degradation dynamics across the globe. Although these countries represent a wide range of environmental conditions, from arid to temperate climates, and encompass various land use systems e.g. cultivation and management practices, land degradation may not be perceived as a pressing priority compared to other socio-economic or environmental issues. Consequently, governments and research institutions may allocate resources to address more immediate concerns such as poverty alleviation, food security, or public health, resulting in fewer studies on land degradation. Hence, future research efforts should aim to address these gaps by exploring land degradation processes in underrepresented regions and by fostering international collaborations to enhance knowledge exchange and capacity building.

4.3 *Methods used to assess land degradation*

The predominant method for assessing land degradation is remote sensing, featured in 33.5% of the publications. This could be due to its high inclusivity, providing a broad, comprehensive view of land degradation across large areas (Xie et al., 2020). Remote sensing integrates various indicators such as vegetation cover, soil moisture, and surface temperature, allowing for detailed monitoring of changes over time and across different scales (Bai et al., 2008; Yang et al., 2020). Although remote sensing is initially expensive due to technology and data acquisition costs, it becomes cost-effective over time because of its wide coverage and the decreasing cost of satellite data (Bai et al., 2008). For a country like Namibia, with its vast and varied landscapes, remote sensing could be particularly beneficial. However, the affordability of high-resolution data depends on available funding and technological infrastructure (Wessels et al., 2004).

Similarly, GIS, accounting for 15.5% of the publications, offers significant inclusivity. It can incorporate multiple data layers, including satellite imagery, soil data, climate data, and topographic information, enabling complex spatial analyses and the creation of detailed maps that highlight areas of concern (Masoudi et al., 2021; Masoudi & Jokar, 2022; Vogt et al., 2011). GIS software, though potentially costly, has become more accessible with open-source alternatives like QGIS. Its cost-effectiveness improves with data availability and skilled personnel (Vogt et al., 2011). Thus, Namibia could leverage GIS effectively with adequate training and data, making it suitable for integrating various local datasets.

In addition, statistical analysis, used in 14.6% of the publications, is inclusive in processing large datasets to identify patterns and trends. It allows researchers to identify significant trends and assess the statistical significance of observed changes in land degradation indicators, although its effectiveness depends on the quality and comprehensiveness of the data inputs (Kawy & Darwish, 2019; Sommer et al., 2011). Statistical analysis is generally cost-effective, especially with existing datasets, though costs can rise with the need for specialized software and expertise (Sommer et al., 2011). For Namibia, the benefits of statistical analysis depend on access to robust datasets and skilled analysts.

Moreover, literature reviews, appearing in 14.1% of the publications, provide a comprehensive understanding of existing knowledge, methodologies, and case studies. They integrate qualitative insights from various studies but do not offer new quantitative data (Sietz et al., 2017; Turner et al., 2007). Literature reviews are very cost-effective as they primarily involve reviewing existing studies, making them suitable for understanding regional studies and methodologies applicable to local conditions (Kawy & Darwish, 2019).

Expert opinions and field surveys, utilized in 11.7% and 9.7% of the publications respectively, provide valuable ground-truth data and context-specific insights. These methods offer detailed, localized information that remote methods might miss, though they are limited by scale and subjectivity (Jaquet et al., 2019; RN et al., 2016). Expert knowledge enhances the contextual understanding of land degradation processes, while field surveys validate remote sensing-derived assessments, enhancing the robustness of research findings (Assefa & Hans-Rudolf, 2016). Although potentially costly due to travel and time requirements, these methods provide invaluable localized insights. They are highly beneficial for Namibia given the specific local knowledge and conditions, though scale and cost are limitations (Hurni et al., 2005).

Furthermore, both Bibliometrix/Biblioshiny software and Multi-Criteria Evaluation, each featured in only 0.5% of the publications, are less inclusive in data collection but useful for meta-analysis and decision-making frameworks. These methods signify the growing adoption of bibliometric analysis tools for mapping research trends and quantifying scholarly impact in the field of land degradation research (Akhtar-Schuster et al., 2011; Xie et al., 2020). Bibliometrix/Biblioshiny and Multi-Criteria Evaluation methods are low-cost but require expertise in bibliometric analysis and multi-criteria decision-making. They could be useful in the context of academic research and policy-making frameworks in Namibia.

The affordability of high-resolution data can be challenging, but international programs and partnerships might offer subsidized or free access to such data for developing countries. Namibia, like many other countries, may face financial constraints, but investments in high-resolution data can be justified by the long-term benefits of effective land degradation monitoring and management (Wessels et al., 2004).

Finally, while remote sensing and GIS stand out for their inclusivity and integration capabilities, their cost-effectiveness and feasibility in Namibia will depend on available resources, infrastructure, and partnerships. Statistical analysis, literature reviews, and expert opinions provide complementary insights but come with their own set of limitations and benefits.

Remote sensing and GIS techniques offer transformative solutions to the challenges of land degradation monitoring in Namibia. These technologies are particularly relevant to Namibia’s arid and semi-arid landscapes, where vegetation is sparse and traditional methods of monitoring are costly and labor-intensive. Remote sensing-based vegetation indices, such as NDVI, effectively monitor subtle vegetation changes, while GIS enables the spatial correlation of degradation drivers, such as overgrazing, with their impacts. Namibia’s unique conditions, including its vast expanses and thinly vegetated terrain, allow for clearer satellite imagery compared to regions with dense forests, enhancing the effectiveness of RS applications. Moreover, RS and GIS facilitate evidence-based policy formulation, aiding Namibia in addressing land degradation under its commitments to the UNCCD. Studies, such as Mariathasan et al., (2019), demonstrate the utility of these techniques in Namibia, highlighting their role in identifying degradation hotspots, monitoring water resources, and supporting sustainable land management.

4.4 *Definitions of land degradation*

The presence of multiple definitions of land degradation underscores a fundamental challenge in its evaluation. The reason for this is that different disciplines and research communities emphasize specific aspects and dimensions of land degradation, leading to varying definitions shaped by unique perspectives and priorities. This is despite the definition provided by the UNCCD which consists of 197 countries. A consequence of this overabundance of definitions is complicating the assessment process due to the lack of standardized methods and criteria for quantitative analysis. This complexity arises from the intricate nature of land degradation, which can manifest in diverse forms such as soil erosion, desertification, deforestation, loss of biodiversity, and salinization (Reynolds et al., 2007).

Additionally, socio-economic, cultural, and environmental contexts further contribute to variations in perception, where what may be deemed degradation in one context could be considered a natural process or even beneficial land use practice elsewhere (Matano et al., 2015). The absence of standardized methodologies exacerbates the issue, as measurement techniques, indicators, and thresholds for evaluating degradation vary widely across studies.

The involvement of diverse stakeholders, including scientists, policymakers, and practitioners, introduces disparate interests and objectives regarding land degradation. While policymakers may prioritize socio-economic concerns, such as food security and poverty alleviation, scientists may focus on ecological indicators and environmental impacts (Reynolds et al., 2007). To address these challenges, there is a pressing need for harmonized approaches and robust criteria to facilitate a more effective quantitative analysis of land degradation (Schwilch et al., 2011). Trends.Earth is one of the systems developed to address some of these challenges.

4.5. *Challenges and limitations associated with land degradation*

Assessing land degradation presents numerous challenges and limitations at both global and local levels. Globally, one of the primary challenges is the variability in data quality and availability. High-resolution, up-to-date data are often lacking, particularly in developing regions, which hampers accurate assessments. UNCCD highlighted significant gaps in the availability of comprehensive, high-resolution datasets necessary for precise assessments (UNCCD, 2017). Additionally, methodological inconsistencies across different studies pose a major hurdle. Various methodologies lead to inconsistent results, complicating the comparison of findings and the development of standardized assessment protocols. Gibbs and Salmon (2015) emphasized that these inconsistencies are a major obstacle to achieving uniform global assessments.

Moreover, technological and resource constraints significantly impact the ability to employ advanced assessment tools like remote sensing and GIS, especially in developing countries. Bai et al., (2008) noted that limited access to advanced technology and expertise hinders effective land degradation monitoring. Another global challenge is the integration of socio-economic factors. Many assessments fail to incorporate these factors effectively, even though they are crucial for understanding the drivers and impacts of land degradation fully. Reed et al., (2015) stressed the importance of integrating socio-economic data to provide a comprehensive assessment.

Metternicht et al., (2010) addressed the critical issue of identifying indicators within the electromagnetic spectrum to detect features of land degradation, revealing the complexities involved in using remote sensing methods for this purpose. Additionally, Kawy & Darwish, (2019) underscored the necessity of employing multidisciplinary approaches that integrate diverse data sources and methodologies to investigate the impacts of land degradation, highlighting the intricate nature of assessing land degradation and the requirement for comprehensive strategies. Furthermore, RN et al., (2016) employed key informants to collect insights on their perceptions of watershed degradation, underscoring the significance of expert knowledge and practical experience in comprehending the challenges associated with land degradation.

Akhtar-Schuster et al., (2011) outlined the obstacles to integrating land degradation concerns into national, regional, and global activities and policies. Similarly, Abdul Rahaman & Solavagounder, (2020) underscored the lack of consensus on the global definition of land degradation and the absence of a uniform approach to its assessment across various spatial scales as significant limitations.

The drawbacks of pixel-based image analysis, as explored by Muhoko et al., (2020), pose significant challenges for accurately assessing land degradation. One of the key limitations is the reliance solely on spectral properties of individual pixels, which may not adequately capture the complexity of land cover dynamics and land degradation processes. The pixel-based analysis treats each pixel as a homogeneous unit, disregarding the spatial configurations and relationships among land cover elements within the landscape.

Climate variability further complicates land degradation assessments. The impacts of climate change on land degradation are not fully understood and are difficult to predict. The Intergovernmental Panel on Climate Change (IPCC) indicated that the interactions between climate change and land degradation require more detailed study and better integration into assessment models (IPCC, 2019).

In Namibia, specific challenges include the lack of high-resolution and up-to-date data. The Namibia Statistics Agency (2017) reported significant gaps in the availability of high-quality geospatial data necessary for detailed land degradation assessments. Financial and technical constraints also pose significant barriers.

Namibia's diverse and heterogeneous landscapes add another layer of complexity. The varying topography and ecosystems require tailored methodologies, as noted by (Richter et al., 2022). Additionally, there is often a disconnect between ecological assessments and socio-economic data, which is crucial for understanding the impacts of land degradation on communities. The Ministry of Environment and Tourism (2021) emphasized the need for integrating socio-economic data to develop effective land management strategies.

Climate change poses a significant threat to Namibia, exacerbating land degradation issues. The increasing frequency of droughts and extreme weather events complicates land degradation assessments and requires adaptive management strategies.

The challenges related to the application of remote sensing technologies for assessing land degradation in Namibia, as illustrated by Mitri et al., (2019), can be justified by several factors. Firstly, Namibia's diverse and rugged terrain, characterized by extensive arid and semi-arid regions, presents obstacles for remote sensing technologies. These areas often lack adequate ground truth data for validation, making it difficult to accurately interpret satellite imagery and assess land degradation processes. Secondly, harsh environmental conditions, such as high levels of dust and atmospheric interference, can affect the quality and reliability of remote sensing data, further complicating the assessment of land degradation.

Finally, addressing these challenges requires a multifaceted approach, including improved data collection and sharing, standardized methodologies, capacity building, and the integration of socio-economic and climate data. By tackling these issues globally and within Namibia, more accurate and effective land degradation assessments can be achieved, leading to better-informed policy-making and sustainable land management practices.

5. Conclusion

In summary, the review offers valuable insights into the methods, challenges, and constraints linked to land degradation assessment globally. To enhance and standardize assessment approaches, it is suggested to integrate remote sensing data with predictive spatial modeling to improve comprehension of land-use changes and their impacts on biodiversity and ecosystem services. Moreover, addressing the limitations of current methodologies entails enhancing accuracy assessment, integrating on-site measurements, and exploring non-linear models to capture the intricate dynamics of land degradation. Additionally, the effective implementation of policy frameworks is vital for mitigating land degradation, underscoring the significance of stakeholder engagement and collaboration. Finally, the assessment of land degradation in Namibia requires a multifaceted approach that integrates traditional field methods with modern remote sensing and GIS technologies. By combining qualitative and quantitative approaches, researchers can comprehensively understand the drivers, extent, and impacts of land degradation in the region.

Recommendations

The recommendations section can be further strengthened by integrating policy proposals tailored to Namibia's socio-economic realities and institutional capacities. Building operational capacity in remote sensing and GIS is critical, as these tools are indispensable for monitoring land degradation and promoting sustainable land management. This can be achieved through targeted training programs for government agencies and academic institutions, equipping them with the skills and resources for independent monitoring. Additionally, the establishment of centralized platforms for sharing spatial and non-spatial data across institutions would streamline access to critical information and reduce duplication of efforts. Public-private partnerships could further enhance this infrastructure, fostering mutual benefits. Policy frameworks should prioritize sustainable land-use practices, such as incentivizing conservation agriculture and rotational grazing while integrating Land Degradation Neutrality (LDN) targets into national development plans. Strengthening collaboration between Namibian universities, regional research institutions, and international bodies will support innovative solutions tailored to the country's unique conditions. Furthermore, adopting a standardized definition of land degradation specific to Namibia is essential for ensuring consistency across studies, facilitating better data integration, and improving policy-making and land management practices. Investing in advanced remote sensing technologies will enhance the accuracy and efficiency of monitoring efforts, while public awareness campaigns and stakeholder engagement are crucial to educating communities and involving them in sustainable practices. Lastly, strengthening policy frameworks and their enforcement at both local and national levels is vital to achieving LDN and fostering sustainable land management. These efforts, coupled with international support, such as EU investments in genetic monitoring and conservation genomics research, can significantly contribute to combating land degradation and promoting sustainable development in Namibia.

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