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REVIEW

Native Plant Species: a Tool for Restoration of Mined Lands

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Abstract
The COVID-19 epidemic, food and water insecurity, and the climate emergency have impacted the lives of billions of people worldwide. Ecosystems play a crucial role in tackling these problems. Hence, it is a prime necessity to keep the ecosystems safe and sustainably manage the resources. But this would not suffice for the protection and sustainable management of our surviving natural landscapes and oceans; we also need to restore the planet's devastated ecosystems and the enormous benefits they give. Mining exerts a lot of pressure on the land resources further depleting the fertility of the soil. The overburdened dumps are devoid of the nutrients which turns natural succession at a slow pace. The restoration of the degraded mined areas is essential to re-establish the ecological balance so that a self-sustaining ecosystem can be maintained. The plantation of selected species of plants could be a sustainable and organic tool for the restoration of the degraded mined land. In today's context, various ways regarding ecological restoration are suggested, but the native plant species plantation is the best tool for restoring the degraded land at a quicker pace. The present paper reviews the importance of the native plant species and their efficacy in restoring degraded mined land based on area and time of succession and climax.

Keywords Natural landscape · Overburdened dumps · Ecological restoration · Natural succession · Self-sustaining

1 Introduction

In the current era, the degradation of an environment is linked with the developmental activities and unconsciousness of people about maintaining the ecological balance of the Earth. Humans since pre-historic times utilized natural resources for their comfort despite of their limited availability. Naturalization of humans has turned into the humanization of nature eventually changing the very existence of repletion of both biotic and abiotic resources. Mining of important elements from Earth's crust is an old phenomenon which eventually turns it into barren nutrient less land. The restoration of such drastically disturbed mined lands had always achieved a great significance throughout the world. The process of restoration has become an integral part of the developmental processes around the globe (Maiti and Ahirwal 2019).

Human activities in the name of development have changed Earth's surface and ecosystems the most in recent decades (Hu et al. 2020), and mining, like most human livelihoods, has had the greatest impact on ecosystem structure and function (Gabarron et al. 2018; Luna et al. 2018). Mining regions often experience severe environmental deterioration, including vegetation loss, soil erosion, and quality reduction (Karaca et al. 2018). Certain measures like tree planting, agricultural reclamation, and other vegetation restoration programs can speed up soil repair and increase the biological richness of land degraded by mining (Hou et al. 2019). The damage which is caused by mining is tabulated in Table 1.

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Table 1 Environmental damage due to mining

Types of damage	Cause of damage	Main hazard/consequences
Ruined topography	After mining, the topsoil is typically replaced with fresh soil or slag, and the pressure exerted by large-scale mining equipment frequently causes the soil to become compacted, hard, and devoid of organic matter, nutrients, and water. The ground collapse led to soil cracking and a decline in groundwater levels. Along with the fractures and surface runoff, nutritional components from the soil also drain into the goaf or depression, causing a scarcity of soil nutrients in many areas and a loss in soil carrying capacity	In comparison to underground mining, which can permanently alter mining regions, open-pit mining causes more harm to the surface terrain. It also has a bigger impact on regional ecology and natural landscapes. Ground sinking, however, is a possibility if the underground tunnel is not completed in a timely manner
Occupying the fertile land resources	A lot of area is needed to accommodate the minerals and waste produced during the development of mineral resources	It causes infertility of soil and land resource
Environmental pollution	Large quantities of pit water and waste rock-leaching water are generated throughout the mining operation. Rain causes the hazardous and damaging components of the solid waste residues in the mines to wash and leach out	Through runoff and air diffusion, the poisonous, acidic, or heavy metal components in mine wastes will contaminate the water, soil, and biological environment, and their impact area will be far larger than the mining area itself
Geological disasters	The stability of mountains and slopes is impacted by underground mining, ground excavation, and side slope excavation. When waste slag from mines is dumped, it is heaped up on slopes or in valleys. To reduce friction, the waste rock is mixed with soil, which reduces its water permeability and causes waterlogging	The geological structure will be severely disturbed by mining, leading to surface cracks, ground collapse, building damage, agriculture destruction, river interruption, water accumulation in mine pits, earthquakes, collapses, and landslides, among other things
Destruction of habitat	The elimination of vegetation, soil contamination and degradation, and soil erosion all pose serious threats to the existence of animals and plants and are lethal blows to the preservation of biodiversity in mining sites	Numerous plants and animals perish due to soil and water contamination, which reduce the biodiversity in the area surrounding the wasteland and tipped the ecological balance off

2 Significance of Soil Restoration

Soil restoration is the most important and foremost step in ecological restoration. Soil being one of the limited resources available to mankind, it needs proper attention during ecological restoration as it takes thousands of years for soil to restore its fertility. Some environmental, natural, and anthropogenic factors directly or indirectly affect the soil. Climate change and global warming affect the decomposition pattern and nutrient cycling. Besides these, natural disturbances like floods, drought, and landslides also add to soil degradation (Williams et al. 2020). Some anthropogenic factors which drastically affect the soil are mentioned in Fig. 1.

Soil health indicators include soil organic matter, total nutrient elemental concentration, available nutrient elemental concentration, pH, and electrical conductivity. Plant recolonization and establishment depend upon the physical, chemical, and biological (nutrient) support from the soil health (Shrestha et al. 2019). Vegetation restoration improves soil conditions making it conducive for species colonization and ecosystem development by increasing soil organic matter and nutrients (Kumar et al. 2015). To forecast vegetation restoration status and soil conditions, humans must understand the likely changes in soil organic matter content and nutrient proportion throughout the restoration period.

Revegetation in arid environments is one of the best approaches to improve the soil quality and address ecological restoration (Li and Liber 2018). However, very few plant species can thrive in degraded mined lands due to the scarce availability of soil nutrients and the high degree of metal toxicity (Wang et al. 2018). Furthermore, choosing promising plants is challenging when biological invasion concerns are considered because invasive species suppresses the growth of native plant species which leads to low biodiversity and an unstable environment (Bauman et al. 2015). For speedy restoration of degraded mined lands, the use of native plant species may be the optimal tool to wade off the threat of invasive and alien species.

Fig. 1 Anthropogenic causes of soil degradation

The mining sector is an important sector and is related to the development of a country. But mining brings deterioration of environmental entities along with it. The degradation of soil is an unavoidable issue which accompanies mining activities. Deforestation, soil erosion, and overburdened dumps are the consequences of mining. Post the mining process, the lands get degraded which if left as such will take many decades to reach the climax stage of ecological succession. The challenging task in ecological restoration is the soil restoration which can be carried out through the plantation of species preferably native plant species for faster growth and reclamation of land.

Ecosystem reconstruction—restoring the land's ability to capture and retain resources—is the main objective of mined land restoration. Ecosystem restoration can stop degradation, increase ecosystem utility, and restore biodiversity. Ecosystems and species loss harm people and the environment. Ecosystem service decrease might cost $10 trillion in global GDP by 2050. Thirty-three percent of commercial fish stocks are overfished, threatening over 60 million fishermen worldwide (FAO 2020). Fresh water supports 1.4 billion livelihoods, including food, energy, and water (United Nations 2018). A healthy and productive ecosystem is required to reap environmental, economic, and social advantages to its optimum. Ecosystem restoration can stop degradation, increase ecosystem utility, and restore biodiversity (Strassburg 2020). Figure 2 shows the need for ecological restoration of degraded mined lands.

Though mineral extraction and utilization in any country are pertinent to boost up its economy, yet in the same context, maintenance of the ecosystem is equally important for the subsistence of life on this planet earth. After mining the overburdened dumps do not support any vegetation, here arises the necessity for human intervention to restore such degraded mined lands. Knowledge on the adaptability of different plant species and their role in nutrient dynamics is vital to indulge in restoration measures through biological means (Gairola 2014).

Margenau et al. (2019) suggested plantation of native plant species accelerates the forest succession on degraded mined lands. The restoration of the degraded mine sites includes the control of all types of disturbances of soil, i.e., physical, chemical, and biological. Various factors like the pH of soil, fertility of soil, and soil microbial community which makes the degraded soil productive need to be monitored for better results. Revegetation with native species has been the oldest yet an effective process for restoration of the degraded lands (Gairola 2014).

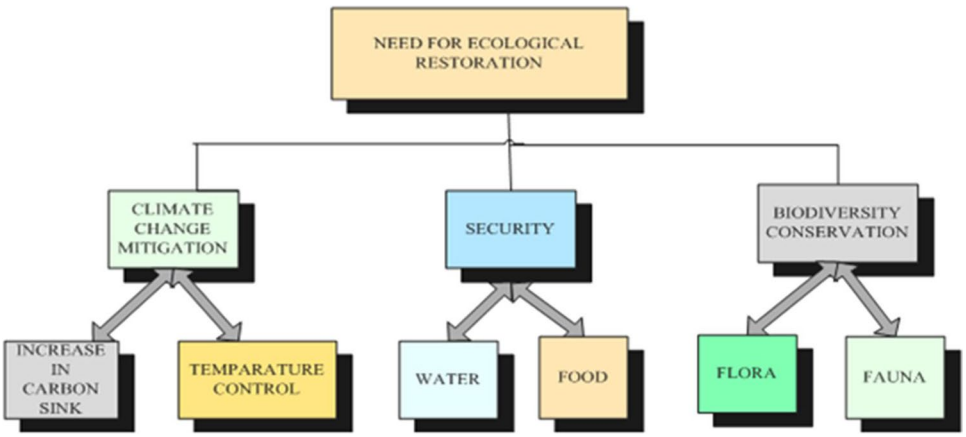

Fig. 2 Need for ecological restoration

2.1 Importance of Plantation in Degraded Mined Lands

The mining methods, height, slope of the overburdened piles, the nature of the mine soil, and the geo-climatic conditions are not only the factors on which the success of the mined soil recovery depends but in addition to these factors like the choice of plant species selected for reclamation/restoration of the mined land plays a key role (Pinto et al. 2020). Ahirwal and Pandey (2020), in their study, focused on the selective plantation of the species which can withhold the stress conditions, climate resilience, and moreover be native to the study area. The restoration success depends on the selection of plant species and various soil amendments made so that the topsoil productivity can be enhanced and degraded mined areas can be recovered and restored quickly. Gordana et al. 2019 studied the importance of vegetation on the fly ash deposits generated from coal combustion by using native plant species. The reason for the selection of native plant species is its best adaptation to the local environment and boosting up the ecorestoration management. Native species can tolerate the harsh weather condition thereby increasing the chances of thriving on degraded areas as stable plant communities. Table 2 describes the important studies taken worldwide on the importance of plantation in degraded lands and their major outcomes.

Pietrzykowski (2019) emphasized that for ensuring landscape and environmental profits of degraded mined lands, restoration and establishment of a sustainable ecosystem are necessary. The plantation of tree species on the reclaimed mined soil is significant, because the success of restoration depends on the selection and adaptation of tree species on the degraded mined lands. Figure 3 shows the impact of ecological restoration on the environment.

Table 2 Importance of selecting native plant species for ecological restoration

S. no	Reference of the study	Outcomes of the study
1	Ahirwal and Pandey 2020	Selective plantation and soil additions with topsoil may help mine-degraded sites recover. Mining businesses and the local people gain from the reforestation of mine-degraded land
2	Pratiwi et al. 2021	Plantation on degraded lands can enhance tropical forest area, which can improve environmental conditions and community revenue. Restoring tropical forest cover after mining helps conserve biodiversity by providing animal homes that mimic their native conditions
3	Nguyen et al. 2020	Two methods for land improvement and restoration have been recommended: (1) designing a method for land improvement by afforestation and (2) designing a method for land improvement by planting fruit trees and short-term crops
4	Lestari et al. 2019	This research suggests that in post-coal mining reclamation using native trees, two key factors to enhance the growth performance of planted species are sloping terrain so that water is not inundated and soil pH so that it is not too acidic in nature
5	Lewis and Rosales 2020	For restoration programs, comprehensive knowledge of the landscape ecology—structure and configuration, soil type, physical, chemical, and biological qualities, dispersal mechanism, and plant community identification and quantification/inventory—is essential. Natural regeneration helps support biodiversity in overburdened dumps and reduces environmental deterioration
6	Lozano-Baez et al. 2022	Spontaneous succession technique in post-mining environments if neighboring semi-natural vegetation may seed mined sites. Technical reclamation of mining-degraded sites should use native plants to attract animals to aid recovery

Fig. 3 Impacts of ecological restoration on the environment

Buta et al. (2019) aimed at developing the strategy on the eco-restoration of degraded mined land in the northwestern part of Transylvania (Romania). The soil quality was improved overall with the increasing years of restoration. The results showed the revegetation in the abandoned and degraded mined land had brought out considerable changes in soil quality. The ecological integrity and self-sustainability of the degraded mined land were restored with the help of revegetation.

Swab et al. (2017) studied many species in combination with prairie species making a standard reclamation mix. The prairie species were used as they were native species of North America and were most helpful in creating higher diversity plantation in the three mined sites in South Eastern part of Ohio. Mishra and Patra (2017) found that the native plant species were helpful for faster restoration of the degraded mined land with initially few human facilitation and then naturally.

Pioneer species mainly the hardy plants, algae, or moss occupies the degraded area as they are able to survive in a hostile environment. They are the first species which returns to the degraded lands. During the restoration of degraded mined lands, emphasis shall be on planting the native species as it fulfills the restoration and reforestation objectives. Native species suits best for the restoration process. The use of native plant species in the ecorestoration process restores the socio-economic gains, and it enhances the environmental gains also, in the form of soil and water retention. It also helps in carbon sequestration and enhances the ecological succession in a degraded area. Figure 4 represents the steps which leads to ecological succession in degraded lands. Some of the major studies which have been undertaken by various researchers are tabulated in Table 3 with the outcome of their studies.

3 Restoration of Degraded Land Sustainably

The goal of the "Decade on Ecosystem Restoration," which the United Nations has designated to run from 2021 to 2030, is to restore damaged landscapes so they may once again

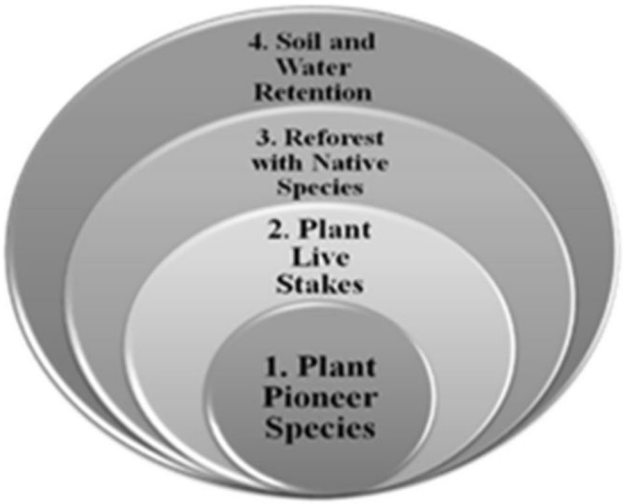

Fig. 4 Steps leading to ecological succession

Table 3 Key findings from degraded mined land studies

References	Nature of degraded site	Species	Advantages of native species/Important results of the study
Yadav et al. 2022	Fly ash dump	*Acacia nilotica, Acmella oleracea, Bacopa monnieri, Cynodondactylon, Cyperus rotundus, Dactylocteniumaegyptium, Digitariasanguinalis, Trianthemaportulacastrum, Typha latifolia. Portulaca oleracea*	• Naturally found • High colonizing nature • Helps in fast restoration of degraded lands
Song et al. 2022	Non-ferrous metal tailing pond	*Bidens pilosa*	• Native hyperaccumulator • Available heavy metal in tailings substrate reduced • Restoration of vegetation • Augmented heavy metal pollution control
Maiti et al. 2021	Mining and oil drilling site	*Erythrina crista-galli, Azolla filiculoides, Brassica, Phaseolus vulgaris, Sorghum bicolor, Phragmites australis*	• The substrate's nature and properties affect plant species selection and ecosystem development • Reclamation must meet short- and long-term goals, and species should be native/indigenous and economically, aesthetically, or environmentally valuable • Container-grown saplings and seed balls can grow several native tree species on the recovered land
Roy et al. 2022	Coal mine degraded arid site	*Ulmus pumila*	• *Ulmus pumila,* the native woody species was found to grow significantly despite of water stress conditions in the study area • Increased photosynthesis, water use efficiency, stomatal conductance was recorded when *Ulmus pumila* was treated with water-nitrogen ratio in greenhouse conditions
Mishra et al. 2021	Iron and Manganese Ore Mine	*Holarrhenaantidysentrica, Mitragyna parviflora, Anogeissus latifolia, Adina cordifolia, Buchnanialanzan, Lanneacoromandelica, Miliusavelutina, Xyliaxylocarpa, Bridelia retusa, Woodfordiafruticosa, Helicteresisora, Nyctanthesarbortristis, Wendlandiaexerta, Flacourtia indica and Cassia auriculate*	• Native plant species have the capacity to endure, recover, and stabilize the soil structure in their particular local environment • The association of microorganisms that are essential to maintain soil quality through the decomposition of organic matter and nutrient cycle is made possible by the occupation of the land with various native or indigenous plant species
Kondratenko et al. 2022	Borodinsky Coal mine	*Euphorbia cyparissias*, *E. fischeriana*, *Desmodiumtriflorum*, *Indigofera gerardiana, Robinia viscose,* Pinus sylvestris, *Salix alba*, *Populus alba*, and *P. tremula*	• Native plant species serves the best tool for achieving ecological succession • Plantation of native tree species significantly accelerated the soil redevelopment process on the mine soil
Gastauer et al. 2021	Iron Mine at Urucum Massif, Brazil	*Eriosemacrinitum, Leucaena leucocephala, Aspiliagrazielae, Canga community*	• Return of ecosystem activities and services to the rehabilitation sites was expedite by plantation of native plant species
Pandey et al. 2022	Fly ash deposited site	*Leucaena leucocephala, Pithecellobium dolce and Prosopis juliflora*	• Native plant species litter have greater decomposition rate and hence the nutrient release is also at high pace • Litter nutrient concentration helps the degraded land to restore at accelerated pace
Sawarkar et al. 2023	Fly ash degraded land	*Bambusa balcooa, B. tulda,* and *B. bambos*	• Physio-chemical attributes of soil gets increased in comparison to initial observation with the plantation of bamboo species • Air pollution tolerance index is measured higher in bamboo species hence bamboo species may also be used as a tool for the mitigation of air pollution

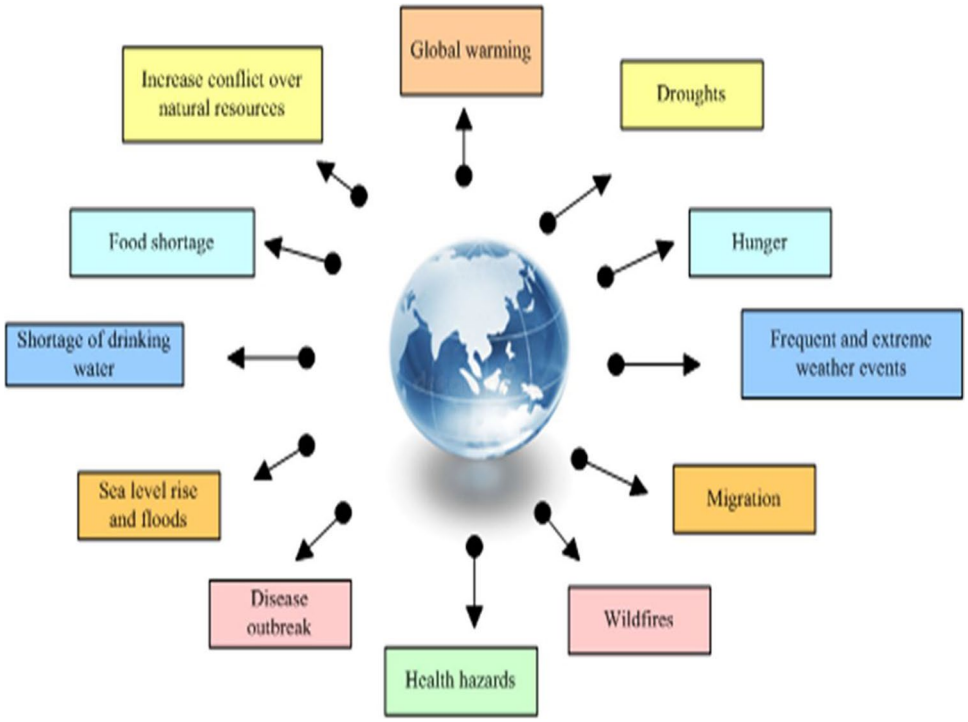

Fig. 5 Effects of climate change on the environment

support human livelihoods, mitigate the effects of climate change, and increase biodiversity. Restoring healthy ecosystems may benefit land and people, promoting biodiversity and stimulating economic growth—both now and after the pandemic, in a sustainable fashion when both environment and economic resiliency are urgently needed. Mansuy (2020) concluded that a chance to restore degraded landscapes and provide co-benefits, such as livelihoods and commercial prospects, is by investing in restoration. In India, 29% (96.4 million hectares) of land is degraded. India became the part of "Bonn Challenge" which is a global effort to restore the world's degraded lands (approximately 150 million hectares) till 2020 and approximately 350 million hectares by the year 2030. While the challenge is a tougher one, therefore, a systematic planning is required for restoring vast amounts of degraded lands (The Hindu 2020).

In the current scenario, the plantation of the native species seems the best possible way not only to restore the degraded land but also to the onset of ecosystem functions and ecosystem services sooner. Singh et al. (2019) in their study discussed about the success of bioenergy plantation in degraded lands. Biofuels are the genetically engineered bioenergy crops which have the capability of growing in stressful conditions and can increase the soil fertility. On the other hand, the consumption of crude oil is increasing at a faster pace. Therefore, the biofuel plantation on the degraded lands can be a solution for solving the problem of energy crises and accelerate the restoration of degraded lands in a sustainable way.

4 Role of Degraded Mined Land Restoration in Mitigating Climate Change

The importance of physical features of restoration, the choice of plant species for biological restoration, and their combined impact on creating socioeconomic and environmental advantages are highlighted through practical approaches that are feasible for ecosystem restoration. Ahirwal and Maiti (2021) advise including a site-specific restoration strategy, using native plants for replanting, and including the neighborhood in restoration initiatives. In addition, they are crucial for achieving the UN-Sustainable Development Goals (UN-SDGs), which include eradicating poverty and hunger, supplying affordable and clean energy, reducing global warming, and restoring life to damaged lands. Some of the impacts are shown in Fig. 5.

Mining and related activities severely disrupt the terrestrial ecology, causing significant land degradation and a crisis in the global climate. The formation of ecosystems and improved SOC sequestration are possible as a result of soil restoration techniques in mine wastes. Reclaiming mine waste increases soil horizon development rather quickly, which increases carbon sequestration capacity. As a result, reclaimed soil serves as a significant sink for atmospheric CO_2. Though initially quite low when compared to undisturbed soils, the SOC content of restored mine soil steadily rises with the age of the revegetation.

The productivity of land uses developed on reclaimed areas and the properties of technosols determine the rate of carbon

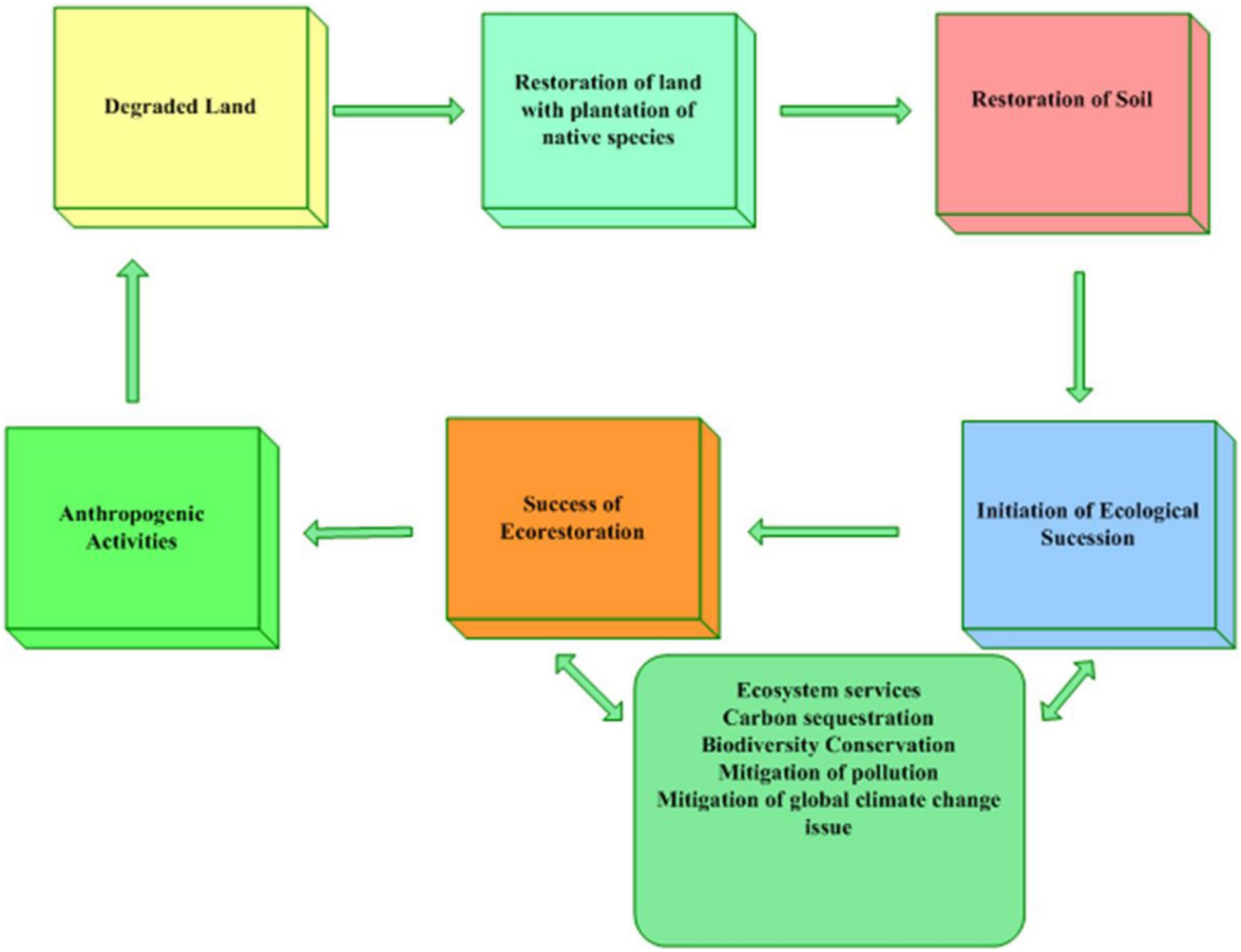

Fig. 6 The ecorestoration of degraded land

sequestration. Mine soils therefore have a great potential to increase their C capital. The accumulation and the current level of carbon in the soil determine a soil 's capacity to sequester carbon (Bandyopadhyay and Maiti 2022). Figure 6 depicts the customary practice of ecological restoration.

Ecological restoration can serve as a genuine climate change adaptation strategy because the plant it produces has a long lifespan and does not require ongoing maintenance (Lim et al. 2022). Degraded lands not only negatively affect the ecosystem services but also adversely affect the livelihood of the people. According to a published study, the restoration efforts in 15% of the total degraded lands in the world can prevent approximately 60% of extinction, and approximately 299 gigatonnes of carbon dioxide can be soaked up which has increased since the onset of industrial revolution. The study further reveals that 70% of the birds, amphibians, and mammals can be saved from the risk of extinction, provided 30% of the world's degraded lands are restored to their original condition, and additional 465 billion tons of carbon dioxide will be sequestered (Strassburg 2020). The degraded mined lands if restored efficiently can act as a carbon sink for greenhouse gases. The process of reclamation is a significant part of mining operation which aims to stabilize degraded mine sites and also results in carbon sequestration. The restored land can act as a carbon sink and can also contribute potentially to the future carbon credit commodity.

5 Future Prospects of Ecorestoration

Active interventions are the need of the hour to stop or reverse ecological function and loss in degraded ecosystems worldwide. Under future climates, restoration may not be enough to reverse habitat loss and restore

functions. Restoration could also include primitive steps to strengthen extant populations' resilience and adaptability to expected future conditions. Adapting lost habitats to future conditions may improve restoration success. In general, restoration in the classic sense of returning a system to a prior state is unlikely to be sufficient or effective under future climates; instead, restoration should strengthen and may redefine populations and species to endure future environmental shocks. According to an online UNEP report, ecosystem services, or the advantages individuals get from ecosystems, are worth more than 10% of global economic production and influence 3.2 billion people or 40% of the world's population (UNEP 2021).

The world needs to fulfil its current obligations to rehabilitate 1 billion hectares of damaged land. One of the most crucial and viable methods for providing biologically based solutions to issues like food insecurity, climate change, global warming mitigation and adaptation, and biological diversity loss is ecosystem restoration. It would not be quick or simple, and it will require significant adjustments to everything from how we gauge economic growth to how and what we consume. The wonder of ecosystem restoration, however, is that it can take place at any scale, and everyone can play a part.

6 Conclusion

The degraded lands are one of the important contributors to climate change as they lose soil carbon and also emit the GHG's (Greenhouse Gases). In the current scenario, when the world is combating the problem of climate change, degraded lands can prove to be an asset if restored efficiently. Degraded lands which are lying unutilized, through proper restoration strategy, can become the bigger source of carbon sink. According to an estimate, ecosystem services loss due to the degradation of land is between 6.6 and 10.6 trillion USD annually. (IUCN 2015). Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem (IPBES) reported the reduction of crop yield by 10% globally, and in certain regions, the reduction will be approximately 50% by the year 2050 (SEI 2018).

Thus, the above-mentioned scenario poses to be the biggest threat for us and our future generation, which can worsen if not controlled. The restoration of degraded lands at an extensive scale has become the need of an hour. Turning the degraded land into agricultural land can be a difficult choice, but when a country like India with the second highest population in the world is developing at a faster pace and wants to end up its food insecurity, then turning the reclaimed land into agricultural land seems to be a good option Lei et al. (2016). Many climate-resilient crops which can undertake the abiotic stress like soil infertility and less availability of water can be planted according to the topography of the area. Apart from the plantation of native species, millets can become a suitable option for restoring the fertility of restored sites. Research and development regarding the plantation of millets in the restoration lands is highly required.

Declarations

Conflict of Interest The authors declare no competing interests.

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