The Biobrio ISSN : 2393-9508 e-ISSN: 2582-4902
An International Quarterly Journal of Life Sciences
Website: www.thebiobrio.in SJIF 2023:8.16
10 (3&4): 1141-1146, 2023

Sustainable approaches and environmentally friendly methods for stabilizing slopes of coal mined area

Prakriti Shahdeo & Shambhu Mishra*
Forest Ecology & Climate Change Division, ICFRE-Institute of Forest Productivity, Ranchi, Jharkhand

Received : 08th November, 2023 ; Accepted : 18th December, 2023

ABSTRACT

Slope stabilization is a crucial aspect of mitigating natural hazards and ensuring the safety and longevity of infrastructure in and around slopes. This review paper synthesizes current knowledge and advancements in slope stabilization methods, providing a comprehensive and reliable source of information for researchers and policymakers. It categorizes stabilization techniques into traditional methods, such as terracing, drainage control, and vegetation reinforcement, alongside modern approaches, including soil nailing and rock bolting. Each method is evaluated based on its effectiveness, applicability to different slope types, environmental impact, and economic feasibility. Moreover, the paper discusses emerging technologies and innovative strategies that enhance slope stability assessment and management. The aim of this review is to guide researchers and policymakers in selecting appropriate methods for sustainable slope stabilization practices in diverse geographic and climatic conditions, thereby contributing to the practical application of geotechnical engineering and environmental science. The comprehensive nature of this review ensures that readers have access to all the necessary information to make informed decisions.

Key Words :- slope stabilisation, traditional methods, sustainable approach.

***Corresponding author :** mishrasn@icfre.org

INTRODUCTION

The extraction of coal has long been a cornerstone of global energy production, yet it often leaves behind a legacy of environmental degradation, particularly in mined areas where slopes are prone to instability. The reclamation and stabilization of these degraded landscapes present multifaceted challenges that require innovative and adaptive solutions. Slope stabilization in degraded coal-mined areas is crucial for mitigating a range of environmental and safety hazards. These landscapes are characterized by disturbed soils, altered hydrology, and compromised geotechnical properties, which exacerbate the risk of erosion, landslides, and sedimentation. This review paper offers a comprehensive examination of the methods and strategies employed for stabilizing slopes in degraded coal-mined areas. It integrates insights from geotechnical engineering, environmental science, and restoration ecology to explore both traditional and contemporary approaches. Traditional methods such as terracing, drainage systems, and re-vegetation have been employed to mitigate erosion and stabilize slopes by enhancing soil structure and promoting vegetation cover. In recent decades, advancements in geosynthetics, soil bioengineering, and innovative engineering techniques have expanded the toolkit available for slope stabilization in challenging mining environments. These technologies offer enhanced durability, adaptability

to varying soil conditions, and reduced environmental footprint, thereby improving the effectiveness and sustainability of reclamation efforts.

Furthermore, the integration of geospatial technologies and remote sensing plays a pivotal role in assessing slope stability, monitoring changes over time, and informing adaptive management strategies. These tools provide critical data on terrain morphology, hydrological patterns, and vegetation dynamics, aiding in the design and implementation of targeted stabilization measures.

By synthesizing current research findings, case studies, and practical applications, this review aims to provide a comprehensive overview of the strengths, limitations, and considerations associated with different slope stabilization methods in degraded coal-mined areas. It seeks to inform stakeholders-including engineers, environmental scientists, policymakers, and mining operators-on selecting appropriate strategies that promote sustainable reclamation and enhance the resilience of post-mining landscapes. Ultimately, the adoption of effective slope stabilization techniques not only mitigates immediate hazards but also contributes to the long-term ecological restoration and socio-economic revitalization of degraded coal-mined areas, fostering a harmonious balance between resource extraction and environmental stewardship.

METHODS OF SLOPE STABILIZATION

Slope stabilization refers to the techniques and methods used to prevent or mitigate the erosion, instability, or failure of slopes, which can occur naturally or due to human activities such as construction or deforestation. Here's a breakdown of methods and plants commonly used for slope stabilization:

1. **Vegetation-Based Techniques:**

- Phytostabilization: Planting native vegetation on the slopes helps stabilize the soil. The roots bind the soil particles, reduce erosion, and enhance slope stability

2. **Bioengineering Techniques:**

- Vegetation Cover: Planting vegetation on slopes helps stabilize soil through root reinforcement, reducing erosion by binding soil particles together.
- Brush Layering: Involves laying live branches horizontally across the slope and securing them to encourage root growth and soil stability.
- Live Fascines and Coir Rolls: Bundles of live cuttings or coir (coconut fibre) rolls placed along slopes to trap sediment and promote vegetation growth.
- Terracing: Creating horizontal steps or terraces on steep slopes to reduce the angle of inclination and prevent erosion.

3. **Mechanical Techniques:**

- Benching: Creating terraces or steps on the slope to reduce the overall angle and prevent mass movement.
- Gabions: Wire mesh cages filled with rocks or other durable materials used to stabilize slopes by reducing erosion and enhancing drainage.
- Retaining Walls: Structures built at the base of slopes or along their length to prevent mass movement and provide support.
- Soil Nailing: Installing steel rods or bars into slopes and securing them with grout to increase stability.
- Geogrid Reinforcement: Installing geosynthetic materials (geogrids) to enhance soil strength and prevent sliding

4. **Hydraulic Techniques:**

- Surface Water Management: Proper drainage systems to control surface water runoff and prevent erosion.
- Riprap: Placing large, durable rocks or concrete blocks along the slope to protect against erosion caused by water flow.
- Hydroseeding: Spraying a slurry of seed, mulch, and binding agents onto the slope to promote vegetation growth and stabilize the soil.

5. **Chemical Treatment:**

- Lime and Cement: Mixing lime or cement with the soil to improve its stability.
- Fly Ash Mixture: Using fly ash (a by-product of coal combustion) to stabilize the soil.

6. **Microbial-Induced Calcite Precipitation (MICP):**

- This natural technique involves injecting bacteria that produce calcite (a mineral) into the soil. The calcite binds soil particles, increasing stability
- Each site may require a tailored approach based on local conditions, soil properties, and environmental considerations. Consulting with geotechnical experts and environmental engineers is essential for successful slope stabilization in coal mine areas

Plants used for slope stabilization typically have deep, extensive root systems that help bind soil particles together and prevent erosion. Some common examples include:

- **Grasses:** Such as vetiver grass (*Chrysopogon zizanioides*), which has deep roots and is effective in stabilizing slopes.
- **Groundcovers:** Including various types of sedges and low-growing plants that provide dense root networks and cover.
- **Shrubs:** Woody plants like willows (*Salix* spp.) and alders (*Alnus* spp.) that have robust root systems and contribute to slope stability.
- **Trees:** Species like pine (*Pinus* spp.) and oak (*Quercus* spp.) that have deep, extensive roots and provide long-term stability.

Plants Suitable for Slope Stabilization:

1. **Grasses:**

- Switchgrass (*Panicum virgatum*): Deep-rooted and tolerant of various soil conditions.
- Fescues (*Festuca* spp.): Form dense mats of roots that stabilize the soil.
- Buffalograss (*Buchloe dactyloides*): Drought-tolerant and suitable for stabilizing slopes.

2. **Shrubs:**

- Willows (*Salix* spp.): Fast-growing and effective in stabilizing soil with their extensive root systems.
- Elderberry (*Sambucus* spp.): Tolerant of various soil types and stabilizes slopes well.

3. **Trees:**

- Poplars (*Populus* spp.): Fast-growing with deep roots that stabilize slopes.
- Pines (*Pinus* spp.): Evergreen trees with robust root systems that help in soil stabilization.
- Leguminous plants play a crucial role in improving soil fertility and stability and contribute:

4. **Groundcovers:**

- Creeping Juniper (*Juniperus horizontalis*): Spreads quickly and forms a dense mat, preventing erosion.
- Periwinkle (*Vinca minor*): Low-growing with extensive root system, effective for stabilizing slopes.
- Nitrogen Fixation: Legumes have a unique relationship with nitrogen-fixing microorganisms called Rhizobia. These bacteria help convert atmospheric nitrogen into a plant-available form, enriching the soil with nitrogen. This biological nitrogen fixation enhances soil fertility and benefits subsequent crops (Stagnari *et al.*, 2017; Ding, 2022).
- Organic Matter: Legumes release high-quality organic matter into the soil. This organic material improves soil structure, nutrient cycling, and water retention, promoting overall soil health (Stagnari *et al*., 2017).
- Crop Residue: Even after harvest, legume crop residues continue to benefit the soil. They decompose, adding organic carbon

and nutrients, which further enhance soil fertility (Stagnari *et al.,* 2017).

- In summary, legumes are valuable allies for sustainable agriculture, whether as growing crops or as beneficial residues in conservation agriculture practices

Methods used for slope stabilization analysis

Some of the widely used methods are Kinematic analysis, Limit Equilibrium Analysis, Numerical modelling, Probabilistic methods, and slope monitoring (Salunkhe *et al*.).

Considerations:

- Erosion Control: Choose plants and methods that effectively control erosion by stabilizing soil and reducing runoff.
- Adaptability: Select species that are adapted to local climate, soil conditions, and slope gradients.
- Maintenance: Regular maintenance, such as watering during establishment and weed control, is crucial for the success of slope stabilization efforts.

By combining these methods and selecting appropriate plant species, degraded coalfields can be rehabilitated effectively, promoting stability and ecological recovery

The choice of plants depends on factors such as soil type, climate, slope angle, and the specific requirements of the stabilization project. Effective slope stabilization often combines several methods and plant species to achieve the desired stability and erosion control over time

Methods of Slope Stabilization in Degraded Coalfields Case Study

1. **Terracing and Benching:**

- Description: Terracing involves creating flat or gently sloping surfaces along the contour of the land to reduce slope steepness and control erosion.
- Case Study: In the coal mining regions of Jharia and Raniganj in India, terracing has been implemented to stabilize steep slopes after mining activities. Terraces help in controlling erosion and stabilizing the land for subsequent reclamation and vegetation establishment.

2. **Retaining Walls:**

- Description: Retaining walls are structures built along slopes to support and stabilize them, preventing collapse and erosion.
- Case Study: In the Singrauli coalfield in Madhya Pradesh, India, retaining walls made of gabions (wire mesh filled with stones) have been used extensively. These walls provide structural stability to the slopes and reduce erosion, allowing for safer rehabilitation and vegetation growth.

3. **Grassing and Matting:**

- Description: Planting grass and installing erosion control mats helps stabilize soil and prevent erosion by providing ground cover and reducing surface runoff.
- Case Study: In the coalfields of Dhanbad in Jharkhand, India, grassing and matting techniques have been employed to stabilize slopes post-mining. Native grass species like Vetiveria zizanioides (Vetiver) and erosion control mats made from coir (coconut fiber) are used to restore stability and facilitate the growth of vegetation.

4. **Slope Draining:**

- Description: Installing drainage systems such as French drains helps manage water flow and reduces saturation that can weaken slopes.
- Case Study: In the coalfields of Korba in Chhattisgarh, India, drainage systems, including French drains, have been installed to control water flow and stabilize slopes. Proper drainage prevents waterlogging and erosion, maintaining slope integrity.

Plants Suitable for Slope Stabilization:

1. **Grasses:**

- Description: Grasses with deep root systems help bind soil particles together and stabilize slopes effectively.

- Case Study: In the coal mining regions of Jharia and Raniganj, species such as *Vetiveria zizanioides* (Vetiver) and *Saccharum spontaneum* (Wild Sugarcane) are used for slope stabilization. These grasses are resilient to local conditions and help in preventing erosion.

2. Shrubs:

- Description: Shrubs with extensive root systems are valuable for stabilizing slopes and preventing erosion.
- Case Study: In the coalfields of Singrauli, species like *Cassia siamea (Siamese Senna*) and C*rotalaria juncea* (Sunhemp) have been planted for slope stabilization. These shrubs are fast-growing and adaptable to the region's climate, contributing to slope stability.

3. Trees:

- Description: Trees with deep roots provide structural support and stabilize slopes by anchoring soil.
- Case Study: In the coalfields of Korba, species like *Acacia auriculiformis* (Earleaf *Acacia*) and Dalbergia sissoo (Indian Rosewood) have been planted to stabilize slopes. These trees are robust and help maintain slope integrity through their root systems.

Case Study Example: Singrauli Coalfield, Madhya Pradesh, India

Problem: The Singrauli coalfield in Madhya Pradesh faces extensive environmental degradation and erosion due to intensive mining activities. After mining operations, slopes are left unstable and prone to erosion, threatening nearby communities and ecosystems.

Solution:

- Retaining Walls: Engineers have constructed retaining walls using gabions along steep slopes to stabilize them. These walls provide structural support and reduce erosion, ensuring safety and stability post-mining.
- Grassing and Matting: Native grass species such as Saccharum spontaneum have been planted extensively to stabilize slopes and facilitate soil restoration. Erosion control mats made from natural fibres enhance vegetation establishment and prevent soil erosion.
- Case Study Plant: Saccharum spontaneum (Wild Sugarcane) is a native grass species known for its ability to thrive in Singrauli's climate and stabilize slopes effectively. Its deep root system binds soil particles together, preventing erosion and promoting ecosystem recovery.

Outcome: These integrated approaches have successfully stabilized slopes in the Singrauli coalfield, reducing erosion and restoring ecological balance. By combining engineering methods with suitable plant species, sustainable land management practices have been achieved, ensuring long-term stability and biodiversity conservation.

CONCLUSION

The combination of engineering methods such as terracing, retaining walls, and drainage systems with appropriate plant species is crucial for effectively stabilizing slopes in degraded coalfields in India. Case studies from regions like Singrauli demonstrate the effectiveness of these strategies in restoring ecosystem functionality and promoting sustainable land use post-mining.

ACKNOWLEDGEMENT

The authors show their gratitude to the Central Coalfield Limited (CCL) for providing financial support and assistance for Research Project on "Top Soil Conservation and Eco-rehabilitation of Selected Degraded Coal Mines of Central Coalfields Ltd. Jharkhand through Forestry Interventions". We are thankful for the generous support, encouragement and motivation of the Director, ICFRE- Institute of Forest Productivity (IFP), Ranchi. We sincerely thank Sh. Rahul Kumar, Ashish Kumar and Bitan Goswami for their support in data collection and analysis.

REFERENCES

Abramson, L. W., Lee, T. S., Sharma, S., & Boyce, G. M. 2001. Slope stability and stabilization methods. John Wiley & Sons.

Bandyopadhyay, S., Novo, L. A., Pietrzykowski, M., & Maiti, S. K. 2020. Assessment of forest ecosystem development in coal mine degraded land by using integrated mine soil quality index (IMSQI): the evidence from India. *Forests*, 11(12), 1310.

Ding, W. 2022. The promotion of legume nodulation in plant-soil-microbe systems under phosphorus-limited conditions. Plant Soil 476, 251-262. https://doi.org/10.1007/s11104-022-05564-5

Ghobadi, M. 1994. Engineering Geological Factors Influencing the Stability of Slope in the Illawarra Region. Ph.D. Thesis, University of Wollongong, Wollongong, Australia, p. 1.

Gray, D.H. 1973 Effects of forest clear cutting on the stability of natural slopes: results of field studies. National Science Foundation, University of Michigan, Washington

Maiti, S. K., & Ahirwal, J. 2017. Ecological restoration of coal mine degraded lands using a grass-legume mixture-a case study from India. In Land Reclamation in Ecological Fragile Areas (pp. 419-431). CRC Press.

Maiti, S.k.Saxena, N.C., 1998. Biological reclamation of coal mine spoils without topsoil: an amendment study with domestic raw sewage and grass legumes mixutures?. *Int. J. Surf. Min. Reclamat Environ.*12, pp.87-90,

Mulia, A. Y., & Prasetyorini, L. A. 2013. Slope stabilization based on land use methods in Ambang Sub River Basin. *Procedia Environmental Sciences,* 17, 240-247.

Naghadehi, M.; Jimenez, R.; Khalokakaie, R.; Jalali, S.-M. 2011. A probabilistic systems methodology to analyze the importance of factors affecting the stability of rock slopes. *Eng. Geol.* 118, 82-92. [Google Scholar] [CrossRef]

Padmavathiamma, P.K., and Li, L.Y. 2007. Phytoremediation technology: Hyper accumulation metals in plants. Water Air Soil Pollution 184(1-4), pp.105-126.

Rai Rajesh and Shrivastava B.K 2014 Numerical simulation of vegetated mine dump slope with reference to small plants, International Journal of Mining Science and Technology 24:111- 115.

Sahu, H. B., & Dash, S. 2011. Land degradation due to mining in India and its mitigation measures.

Saini, V., Gupta, R. P., & Arora, M. K. 2016. Environmental impact studies in coalfields in India: a case study from Jharia coal-field. *Renewable and Sustainable Energy Reviews,* 53, 1222-1239.

Stagnari, F., Maggio, A., Galieni, A. *et al.* 2017. Multiple benefits of legumes for agriculture sustainability: an overview. Chem. Biol. Technol. Agric. 4, 2. https://doi.org/10.1186/s40538-016-0085-1

Usluogullari, O. F., Temugan, A., & Duman, E. S. 2016. Comparison of slope stabilization methods by three-dimensional finite element analysis. *Natural Hazards,* 81, 1027-1050.

Verma, D., Kainthola, A., Thareja, R., & Singh, T. N. 2013. Stability analysis of an open cut slope in Wardha valley coal field. *Journal of the Geological Society of India*, 81, 804-812.

Wu, T. H. 2003. Slope stabilization. In Slope stabilization and erosion control: A bioengineering approach (pp. 233-281). Taylor & Francis.

Y. Cheng *et al.* 2022. Stability of expansive soil slopes reinforced with anchor cables based on rotational-translational mechanisms Comput. Geotech.

***