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Land Degradation in the North Eastern Region of India and its Mitigation

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ABSTRACT: The North Eastern Region (NER) of India is not an exception to the impact of land degradation. These states have seen varying degrees and types of damage. Many anthropogenic activities, such as mining for natural resources, stone quarrying, oil exploration, and other industrial operations, accelerate land degradation in this delicate ecosystem. These activities also include large-scale deforestation that results in changes in the forest cover, waterlogging, flooding, and soil and water erosion. Lime application, integrated nutrient management, integrated farming systems, agroforestry systems employing multipurpose trees, various soil and water conservation techniques, rehabilitation of contaminated soils, etc. are some of the approaches used to mitigate land deterioration in the area.

Keywords: Land degradation, Acid soil, Soil erosion, Mining, Jhum, Soil conservation.

INTRODUCTION

The North Eastern Region (NER) of India is comprised of eight states which covers 26 million hectares (m ha) of land, or 7.9% of the country's total geographical area (TGA). Of this, two-thirds (~72%) are in mountainous terrain, with the remaining portion being made up of flat land and valleys, such as the Brahmaputra, Barak, and Imphal valleys (Kumar and Meena 2016). Although more settled cultivation is also practiced in plains and valleys, rain-fed jhum, or shifting agriculture, is the primary crop husbandry method and the primary source of income for tribal populations in this hilly region due to its distinct feature of hilly terrain coupled with abundant rainfall (Choudhury *et al.*, 2022). The region's agriculture ecosystem is primarily at the subsistence level due to its hilly terrain, and it lacks 1.6 million tons of food grains overall (Kumar and Meena 2016).

LAND DEGRADATION

Land degradation and desertification in the region are caused by increasing population, overuse of its abundant natural resources, improper agricultural practices, unsustainable land usage, and shifting climatic conditions like heavy rainfall and flooding (Singh and Chaudhary 2023).

Estimated 4.16 × 10^{18} ton top soil has been removed every year. It causes of about 93 × 10^{3} hectares of land degradation in every year (Islam & Roy 2017). According to Grinand *et al.* (2019), land degradation is the continuous decrease in the land's ability to produce. This can occur from a variety of interconnected processes, including soil erosion, nutrient deterioration, loss of biodiversity, deforestation, deteriorating vegetative health, etc. Land degradation and desertification have grown to be a crucial issue globally, particularly in developing nations where concerns about food security are greatly exacerbated by ongoing land degradation brought on by deforestation and ineffective agricultural practices that result in severe soil erosion, salinization, fragmentation of land, intensive cultivation, labour shortages, and overuse of natural resources (Dagar and Gupta 2022). Due to factors including the growing population, increase food demand, fast urbanization, industrialization, ecological degradation, and the inconsiderate exploitation of natural resources, land degradation has escalated during the 20^{th} century (Hammad and Tumeizi 2012). According to the United Nations Convention to Combat Desertification (UNCCD) study on the state of land degradation worldwide, 75% of global land has been transformed and 23% is classified as no longer productive. Currently, various forms of degradation affect over 120.7 million hectares of India (NAAS, 2010).

The NER is experiencing a very rapid rate of desertification and land degradation. According to estimates from the National Remote Sensing Centre (2019), the region's land degradation extent is around 4.60 m ha, or 18.2% of the total ground area. About 30% (1.42 m ha) of this is due to water erosion, and the remaining 70% (3.35 m ha) is due to various other forms of deterioration, including acidity of the soil, waterlogging, barren rocks, mining, quarrying, riverine sands, industrial effluents, etc. Nagaland has the highest percentage of degraded land (47.1%) among the eight northeastern states, followed by Mizoram (34.92%), Manipur (33.21%), and Meghalaya (28.38%). In the same vein, Mizoram (12.6%) has more severe land deterioration due to water erosion, followed by Manipur (9.9%) and Arunachal Pradesh (5.3%) (NRSC, 2019).

CAUSES OF LAND DEGRADATION

Land degradation has a wide range of underlying factors. Although it happens naturally, human activity has recently amplified it. The primary factors contributing to land degradation in the region are soil acidity, erosion, deforestation, waterlogging, flooding, and industrial operations like mining, quarrying, refining, and crude oil extraction. According to Choudhury *et al.* (2022), soil erosion is the greatest danger to the sustainability of ecosystems and land degradation.

Soil erosion. A significant obstacle to environmental sustainability is soil erosion, especially in India's vulnerable tropical hilly regions. Due to its mountainous topography and high annual rainfall of 1500–11500 mm, the area is extremely susceptible to soil and water erosion, which causes land degradation. This made the region's ecological imbalances worse, causing siltation of downstream water bodies, frequent floods in the vast low-lying valleys and plains, and a decrease in soil fertility on the sloping highlands (Choudhury *et al.*, 2021). Unsustainable land-use practices in the hills and other human activities including jhum cultivation, deforestation, vegetation burning, urban growth, mining, and quarrying, among others, aggravate it even more (Choudhury *et al.*, 2022). Numerous case studies carried out in the area demonstrated how susceptible the area is to soil erosion. According to Ghosh *et al.* (2013), low soil loss zones (<50 t ha^{-1} yr^{-1}) have primarily been documented under deep forest, while the average annual soil loss in the Dhalai River Basin (Tripura) is estimated to be between 11 and 836 t ha^{-1} yr^{-1}. The Gumti River Basin (Tripura) exhibits a significant rate of erosion (>45 t ha^{-1} yr^{-1}) throughout its main course, interhill valley portion, and floodplain area. Conversely, the highly forested and plantation areas of the basin show a low level of soil loss (<10 t ha^{-1} yr^{-1}) (Bera, 2017). According to Jaiswal and Amin (2020), land use dynamics caused the Normalized Difference Vegetation Index (NDVI) value to change from 0.45 in 1990 to 0.35 in 2015, along with a corresponding increase in soil erosion from 12.06 to 18.30 t ha^{-1} yr^{-1} in the Panchnoi River basin (Assam). Palasbari town (Assam) experiences an average yearly rate of soil loss of roughly 42 t ha^{-1} yr^{-1} (Sarma and Dutta 2021). Soil erosion is more common in areas with steep slopes, high slope length, and strong, intense precipitation. Using the ^{137}Cs method in the mass balance model, the projected annual soil loss in the steep terrain of the Meghalaya Plateau is between 29-79 t ha^{-1} yr^{-1} (Sarma and Dutta 2021). Based on the Revised Universal Soil Loss Equation (RUSLE), an analysis of the upper Tuirial River basin (Mizoram) revealed that the river basin experiences an average annual soil loss of 115.4 t ha^{-1} yr^{-1} and an annual sediment loss of 6.161 million tons yr^{-1} (Barman *et al.*, 2020). The features of rainfall and soil loss are closely correlated, and an increase in rainfall quantity is typically accompanied by an increase in soil loss (Dabral *et al.*, 2008). Thus, the majority of soil loss in the area exceeds India's allowable limit of 12.5 t ha^{-1} yr^{-1}, which calls for rapid conservation measures (Mandal and Sharda 2011).

Soil acidity. More than 21.23 m ha (>80% of TGA) is occupied by acid soils having pH <6.5, and more than 50% of India's acid soils having pH <5.5 belong to this region (Hazarika, 2021). Deficiency of essential elements, such as calcium, magnesium, phosphorus, boron, molybdenum, and low CEC affect crop growth directly or indirectly through retarded biological activity in the rhizosphere, are among the elements that cause soil acidity to limit crop productivity. It is necessary to recover this problematic soil to increase agricultural productivity

Shifting cultivation. In the region, eighty-five percent of the total area under total cultivation is shifting cultivation. To produce crops, forest areas are cut, burned, and tilled in this slash-and-burn agricultural technique. Significant deforestation, a decline in biodiversity, increased soil erosion, the loss of organic matter, the depletion of soil nutrients, and ultimately a decrease in crop productivity have resulted from this (Hazarika, 2021). Jhum land has the highest rate of soil organic carbon pool depletion (41.8%) among the various land use types. Converting natural forest to jhum also significantly lowers soil organic carbon stock, enzymatic activities, carbon fractions, and worsens soil degradation (Mishra *et al.*, 2021; Kumar *et al.*, 2023). The region's soil health and quality are enhanced when jhum is reversed to a prolonged fallow season (Temjen *et al.*, 2022).

Change in forest cover. The primary threats to forests are anthropogenic pressure, natural disasters, excessive bamboo cutting, indiscriminate tree felling for firewood, lumber, and shifting agriculture; however, development activities and anthropogenic pressure are also factors (Reddy *et al.*, 2013). As per the Indian Forest Survey Report (2021), the region's forest cover amounts to 16.9 million hectares or around 64% of its TGA. In these states, the total amount of forest cover has decreased by 1020 km^2 in 2021 as compared to 2019. The states with the biggest changes in forest cover from 2019 to 2021 are Nagaland (-235 km^2), Manipur (-249 km^2), and Arunachal Pradesh (-257 km^2). Conversion of the dense forest led to loss of carbon from the soil. The overall carbon stock was dramatically decreased from 4.88 to 3.04% by converting forest land to tree-based land uses, and it was further reduced to 2.05% by converting it to agricultural land uses (Ansari *et al.*, 2022).

Waterlogging and flood. Excessive water or waterlogging is a serious hindrance to urban life as well as agricultural productivity. The three states of Meghalaya, Manipur, and Assam are most impacted by seasonal flooding. During the rainy season, runoff water accumulates in the lowlands and depressions, or the river releases extra floodwater, causing flooding to occur in the neighboring land (Kumar and Meena 2016). The livelihoods of people in Assam are impacted by floods and waterlogging, especially those of small and marginal farmers who reside in low-lying areas affected by flooding. In addition, these occurrences demolish houses, uproot trees, induce erosion, break embankments, wash away animals, and even have an impact on wildlife sanctuaries (Dikshit and Dikshit 2014).

Mining. In Meghalaya and Assam, coal mining is a significant contributor to land degradation and has several negative environmental effects. As per the Ministry of Coal (2022), the coal resources of Meghalaya, Assam, Nagaland, Sikkim, and Arunachal Pradesh are approximately 576, 525, 478, 101, and 90 million tons, respectively. Some of the obvious environmental effects of mining these coal reserves in the region's hilly and rugged terrain include a significant reduction in the amount of forest cover, pollution of the air and water, water scarcity, degradation of agricultural lands and soil, land subsidence, careless coal dumping, and overburdening the land (Swer and Singh 2004). Additionally, it had a negative impact on the vegetation in mined regions, specifically the density of trees, bushes, and herbs (Sarma and Barik 2011). The mine releases dust, fine coal particles, and other gaseous pollutants into the air, which might lead to respiratory illnesses in the adjacent residents (Mukhopadhyay *et al.*, 2010).

The discharge of highly acidic acid mine drainage from the mines has an impact on the surrounding water and soil quality, which in turn impacts plant growth and the majority of aquatic life (Kumar *et al.*, 2023). High sulfate, Fe, Al, Mn, Ni, Pb, and Cd are also present in the mine drainage, contaminating the soil and rendering it unusable for any kind of economic purpose (Singh and Sinha 1992; Bhole, 1994; Equeenuddin *et al.*, 2010). Over the past 20 years, Makum Coalfield (Assam) has seen a 194-hectare increase in coal mining areas. This has resulted in increasing acid mine drainage and soil erosion, which has worsened land degradation (Kumar *et al.*, 2023). Large tracts of land in Jaintia Hills (Meghalaya) have been damaged by extensive coal mining, which has resulted in heavy metal contamination that is unfavorable for plant growth (Sanjay and Lyngdoh, 2019).

Quarrying. Accelerated land degradation is caused by quarrying, particularly by unlawful and unregulated operations inside the region's delicate environment. In addition to destroying forests and depleting highly fertile soil, it also sediments riverbeds, reduces biodiversity, and is unhealthy for the general public. Numerous quarry sites and a lack of scientific planning have resulted in large-scale landslides and slope failure, which have claimed lives and damaged property (Singh *et al.*, 2012). According to Devi *et al.* (2015), sandstone quarrying in the villages of Sihhmui and Sairang (Mizoram) resulted in a significant drop in soil organic carbon from 3.64 to 2.08%, total nitrogen from 0.31 to 0.12%, phosphorus from 0.32 ppm to 0.11 ppm, and C:N ratio from 20 to 11 from highly disturbed to the undisturbed stand.

Oil industry. Assam is home to four significant oil reserves in the NER: Noonmati, Namuligarh, Bongaigaon, and Digboi refinery. These refineries produce massive amounts of oily sludge that contain a variety of highly toxic and persistent hydrocarbons and heavy metals that have serious environmental consequences (Reza *et al.*, 2014; Sarma *et al.*, 2016). An analysis of ten distinct crude oil drilling sites in Assam revealed the presence of eight heavy metal concentrations ranging from 69.51 to 336.06 mg kg^{-1} and sixteen polycyclic aromatic hydrocarbons ranging from 13.48 to 86.3 mg kg^{-1} in the soil (Sarma *et al.*, 2016). The pH of the soil was considerably lowered by the crude oil spill, however in both oil fields, the organic carbon content is highest close to the spill site because of the high total petroleum hydrocarbon content (Goswami *et al.*, 2020). According to an assessment of the heavy metal contamination near the Digboi refinery, 10% of the study site had concentrations of Cd and Ni that are greater than the maximum permissible limit values (Reza *et al.*, 2014).

STRATEGIES TO MITIGATE LAND DEGRADATION

Liming acid soils. It has been acknowledged that the best way to increase crop productivity in acidic soil is to lime it. Large amounts of lime (2-10 t ha^{-1}) are typically needed to rectify the severe type of acidity present in this region in order to achieve acceptable crop growth, which is sometimes unfeasible for resource-poor farmers for both logistical and financial reasons (Hazarika, 2021). According to Kumar *et al.* (2012), liming (3 t ha^{-1}) in the furrow increases maize yield by 32% compared to no liming. Liming and integrated nutrient management enhanced the status of organic carbon, nitrogen, phosphorus, and groundnut yield in Tripura's acidic soil (Dey and Nath, 2015).

Integrated nutrient management. For an agroecosystem to be more sustainable, degraded areas must be reclaimed, soil fertility must be improved, and nutrient usage efficiency must be increased (Das *et al.*, 2014). An appropriate combination of organic manure with bio-fertilizer and micro-dosing of macronutrients in maize, upland rice, soybean, and groundnut showed better gross and net returns, crop profitability, production efficiency, and higher soil fertility under shifting cultivation in Nagaland (Baishya *et al.*, 2022). Higher grain and biomass yields, increased nutrient use efficiency, and enhanced physicochemical properties of acid soils were also achieved in Arunachal Pradesh's upland rice through the integrated use of 75% recommended dose of nitrogen from organic sources and 25% recommended dose of fertilizers (Borah *et al.*, 2016; 2019). Inclusion of legumes as intercrops also further improves the productivity, profitability, energy budget, and soil health in hill terraces (Baishya *et al.*,2021). Long-term integrated nutrient management not only sequesters higher soil carbon, it also sustains productivity. The addition of macronutrient fertilizers along with organic manure, lime, and biofertilizers increased soil organic carbon content, aggregate stability, moisture-retention capacity, and infiltration rate of the soil while reducing bulk density (Saha *et al.*, 2010). Long-term continuous integrated nutrient management with farmyard manure /rice stubbles/*Azolla* and chemical fertilizer inputs sustained rice-rice productivity with an enhancement in soil carbon status in the long term (Gogoi *et al.*, 2021).

Integrated farming systems. Integrating crop production with livestock, fish, poultry and trees is a sustainable agricultural system that aims to maximize production through optimal use of local resources; and effective recycling of farm waste for productive purposes (Behera *et al.*, 2023). A combination of an integrated farming system (IFS) with rainwater harvesting increased yields of cereals (29%), oilseeds (40.7%), pulses (15%), fruits (9.9%), vegetables (298%), and spices (53.6%) (Ray *et al.*, 2020). The ability to recycle biomass and create mature compost was made possible by the introduction of vermicompost technology in IFS. The addition of livestock components to the model increased net income by as much as 56.59%. The maximum production of rice and protein equivalent from pond-based integrated farming systems included vegetable, pig, fruit, and pond systems; this was almost eight times higher than farmer practices in South Garo Hills (Meghalaya) (Das *et al.*, 2021).

Agroforestry. Combining seasonal crops and multipurpose trees such as teak, neem, sissoo, eucalyptus etc. including fruits in this fragile hilly region offers a viable option to meet the needs of farmers while reducing soil erosion. Judicious integration of agriculture with forestry is an eco-friendly system that has the potential to restore degraded land, fix atmospheric carbon, and enhance soil quality by reducing soil erosion (Jinger *et al.*, 2022). In contrast to 52.8 t ha^{-1} carbon stored in cultivated land in the top 0.10 m of soil, several agroforestry systems in Lembucherra (Tripura) could store roughly 65.3 and 71.6 t ha^{-1} soil organic carbon (Yadav *et al.*, 2021). Significant improvements in soil aggregation, water holding capacity, erosion susceptibility, soil organic carbon, microbial biomass carbon, and basal respiration, were also observed by Meetei *et al.* (2020) under agroforestry systems. In hill ecosystems, agroforestry, agri-silvi-horti-pastoral, or horticulture-based systems coupled with appropriate soil water conservation measures also reduce soil erosion while sustaining soil quality attributes and food security (Choudhury *et al.*, 2022). Thus, large-scale adoption of agroforestry systems may restore degraded lands and provide a feasible option for livelihood through concurrent cultivation of multipurpose tree species and agri-horticulture crops (Yadav *et al.*, 2021). Under the conditions of high rainfall, moderate to steep slopes, and shallow soil depth, agroforestry systems, such as the agri-horti-silvi-pastoral system, outperformed shifting cultivation in terms of improvement in soil organic carbon (44.8%), mean weight diameter (29.4%), dispersion ratio (52.9%), soil loss (99.3%), soil erosion ratio (45.9%), and in-situ soil moisture conservation (20.6%).

Soil and water conservation measures. Reducing soil and water erosion requires a variety of conservation strategies, including both conventional and cutting-edge techniques. The type of soil, topography, and rainfall characteristics of a given area are the primary determinants of the selection and design of conservation measures (Das *et al.*, 2018). Agronomic practices that have been shown to be effective in reducing soil erosion and preserving water include crop rotation, conservation tillage, mulching, strip cropping, cover crops, green manuring, and so on. Terracing, trenching, bunding, half-moon terraces, bench terracing, level terraces, etc. are examples of mechanical/engineering measures. Bench terraces may hold up to 207.5 t ha^{-1} in the first year, 136.5 t ha^{-1} in the second year, 88.9 t ha^{-1} in the third year, and 78.3 t ha^{-1} in the fourth year, according to a study conducted in Chandel, Manipur (Singh, 2021). When compared to typical jhum agriculture, contour farming and contour farming with cover crops can successfully minimize soil loss by 90 and 342%, respectively (Lenka *et al.*, 2017). It also decreased fertilizer loss and increased crop output. By using techniques such contour bunding, terracing, and grassed rivers in conjunction with integrated farming systems (IFS), it is possible to decrease runoff by 13.0-17.1% and soil loss by 12.6–15.1% in comparison to forestry (Choudhury *et al.*, 2022). Perennial grass primarily maintained as fodder also could conserve resources and improve soil organic carbon by 30%, mean weight diameter by 70%, available soil water by 20%, hydraulic conductivity by 40%, infiltration rate by 63%, and soil microbial biomass by 10% relative to the control (Ghosh *et al.*, 2009). By slowing the flow, structures such as loose boulder check dams, sandbag check dams, gravel bags, retaining walls with bamboo mats, concrete stacked blocks, rock-filled check dams, and geotextiles are effective in preventing erosion and gullies (Choudhury *et al.*, 2022). When combined with one another, soil water conservation methods generally had a greater impact on controlling erosion than when applied singly (Choudhury *et al.*, 2022).

Remediation of polluted soils. Urgent action is required for soil contaminated by oil refineries, mining, and quarrying. Polluted areas can be cleaned up by using physical, chemical, electrical, thermal, and biological approaches to eliminate organic contaminants. Any remediation method's selection is influenced by the kind, extent, and source of pollution; the efficacy, cost, and efficiency of the technology; and the topography, soil composition, and physicochemical characteristics of the contaminated site (Haokip *et al.*, 2023). A pot culture experiment showed that heavily metal polluted coal mined soil of Jaintia Hills can be phytoremdiated using sunflower and asparagus although sunflower was a superior phytoremediating crop in comparison to asparagus (Sanjay and Lyngdoh, 2018). A native grass species, *Axonopus compressus* could remove about 40-70% of total petroleum hydrocarbon compared with 9-11% in control in crude oil-contaminated soil in Assam (Bordoloi *et al.*, 2012).

CONCLUSIONS

The mountainous nature of the NER of India makes it a fragile ecosystem inherently vulnerable to land degradation. The slash-and-burn type of agriculture coupled with the heavy dependence of the majority of the population on forest products, and industrial and developmental activities accelerates deforestation, soil and water erosion, biodiversity, and even loss of human lives. Steps to mitigate land degradation should include measures that could reduce degradation *vis-a-vis* improve productivity, profitability, and sustainability of the ecosystem.

FUTURE SCOPE

To impede the various factors that reduce the functioning capacity of the land, interdisciplinary studies need to be taken up encompassing various stakeholders. Also, the local people need to be apprised of the ill effects of land degradation activities on soil, the environment, and human lives.

Conflict of interest. None.

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