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LANDSCAPE-BASED DISASTER MITIGATION: IMPACT OF ORNAMENTAL GROUND COVER PLANTS IN SLOPE PROTECTION AND SEISMIC RESILIENCE

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ABSTRACT

Landscape-based disaster mitigation has emerged as an eco-friendly and sustainable approach for reducing the impacts of natural hazards such as landslides, soil erosion and seismic disturbances in vulnerable terrains. Among various biological measures, ornamental ground cover plants play a significant role in slope protection and enhancement of seismic resilience through their ecological, mechanical and hydrological functions. These plants form dense vegetative mats that stabilize soil surfaces, reduce runoff velocity and improve infiltration, thereby minimizing erosion and slope failure during intense rainfall or seismic activity. Their fibrous and spreading root systems bind soil particles together, increase soil shear strength and reinforce slope stability, particularly in hilly and earthquake-prone regions. Ground cover species such as vetiver grass, wedelia, lantana, creeping juniper and carpet grass are widely recognized for their extensive root architecture and rapid ground coverage. In seismic zones, vegetation reduces secondary hazards such as earthquake-induced landslides and soil degradation by strengthening the soil matrix and dissipating minor ground vibrations. Apart from structural stabilization, ornamental ground covers provide environmental and aesthetic benefits including biodiversity conservation, carbon sequestration, urban cooling and landscape beautification. Their integration into highways, embankments, urban slopes, riverbanks and hill landscapes offers a cost-effective alternative to conventional engineering methods such as concrete retaining walls and stone pitching. Furthermore, combining ornamental ground covers with bioengineering techniques, geotextiles and contour planting systems enhances long-term disaster resilience and ecological sustainability. The present study highlights the significance of ornamental ground cover plants as multifunctional components in landscape-based disaster mitigation strategies.

***Keywords* :** ornamental ground cover plants, natural hazards, structural stabilization, disaster resilience, minimize erosion.

Introduction

India is one of the most disaster-prone countries in the world because of its diverse geographical and climatic conditions. The country frequently experiences natural disasters such as earthquakes, cyclones, floods, droughts and landslides. Rapid urbanization, deforestation, climate change and unplanned development have further increased the vulnerability of people and ecosystems to these hazards. According to the National Disaster Management Authority and United Nations Development Programme, nearly 60% of India's landmass is vulnerable to earthquakes, around 8% of the coastline is prone to cyclones and large hilly regions such as the Himalayas and Western Ghats are highly susceptible to landslides. Natural disasters not only cause loss of human life but also damage agriculture, infrastructure, forests, biodiversity and the economy. India records thousands of disaster-related deaths every year. Recent government statistics reported more than 3,000 deaths from natural disasters and extreme weather events during 2024–25.

Earthquakes in India: Earthquakes occur due to sudden movements of tectonic plates beneath the Earth's crust. India is highly vulnerable because the Indian Plate continuously collides with the Eurasian Plate, especially along the Himalayan region. States such as Uttarakhand, Himachal Pradesh, Jammu & Kashmir, Gujarat, Assam and other northeastern states fall in high seismic zones. About 60% of India's geographical area is prone to moderate to severe earthquakes (NDMA, 2020). Major earthquakes in the last 15 years caused more than 20,000 deaths collectively.

Landslides in India: Landslides are the downward movement of rock, soil and debris along slopes due to heavy rainfall, earthquakes, deforestation, mining, or road construction. In India, landslides are common in the Himalayan region, Western Ghats, Nilgiris and northeastern states. Heavy monsoon rainfall is the major trigger for landslides (IPCC, 2007). States such as Uttarakhand, Himachal Pradesh, Kerala and Sikkim experience frequent slope failures during the rainy season (NDMA, 2020). Uttarakhand alone recorded over 4,600 landslide incidents between 2015 and 2024, resulting in at least 316 deaths. The 2013 Kedarnath disaster caused over 5,000 deaths due to flash floods and landslides (Landslide Atlas of India, 2025). Earthquakes and landslides are among the most destructive natural disasters affecting India (Van Westen *et al*., 2006). Increasing population pressure, environmental degradation and climate change have intensified their frequency and impacts (United States Geological Survey, 2023). Therefore, sustainable land management, disaster preparedness, afforestation and the use of vegetation such as ornamental ground cover plants for soil stabilization are becoming increasingly important strategies for disaster risk reduction in India.

Ground cover plants : Ground cover plants are low-growing, spreading plants that grow densely over the soil surface and form a protective vegetative cover. They are used to cover bare ground, reduce soil erosion (Chowdhury *et al*., 2023), conserve soil moisture, suppress weeds and improve the aesthetic and ecological value of landscapes (Grace, 2002). They range from annuals to shrubs and can be evergreen or deciduous, creating a living mulch with added colour and texture (Bochet *et al*., 2009). These plants may spread through runners, rhizomes, stolon's, creeping stems, or dense branching habits, creating a continuous mat-like layer over the soil. Ground covers can be grasses, herbaceous plants, creepers, succulents, or dwarf shrubs. In disaster-prone regions, ground cover plants help protect the soil from the impact of rainfall, wind and surface runoff (Phan *et al*., 2025). Their root systems bind soil particles together and reduce slope instability, thereby minimizing erosion and landslide risks (Bronstert *et al*., 2023). Examples: *Wedelia trilobata, Vetiver grass, Cynodon dactylon, Lantana montevidensis, Ipomoea pes-caprae, Alternanthera ficoidea, etc.,* Ground cover plants generally grow to a height of less than 1 meter and most commonly between 5 cm and 50 cm depending on the species and growth habit.

Table 1: Ground cover plants classification based on height

Very low ground covers	Medium ground covers	Tall ground covers
5–15 cm	15–30 cm	30–100 cm
Cynodon dactylon	*Alternanthera ficoidea*	Vetiver grass

Table 2: Occurrence of landslide (Landslide Atlas of India, 2025)

Rank	State/ Region	Total landslides (2000-2025)	Rank	State/ Region	Total landslides (2000-2025)
1	Mizoram	12,385	6	Kerala	6,039
2	Uttarakhand	11,219	7	Manipur	5,494
3	Tripura	8,070	8	Maharashtra	5,112
4	Arunachal Pradesh	7,689	9	Meghalaya	2,639
5	Jammu and Kashmir Ladakh	7,293	10	Asoam	2,569

Table 3: Earthquake frequency in India (2020–2025) (Government of India earthquake report, 2025)

State	2020	2021	2022	2023	2024	2025
Arunachal Pradesh	33	33	19	32	34	5
Asoam	52	113	24	61	77	10
Himachal Pradesh	80	65	54	44	37	5
Jammu & Kashmir	50	17	35	52	44	2
Maharashtra	91	39	37	43	38	1
Uttarakhand	23	11	40	92	55	1

Natural disasters such as earthquakes, floods, cyclones, and landslides have wide-ranging negative impacts on humans, the environment and the economy (Nadim *et al.*, 2006).

Role of ground cover plants in the control of natural hazards: control of soil erosion (Pan *et al.*, 2006), landslide prevention and slope stabilization, flood mitigation, cyclone and wind damage reduction, drought resistance and moisture conservation, improvement of soil health, reduction of surface temperature, ecological and environmental benefits (Hong-in *et al.*, 2024).

Table 4: Criteria for selection of ground cover plants

Root system		**Tolerance to local climatic stresses**	
Dense fibrous roots	**Deep rooting plants**	**Drought tolerance**	**Flood tolerance**
Cynodon dactylon *Zoysia grass* *Axonopus compressus*	*Chrysopogon zizanioides* • *Ipomoea carnea* *Lantana camara*	*Portulaca* *Sedum* *Carpobrotus*	*Cyperus* *Colocasia* *Bacopa monnieri*
Growth habit		**Wind tolerance**	**Low maintenance & high coverage rate**
Spreading plants	**Mat-forming plants**		
• *Wedelia trilobata* • *Ipomoea pes-caprae* *Portulaca grandiflora*	• *Alternanthera* spp. • *Ophiopogon japonicus* • *Phyla nodiflora*	*Ipomoea pes-caprae* *Spinifex littoreus*	*Wedelia trilobata* *Vinca minor* *Trachelospermum asiaticum*

Table 5: Different systems of planting on slopy areas

Sl. No.	**Systems of planting**	**Function**	**Examples**
1.	Contour planting system	Reduces runoff velocity Prevents soil erosion	*Cynodon dactylon*, *Vetiver* Shrubs like *Leucaena leucocephala*
2.	Hedgerow (live barrier) planting	Trap sediments and reduce erosion Improve soil fertility (leaf litter addition)	*Vetiver grass*, *Gliricidia sepium*, *Leucaena*
3.	Terracing system	Reduces slope length and steepness Prevents landslides and erosion	Common in hilly regions (Himalayas, Western Ghats) Crops + grasses planted on terrace edges
4.	Strip or band planting	• Breaks flow of water • Reduces soil loss	Crop strips + grass strips (*Vetiver*, *Napier grass*)
5.	Grid or checkerboard planting	Controls wind and water erosion Stabilizes loose soils (deserts/coastal dunes)	• *Spinifex*, *Ipomoea pes-caprae*,
6.	Pocket or pit planting	Conserves water and nutrients Suitable for dry and degraded lands	Tree seedlings, shrubs in arid zones
7.	Mulch–planting system	• Reduces evaporation • Protects soil from erosion • Improves soil fertility	Straw mulch + ground covers like *Portulaca*, *Wedelia*
8.	Bioengineering / vegetative reinforcement system	Roots provide mechanical strength Structures (coir mats, geotextiles) provide initial support	• Vetiver grass + coir matting • Live staking (*Salix*, *Gliricidia*)

Table 6: Slope wise recommendation of planting of ground covers (Kumar *et al.*, 2025)

Slope angle	**Recommended planting system**	**Slope angle**	**Recommended planting system**
<10°	Strip planting, grid planting	25–35°	Terracing, bioengineering
10–25°	Contour planting, hedgerows	>35°	Structural + vegetative methods

Slope stabilization with ground covers

a) **Mechanical (root-based) stabilization :** is the process by which roots of ground cover plants physically strengthen soil, increasing its resistance to erosion and slope failure (Deng *et al.*, 2025). It is a key principle in vegetative (bioengineering) slope protection (Phan *et al.*, 2025)

Table 7: Roots of ground cover plants for mechanical stabilisation

Dense fibrous root systems	Deep root systems	Creeping ground covers
• *Cynodon dactylon* • *Zoysia spp.* • *Axonopus compressus*	*Chrysopogon zizanioides Pennisetum purpureum*	• *Wedelia trilobata* • *Phyla nodiflora*

b) **Surface erosion control (protective cover) by ground covers:** refers to the protection of the topsoil from being removed by rainfall, runoff, or wind (Highland LM & Bobrowsky P.2008). Ground cover plants act as a living protective layer over the soil surface (Ali *et al.*, 2012).

Table 8: Plants for Surface erosion control

Herbaceous covers	Creeping plants
• *Cynodon dactylon, Axonopus compressus*	*Wedelia trilobata, Phyla nodiflora*

c) **Water regulation by ornamental ground cover plant**
Ground cover plants play a major role in regulating water movement in soil, which helps in controlling floods, drought stress, and soil erosion Van der Maarel, 2005).

d) **Bio-engineering stabilization (vegetative slope stabilization):** is the use of living plants combined with simple engineering materials to stabilize soil, slopes, riverbanks, and coastal areas (Ni *et al.*, 2024) . It is widely used as a nature-based solution for landslides, erosion, and water-related hazards (Jandyal and Shah, 2024).

e) **Ecological stabilization:** is the use of natural vegetation and ecosystem processes to restore and maintain the stability of soil, slopes and landscapes (Wang *et al.*, 2024) . Unlike purely mechanical methods, it focuses on long-term sustainability, biodiversity and natural balance (Wang *et al.*, 2024). Allowing vegetation to grow naturally with minimal disturbance. Introducing native ground covers, grasses, shrubs and trees. Combining different plant types for layered protection

Table 9: Examples of plants Ecological stabilization

Ground covers	Shrubs	Trees
Cynodon dactylon *Phyla nodiflora*	*Lantana camara* *Vitex negundo*	*Azadirachta indica* *Acacia spp.*

Aesthetic + functional stabilization is an approach that combines visual landscape beauty with practical soil and slope stabilization functions using ornamental ground cover plants and designed vegetation systems. **Key functions like:** Soil stabilization, surface protection, water regulation, microclimate improvement, biodiversity support.

Table 10: Examples of suitable plants for Aesthetic + functional stabilization

Slope stabilization	Examples	Function
Functional + ornamental ground covers	*Wedelia trilobata, Alternanthera spp., Phyla nodiflora*	yellow flowers, erosion control colourful foliage, low-growing, dense mat
Grasses for structure	*Vetiver grass* *Zoysia grass*	strong roots, neat clumps, lawn-like appearance
Creepers for coverage	*Ipomoea pes-caprae* *Vinca minor*	coastal stabilization + aesthetic value ornamental ground cover)

Different colour schemes of ornamental ground covers

White-flowered ground covers: Create visual calmness, reflect light, suitable for shaded areas and moon gardens. e.g. *Sphagneticola trilobata, Phyla nodiflora, Ruellia simplex, Catharanthus roseus, Alternanthera sessilis*

Yellow-flowered ground covers: Bright appearance, high visibility, commonly used along slopes and roadsides. E.g. *Sphagneticola trilobata, Turnera subulate, Portulaca grandiflora, Chrysogonum virginianum.*

Pink-flowered ground covers: Soft aesthetic appeal, widely used in parks and residential landscapes. E.g. *Catharanthus roseus, Phlox subulate, Ruellia simplex, Antigonon leptopus, Verbena × hybrida*

Red-flowered ground covers: Strong visual impact, commonly used for focal points and borders. E.g. *Portulaca grandiflora, Verbena canadensis, Salvia splendens, Alternanthera ficoidea, Ixora coccinea*

Purple / Violet-flowered ground covers: Create contrast with green foliage, often used in formal landscaping. E.g. *Vinca minor, Ruellia simplex, Ajuga reptans, Lantana montevidensis, Verbena rigida*

Blue-flowered ground covers: Rare and highly valued, provide cool colour tones in landscapes. E.g. *Evolvulus glomeratus, Plumbago auriculata, Lobelia erinus, Vinca minor, Scaevola aemula*

Orange-flowered ground covers: Warm tones, attractive to pollinators. E.g. *Lantana montevidensis,* Portulaca grandiflora, *Gazania rigens, Zinnia angustifolia*

Research findings

Few research studies within the mitigation framework of slope stability have increasingly leaned towards the influence exerted by either vegetation canopy or vegetation root mechanisms, with more emphasis on the surface runoff on vegetative cover. The study area in Longling County, Baoshan City, Yunnan Province, at the intersection of the south subtropical climate zone and the north tropical zone. Analyzed two herbaceous plants "Vetiver grass and *Pennisetum hybridum*" on soil reinforcement and slope protection effects through artificial planting experiments. With abundant rainfall, the annual average precipitation falls between 1400 and 2100 mm, mainly concentrated in May and October, accounting for approximately 88–90% of the annual rainfall. The average yearly precipitation in other areas is mostly 800–1100 mm. The annual average temperature is 14.9 ◦C. Two slopes of 15° and 30°, two herbaceous species, vetiver grass and *Pennisetum hybridum.* The average runoff generation rate for the three types of slopes is bare slope > vetiver slope> *Pennisetum hybridum* (Wang *et al*., 2024). Both herbaceous plants have an excellent soil-fixing and slope-protecting impact on the fully weathered granite backfill slope (Yu *et al*., 2021, Liao *et al*., 2021). *Pennisetum hybridum* soil and water conservation effect is significantly better than that of the Vetiver grass. In contrast, Vetiver grass roots slightly outperform *Pennisetum hybridum* in enhancing the shear strength of the soil (Liao *et al*., 2024). The slope protected with synthetic fibre was 121 percent more stable than the natural slope whereas the natural fibre showed 136 percent. The bio-engineering technique of short-root reinforcement exhibited 174 percent stable than the natural slope, and the deep-root reinforcement, using vetiver, showed 189 per cent stability (Krishnan *et al*., 2025). Moreover the time required for the slope to get destabilized also increased with the same type of protective measures. For three species that established well, soil cores were collected to measure root biomass at depths up to 40 cm. Vetiver grass (*Vetiveria zizaniodies*) had substantially higher mean root biomass (3.75 kg/m^3) (De Baaets *et al*., 2008, Simon *et al*., 2002) than juniper shrubs (*Juniperus chinensis*; 0.45 kg/m^3) and fescue grass (*Lolium arundinaceum*; 1.28 kg/m^3) (Bordoloi and Ng, 2020), at depths up to 40 cm, with the most pronounced difference in the deepest soil layers. Juniper and vetiver both had slightly lower sediment yield than fescue grass when sediment yield from the whole plot was considered. Erosion pins indicated that there was more spatial variability in erosion and deposition within the juniper and fescue plots, likely due to uneven vegetation establishment. Selecting a species with strong and even establishment is important to preventing surface erosion (Bochet *et al*., 2010, Grace, 2002). Vetiver grass had more abundant and deeper root biomass than the other species in the study, suggesting it will be best for slope stabilization (Asima *et al*., 2022). Recovered vegetation at landslide sites plays an important role in maintaining post-seismic deposit stability and indicates provisional stability of the landslide deposits (Marc *et al*., 2015, Shiels and Walker, 2013). Post-seismic vegetation recovery at landslide sites is also closely linked to the decrease of exposed land slide surface and can be used to indicate post-seismic landslide activity (Yang *et al*., 2018). Based on vegetation recovery during the eight years since the earth quake, the post-seismic landslide activity was expected to return to pre-seismic conditions within two decades. The Cenchrus ciliaris alone and in combination increases the SOC content and MWD and it decreases bulk density, resistance to penetration, runoff and soil loss in silty clay loam to clay loam soil under semi-arid climatic conditions (Wang *et al*., 2003). Cenchrus ciliaris can be used alone or in combination with plants for protection of natural resources from water-induced soil erosion, runoff conservation and maximization of precipitation water use for productive purposes (Meena *et al*., 2023). Aboveground characteristics played a pivotal role in the anti-erosion potential of the plants. The most effective species were *Ceratostigma plumbaginoides* (Cer), *Dianthus gratianopolitanus* (Dia) and *Bergenia* 'Baby Doll' (Ber), which exhibited dense and continuous soil surface cover throughout the seasons and years (Sun *et al*., 2021). In particular, Cer's anti-erosion effectiveness was derived from its continuous rhizomatous activity, which rapidly colonized the entire plot, resulting in the emergence of a high density of new epigeal stems. Ber produced robust stems and large, leathery leaves that remained close to the ground surface (Terzaghi *et al*., 2025).

Conclusion

Ornamental ground covering plants plays an indirect role in enhancing soil stability, slope reinforcement and surface protection. Dense root systems of ground covers improve soil binding capacity. Ornamental ground covering plants act as protective vegetative layers, minimizing soil erosion, runoff velocity and nutrient loss. Ornamental ground covering plants help in post-seismic stabilization. Ornamental ground covers contribute to aesthetic value, biodiversity enhancement and ecological restoration. Integration of ground covers into landscape planning offers a sustainable, low-cost and eco-friendly strategy for climate-resilient infrastructure.

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