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Ecological Restoration of Degraded Lands

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ABSTRACT

Land degradation, stemming from both natural and anthropogenic factors, poses a significant threat to global agriculture, environmental sustainability, and human well-being. This review explores the multifaceted dimensions of land degradation, its impact on crop productivity, and the diverse processes leading to its occurrence. The intricate interplay of physical, chemical, biological, and ecological factors contributing to the degradation of fertile topsoil is discussed, emphasizing the consequences of unfavourable alterations in soil chemistry and reduced microbial activity. The review assesses the extensive global economic ramifications of soil erosion, compaction, and nutrient depletion. Furthermore, it delineates the methodologies employed for the estimation of degraded land, utilizing both ground-based measurements and remote sensing techniques. The classification system for land degradation is presented, encompassing diverse degradation types, degrees, and units. The causes of land degradation, predominantly attributed to anthropogenic activities, are explored, with a focus on agricultural intensification and poor land management practices. To address this global challenge, the review comprehensively examines the processes and techniques involved in land restoration, encompassing organic carbon pool enhancement, peat land restoration, cultivation methods, and the addition of chemical or organic amendments. The complexities of land degradation demand a holistic understanding and the implementation of sustainable strategies for land restoration to ensure food security and environmental equilibrium.

Keywords: *Land Degradation, land information system (LIS), climate change, remote sensing, desertification, crop productivity, anthropogenic causes.*

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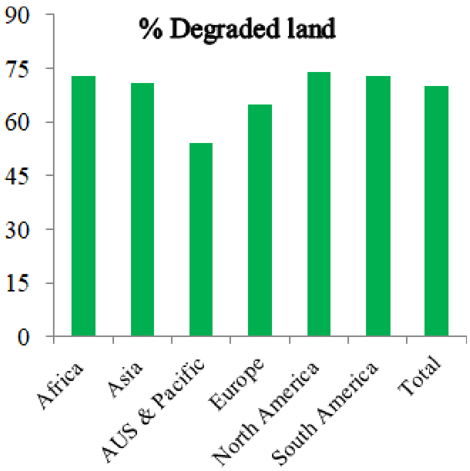
INTRODUCTION

Land degradation can considered as terms of the loss of actual potential, productivity or utility as result of natural or anthropogenic factors (Eswaran et al., 2019). Land degradation's negative effects on agronomic productivity, the environment, food security, and quality of life mean that it will continue to be a significant global issue in the twenty-first century (Hossain et al., 2020). The decrease in land quality that results from land degradation, such as erosion, both on the site where the degradation takes place and off the site where sediments are deposited, has an impact on productivity (Issaka & Ashraf, 2017). However, the utilization of additional inputs and the adoption of advanced technologies can easily disguised the on-site impacts of land degradation on production, which has prompted some to dispute the detrimental effects of desertification. There is also disagreement over how much money is lost economically as a result of declining productivity compared to environmental degradation (Briassoulis et al., 2019). According to some the experts, the effects of soil erosion and other degradation processes are not severe enough locally to justify the implementation of any kind of national or worldwide action plan (Blum, 2008).

Land degradation impacts on crop productivity

Pimentel and Burgress (2017) stated that due to soil erosion and desertification, the production of certain farms has decreased by 50%. Africa's yield loss from historical soil erosion can vary from 2 to 40%, with an average loss of 8.2% across the entire continent. An estimated 36 million tons of cereal equivalent are lost to erosion each year in South Asia, with water erosion costing US$5,400 million and wind erosion US$1,800 million. According to estimates, erosion caused by agriculture in the United States costs roughly US$44 billion year, or US$247 per hectare of pasture and cropland (Rhodes, 2014).

Globally, the loss of 75 billion tons of soil annually costs the globe over US$400 billion, or almost US$70 per person (Zorn & Komac, 2013). The world's prime land, or Class I land, makes up only 3% of the total land area and is not found in tropical regions. Classes II and III comprise an additional 8% of the land. Six billion people now and the 7.6 billion predicted for 2020 must be fed by this 11% of land.



Continent	Total area	Degraded area †
Africa	14.326	10.458
Asia	18.814	13.417
Australia and the Pacific	7.012	3.759
Europe	1.456	0.943
North America	5.782	4.286
South America	4.207	3.058
Total	**51.597**	**35.922**

Data and graphics are adopted from the publication of Hall and Smith, 2019

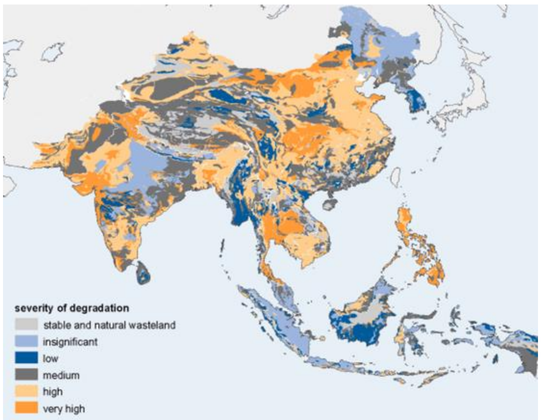
More than a billion people are impacted by desertification, which affects 33% of the world's land area and is mostly an African problem. More than a billion people are impacted by desertification, which affects 33% of the world's land area and is mostly an African problem (FAO, 2018).

Causes of land degradation

Land degradation possibly caused by the two processes, natural and anthropogenic activities (Ali et al., 2022). Agricultural intensification, cropland expansion, livestock extension, shifting cultivation without sufficient fallow periods, lack of soil conservation measures, cultivation of fragile or marginal lands, uneven application of fertilizers and pesticides, potential issues resulting from poor irrigation planning or management, use of high-yield hybrid crops, etc. are the main anthropogenic causes of land degradation. According to estimates, up to 40% of agricultural land worldwide is degraded (Kertész, 2009).

The primary human-caused factors causing land degradation are related to agriculture (shifting cultivation without sufficient fallow periods, lack of soil conservation measures, cultivation of marginal or fragile lands, uneven application of pesticides and fertilizers, potential issues resulting from improper irrigation planning or management, use of high-yield hybrid crops, etc.). It is estimated that degraded land accounts for up to 40% of global agricultural land (Zorn & Komac, 2013).

Country	Total land area (in thousand ha)	Estimated degraded land areas (in thousand ha)	(%)
Bangladesh	13,391	989	7.4
China	932,641	280,000	30.0
India	297,319	148,100	49.8
Indonesia	181,157	43,000	23.7
Laos	23,080	8,100	35.1
Myanmar	65,753	210	0.3
Pakistan	77,088	15,500	20.1
The Philippines	29,807	5,000	16.8
Samoa	283	32	11.3
Sri Lanka	6,474	700	10.8
Thailand	51,089	17,200	33.7
Tonga	72	3	4.2
Vietnam	32,536	15,900	48.9



Data and maps are adopted from the publication of Gilson (2018)

A global issue, soil compaction has increased with the use of mechanized agriculture. In some parts of Europe and North America, it has resulted in yield reductions of 25–50%; in West African countries, it has caused reductions of 40%–90%. In the USA, it is estimated that on-farm losses due to land compaction cost US$1.2 billion annually (Eswaran et al., 2001). The global economic consequences of nutrient depletion, a type of land degradation, are particularly acute in sub-Saharan Africa. Soil erosion costs Zimbabwean taxpayers US$1.5 billion annually in lost N and P alone. According to Eswaran et al. (2001), the yearly economic losses in South Asia are estimated to be US$1,200 million from soil fertility depletion and US$600 million from nutrient loss through erosion.

Land degradation resulted from population growth-related land degradation. In addition, there are other ways that population pressure functions. For example, improper agricultural practices only arise in situations where there are restrictions, such as when good lands are saturated by population pressure, forcing settlers to cultivate too shallow or steep of soils, plow fallow land before it has regained its fertility, or try to grow multiple crops by irrigating unsuitable soils (Tully et al., 2015).

Processes of land degradation

There are many processes of land degradation. The following processes are responsible for the degradation of lands;

Physical

Degradation of fertile topsoil is due to physical processes.

Degradation of the soil's structure, composition, and fertility over time is detrimental (Ali et al., 2022d; & Riaz et al., 2022a). Degradation of the soil's structure, composition, and fertility over time is detrimental (Valero et al., 2022).

Chemical

Unfavourable alterations in soil chemistry, primarily brought about by synthetic fertilizers and pesticides, reduce plant nutrition by lowering the amount of humus and beneficial microbes and shifting the pH of the soil (Urra et al., 2019).

Biological

Destructive biochemical reactions leading to decreased microbial activity, particularly in bare/unprotected earth, lower yields and make land less suitable for crop cultivation (Page et al., 2020).

Ecological

According to Ali et al. (2022c) that change in climate such as precipitation pattern, increasing temperature, higher CO_2 concentration leads to degradation of land. By exposing soil to erosion and upsetting ecosystems, deforestation and ground cover loss lead to the ecological degradation of soil (Ali et al., 2022a; & Ferreira et al., 2022).

Methodology for the estimation of degraded land

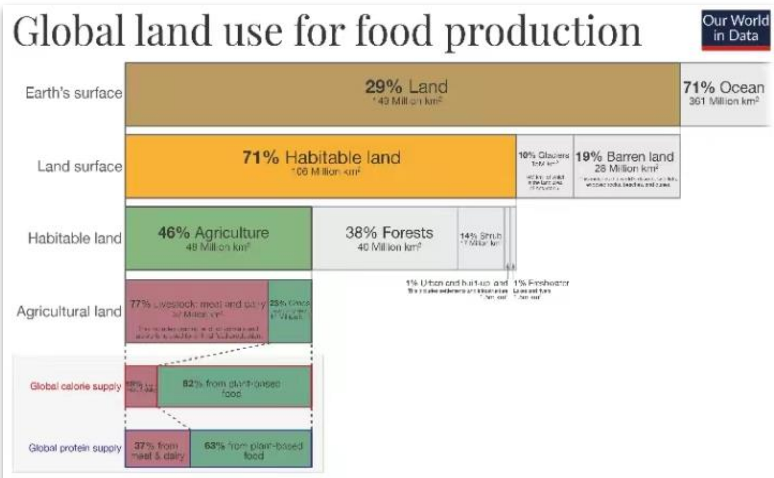
Remote sensing and measurements made on the ground are the two main methods used to assess land degradation (Kirui et al., 2021). According to Van Lynden and Kuhlman (2002) that ground-based measurements, also called survey-based (direct) field observations, encompass methods like expert and land user opinions, field measurements and monitoring, productivity shifts, studies and modeling at the farm level. These methods are crucial for assessing the process of land degradation both nationally and locally.

In contrast, remotely sensed satellite imagery, radio detection and ranging (RADAR), and geographic information system (GIS) data are used in aboveground measurements. A thorough analysis of these techniques, including their applicability, advantages, and disadvantages, is explained by Kapalanga (2008) and Bender et al. (2016).

The complete land information system consists of RS, GIS, and modeling, which can be expressed as following formula;

LIS = Spatial data + Statistical data+ Attributed data + Modeling

According to estimation of land information system by FAO (1976), our earth consists of 29% lithosphere and 71% hydrosphere in the form of ocean, glacier, rivers, streams, and available water resources. The 29% of lithosphere consists of 71% habitable land and remaining 29% occupied by glacier and barren land as 10% and 19% respectively.



Global land use for food production adopted from the report of FAO (1976).

Procedure for the estimation of degraded land

According to FAO (2004) degraded land estimation and information system should consists of the following procedure key points that enables the procedure to measure accurate data according to requirement of land information system (LIS).

(1) Comprehensive land type mapping, land cover and vegetation index study (2) Land characteristics data base construction based on land mapping units (3) Land Information System (LIS) Construction: Maps are digitalized within ARC/INFO, ILWIS or other environment. (4) Set up an applied land information system: Land type units, integrated with land cover and vegetation index, are compared with land degradation classification systems. (5) Reinterpretation of land type map into land degradation map: Extraction, Integration and conversion of the spatial data e.g. for the land degradation map production. (6) Conversion and reconstruction of statistic data. (7) As map land and land inventory are produced, then sustainable land use planning can be carried on.

Classification of land degradation system

Land degradation classification system must include ***(a)*** degradation types, ***(b)*** degrees with each type and ***(c)*** degradation units.

(a) Degradation types

According to the Beek (1980), there are four kinds of degradation recognized ***(i)*** desertification ***(ii)*** soil erosion ***(iii)*** secondary salinization and ***(iv)*** wasted land.

Type	Degradation level	Effects
Type C1	No degradation	Not very slightly degraded
Type D	Desertification	Land degradation caused by drought, wind erosion, opportunistic farming, over grazing and over cutting in arid to semi-arid region.
Type E	Soil erosion	Land degradation caused by water or wind erosion.
Type S	Salinization	Land degradation caused by salinization including secondary salinity due to poor irrigation management.
Type V	Vegetation degradation	Vegetation degraded both in quality and quantity over stocking or fuel cutting.
Type W	Waste land	Land degradation caused by unsuitable use, such as unreclaims mining sites and polluted area.

(b) Degree with each type

Degree with an each type expressed as in Arabic numbers, with increasing degrees of degradation within the type e.g. D1, D2, E1……E5.

Degradation classes	Recognization
Class 1	Potential degradation, but no evidence or improved.
Class 2	Light degradation, mainly vegetation quality degraded so that its utilization value is reduced.
Class 3	Moderate degradation, vegetation and / or soil soils are influenced. .
Class 4	Severe degradation, vegetation, soils and land form are strongly influenced, so that land use had to be changed from former practice.
Class 5	Very severe degradation, land lost its productivity and it's very difficult to reclaim

(c) Degradation units

They are indicated as land type units, e.g. D1A22, E3H24.

Land degradation Factors

Land degradation classification system consists of these factors ***(i)*** Soil erodibility (e) ***(ii)*** Slope degrees (p) ***(iii)*** Farming land use (f) and ***(iv)*** Vegetation type and vegetation cover (v)

Types of land degradation assessed Assessed land degradation have been classified into six classes ***(a)*** Water erosion ***(b)*** Wind erosion ***(c)*** Soil fertility decline ***(d)*** Water logging ***(e)*** Salinization ***(f)*** Lowering of water table

Other type of land degradation assessed

Further land degradation has been grouped into four classes **(a)** Forest degradation **(b)** Rangeland degradation **(c)** Acid sulphate formation **(d)** Soil pollution

Land restoration

The process of restoring a site ecologically to a neutral landscape and habitat that is safe for people, animals, and plant communities is known as land restoration. Land restoration is not the same as land reclamation, where existence of ecosystems are altered or destroyed to give the way for cultivation of construction. Land restoration can enhance the supply of valuable ecosystem services that benefits the peoples.

Techniques for land restoration

According to FAO (2023) there are several techniques used for land restoration and improvement of land including organic carbon pool, peat land restoration, by cultivation method, and addition of synthetic or organic amendments.

(a) Improvement in organic carbon pool

Crop yield can be increased by 20-70 kg/ha for wheat, 10-50 kg/ha for rice, and 30-300 kg/ha for maize with every 1 Mg/ha increased in soil organic carbon pool in root zone (Ali et al., 2023; & Riaz et al., 2022c). Adaptation of recommended land management practices improves the agricultural land health, soil quality, soil aggregation, susceptibility to crusting and land erosion.

(b) Peat land restoration

Organic or peaty soils accumulated large quantities of carbon due to anaerobic decomposition of the organic matter. Anaerobic decomposition, or decomposition under absence of oxygen, occurs due to the flooded conditions of peat lands. When converted to agricultural lands the soils are drained, which removes the anaerobic conditions as it introduces oxygen into the soil. This process favors aerobic decomposition (decomposition with oxygen) which results in high CO_2 and N_2O fluxes (Ali et al., 2021).

(c) By cultivation method

(i) The traditional system under rainfed conditions is to restore the lost fertility through bush fallow system. Vegetation, mainly bushes, colonizes the area naturally. Such as cultivation of *Acacia senegal* on degraded land (Elmquist et al., 2005)

(ii) Some plant species used as shelterbelts to protect the crops. These are used to protect both irrigated and rainfed farms. Their main function, at present, is to protect valuable agricultural land and irrigation canals from creeping sands (Riaz et al., 2022b; & Safi et al., 2022). According to Li (2021) shelterbelts reduce wind velocity, improve the microclimate and increase yields. Field investigations in dry areas show that crop production may be increased by as much as 300% while the increase in average years is often 30 to50%. *Eucalyptus, Casuarina sp., populus and prosop.* seedlings are used for establishment.

(iii) Green manures and cover crops serve as mulch to the soil preventing the soil from wind/water erosion and moisture loss. They also increase the soil organic matter content as they decompose in the soil. Green manure and cover crops that are legumes (plants which produce seeds in pods) have nitrogen fixing ability. The nitrogen fixing bacteria in their root nodules help capture nitrogen from the atmosphere (Scavo et al., 2022).

(iv) According to Yu et al. (2022) and Ali et al. (2022b) that crop rotation is a farming practice which involves growing different types of crops in one location sequentially. This practice reduces soil erosion, increases the soil fertility and subsequently crop yield.

(v) Meng et al. (2018) reported that salt tolerant plants are known as halophytes and they ability to tolerate and accumulate the salts in plant body. Halophytes accumulate salts in their shoots and other aerial plant parts. Examples includes *Allenrolfea occidentalis* (iodine bush), *Salicornia bigelovii* (dwarf saltwort), *Panicum virgatum* (switch grass), and *Sesuvium portulacastrum* (sea purslane).

(d) Addition of chemical or organic amendments

(i) According to Sayara et al. (2022) that organic compost is a mixture of decomposed plant parts and animal waste. The key benefit of composting is that it increases soil organic matter content. Organic matter improves the soil fertility, the soil structure and its water holding capacity. It also sequesters carbon in the soil.

(ii) Addition of gypsum (calcium sulphate dehydrate) to sodic soils. Sodic soils have high content of sodium chloride. Gypsum mixed into the layers of sodic soils replaces sodium with calcium, reducing the sodium level (Pistocchi et al., 2017)

(iii) Sulfuric acid in minor quantity also considered as the crucial component for the restoration of crop from saline or sodic soil (Daba & Qureshi, 2021).

CONCLUSION

In conclusion, addressing the urgent challenge of land degradation is essential for sustaining agriculture, protecting the environment, and ensuring global food security. The diverse impacts of land degradation on agronomic productivity, ecosystems, and overall quality of life necessitate comprehensive restoration strategies. Anthropogenic activities, such as agricultural intensification and improper land use, underline the importance of proactive measures. Utilizing tools like remote sensing and ground-based assessments is crucial for accurately evaluating and monitoring degraded land, providing a comprehensive understanding of its extent and severity. The proposed classification system, encompassing various degradation types and factors like soil erodibility and vegetation type, offers a structured approach for global assessment. Looking ahead, embracing effective land restoration practices, including improving the organic carbon pool, peatland restoration, and sustainable cultivation methods, is crucial. These approaches not only enhance soil health but also contribute to increased agricultural productivity. As we navigate the complexities of land degradation, the outlined methodologies for estimating and classifying degraded land provide valuable tools for informed decision-making. Ultimately, land restoration emerges as a vital endeavor, offering ecological benefits and crucial ecosystem services that support the well-being of communities worldwide.

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Author Contribution

All authors have participated in critically revising of the entire manuscript and approval of the final manuscript.

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