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Wayanad Landslide Disaster: Impact, Response, and Implications for Future Resilience

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Abstract

This study evaluates the Wayanad landslides of 2024, examining their socio-economic and ecological impacts, the effectiveness of response and rehabilitation efforts, and implications for future resilience in Kerala. The landslides have caused substantial damage, disrupting the lives of plantation workers and their communities, resulting in material loss, economic decline, and long-term environmental degradation. While Kerala's immediate rescue and relief efforts, supported by NGOs and volunteers, have been commendable, the state faces challenges in implementing permanent rehabilitation and mitigation measures, making it crucial to provide access to suitable livelihoods and diversify local economies as part of an effective post-event response for the permanent rehabilitation of hundreds of survivors of Kerala's deadliest disaster. To enhance disaster preparedness, Kerala needs to adopt robust institutional mechanisms, update hazard maps, and improve early warning systems, all integrated into a comprehensive pre-event strategy. By learning from successful international frameworks and integrating advanced technologies, Kerala can strengthen its resilience against climate change-induced disasters.

Keywords: Wayanad landslide disaster; socio-economic and ecological impacts; state response; Preparedness and mitigation

JEL Classification: Q54, H84, D74, R58, I31

Natural disasters, though often beyond the full control of individuals and governments, are influenced by human activities and environmental factors. Among these, landslides are less frequent but rank as the third most critical natural disaster worldwide and the seventh leading cause of death among natural disasters (Zillman, 1999; Herath and Wang, 2009; Aliimohammadlou et al., 2013). They pose a substantial threat, particularly to vulnerable populations in rural areas, contributing significantly to disaster-related mortality.

Landslides, caused by the movement of large volumes of earth, rock, and debris down slopes due to gravity, are triggered by heavy rainfall, seismic activity, or human intervention. These events reshape the Earth's topography and can cause severe damage to human settlements, particularly in regions already susceptible to natural disasters. In countries like India, the economic and human costs of landslides can exceed those of other natural disasters. This is evident from the impact of landslides in both developed and developing nations, including the USA, Greenland, Japan, Brazil, the Philippines, Papua New Guinea, Nepal, and India.

India is recognized as one of the top four countries with the highest landslide risk, with an estimated loss of life per 100 km² exceeding one. The country contributes approximately 8 percent of global landslide fatalities, with 13.17 percent of its land area susceptible to landslides and 4.75 percent categorized as 'very highly susceptible' (National Remote Sensing Centre, 2023). Kerala, in particular, is highly vulnerable, with over 14 percent of its land classified as 'very high susceptibility.' Since the devastating floods of 2018, the frequency of landslides in Kerala has increased, exacerbating the state's vulnerability to torrential rains. In 2018 alone, over 5,000 landslides were reported in Kerala (IEEE, 2019). Between 2015 and 2022, Kerala experienced 2,239 out of 3,782 reported landslides in India, marking it as one of the most affected states (Tiwari, 2024). Notably, on July 30, 2024, Kerala endured three of its deadliest landslides, particularly in the Wayanad district, which resulted in over 350 deaths and left more than 200 people feared trapped. The landslides, which struck while the villages were asleep, obliterated densely populated settlements along the fragile Western Ghats in Wayanad.

This study is significant as it evaluates the Wayanad landslides of 2024, aiming to assess their socio-economic and ecological impacts, the effectiveness of response and rehabilitation efforts, and the implications for future resilience in Kerala. The paper is structured as follows: it begins with a review of the theoretical and literature background, followed by a detailed examination of landslides in Kerala, including past experiences and recent events. The study then addresses the socio-economic and ecological impacts of the landslides, assesses Kerala's response and rehabilitation efforts, and concludes with a discussion on the implications for future resilience.

1 Theory and Literature Background

Landslides are a pervasive and destructive natural hazard characterized by the downward movement of soil, rock, debris, and other materials. These events can vary significantly in their

speed, from slow movements measured in millimeters per year to rapid flows exceeding tens of meters per second. The classification of landslides is complex, including various types such as falling, toppling, sliding, spreading, and flowing, each shaped by distinct slope conditions and causal factors (Varnes, 1978). The stability of slopes is fundamentally a balance between factors that increase shear stress and those that enhance the soil mass's resistance to sliding. Terzaghi (1950) emphasized that landslide occurrence is driven by internal changes within a slope—such as reductions in shear strength—and external causes that heighten shear stress.

Precipitation, seismic activity, and human interventions are key triggers of landslides, with rainfall and snowmelt being particularly influential. The interplay of geological and geotechnical properties of the slope materials, along with the velocity and volume of the sliding mass, determines the landslide type and severity. Zezere et al. (1999) highlighted that human activities contribute significantly to landslide occurrences, with modifications like excavation, overloading, deforestation, and urbanization exacerbating natural triggers. For instance, urban expansion often involves altering slopes and increasing surface runoff, thereby enhancing landslide risk. The impacts of such modifications are compounded by climatic changes, including altered rainfall patterns due to factors like cloud seeding and industrialization.

The socio-environmental impacts of landslides are significant and diverse. On the natural environment side, landslides can alter land morphology, damage vegetation, and disrupt water systems. They can create natural dams that may lead to catastrophic flooding if breached and contribute to phenomena such as landslide-generated tsunamis (Costa and Schuster, 1988; Locat and Lee, 2002). The destruction of vegetation and habitats can have long-lasting effects on ecosystems and biodiversity (Geertsema et al., 2009). Landslides, by altering landscapes and destabilizing environments, can lead to significant ecological damage, including habitat destruction and soil erosion (Turner, A. K., 2018). Economically and socially, landslides cause direct damage to infrastructure, property, and human health, and indirectly affect local economies by reducing productivity and disrupting community life (Atta-ur-Rahman et al., 2011; Kjekstad and Highland, 2009; Winter, M. G., et al 2016; Perera, S., et al 2018).

The increasing frequency and intensity of landslides, driven by climate change, highlight the critical need for effective response and mitigation strategies. Both the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Sendai Framework for Disaster Risk Reduction (SFDRR) emphasize the critical importance of implementing robust risk management frameworks to address and reduce landslide vulnerabilities. These guidelines advocate for systematic vulnerability assessments and the development of tailored mitigation measures to better manage landslide risks. To address these challenges, the Asian Disaster Preparedness Center (ADPC) has launched the Regional Capacity Enhancement for Landslide Impact Mitigation (RECLAIM) program, which focuses on improving landslide risk management in vulnerable cities across Asia. This initiative highlights the need for long-term, context-specific strategies.

Risk management for landslides involves both structural and non-structural interventions. Structural measures include physical approaches such as slope stabilization, drainage systems, vegetation management, and construction codes (Lacasse & Nadim, 2009; Andersson-Skold et al., 2013). These methods aim to prevent landslides or minimize their impact by altering the physical environment. However, many developing countries face financial and technical constraints, limiting their ability to implement extensive structural measures. Consequently, non-structural strategies—such as land use planning, early warning systems, and public awareness campaigns—become crucial (Lacasse & Nadim, 2009; Andersson-Skold et al., 2013). Early Warning Systems (EWS) and community-based mapping have been identified as effective non-structural interventions. EWS can provide timely alerts, helping communities prepare and respond to imminent landslide threats (Dai et al., 2002; Holcombe & Anderson, 2010). Similarly, community-based mapping of slope attributes and drainage network construction can enhance local risk perception and response capabilities (Holub & Fuchs, 2009). These approaches are often more feasible and less costly than large-scale structural projects, especially in resource-constrained settings.

The ecosystem-based approach to disaster risk reduction has gained attention as well. Sustainable Forest Management and afforestation can play a significant role in reducing landslide risks by stabilizing slopes and preventing soil erosion (McElwee et al., 2017; Bendito & Barrios, 2016). This approach integrates environmental management with disaster risk reduction, offering a sustainable and cost-effective solution for many regions.

Despite these advances, the implementation of landslide risk management strategies faces numerous challenges. In both developing and developed countries, decision-makers often encounter obstacles such as limited budgets, complex regulations, and inadequate risk information (Holub & Fuchs, 2009; Gamper & Turcanu, 2009). Effective mitigation requires overcoming these barriers and integrating both physical and non-physical measures into a comprehensive risk management framework.

2 Landslides in Kerala: Experience and Recent Events

Kerala, renowned for its tropical climate and diverse geography, is one of the most livable states in India. Its lush environment benefits from the South-West Monsoon (June to September) and the North-East Monsoon (October to November), which sustain a rich array of flora and fauna. The state's unique ecology is supported by 44 rivers and the Western Ghats, which shield the region from extreme climate conditions. The Arabian Sea to the west and the Western Ghats to the east play crucial roles in maintaining Kerala's moderate climate, avoiding the extremes experienced in other parts of India.

However, Kerala's precipitation patterns have recently undergone significant changes, reportedly due to climate change and rising temperatures over the Arabian Sea (Abhilash 2024). These changes have led to uneven and extreme rainfall, including frequent cloudbursts. Such

meteorological shifts, combined with poor land use practices, have rendered the state ecologically vulnerable and highly prone to massive landslides, particularly since the catastrophic floods of 2018.

Historically, Kerala has experienced several deadly landslides, even before the 2018 floods. Notable incidents include the Mundakkai landslide in 1984, the Kappikalam landslide in 1992, and the Vallamthode landslide in 2007, which resulted in 14, 11, and 4 deaths respectively (Kuriakkose et al., 2009). Other significant landslides include the Amboori landslide in 2001, which killed 39 people, the Pamba landslides in 1999 with 25 fatalities, and the Nittumkoottamala landslide in 2004, which claimed 10 lives. Since the 2018 floods, landslides have become increasingly frequent and severe. That year alone, over 5,000 landslides were reported in Kerala, with over 3,000 occurring in the districts of Idukki and Wayanad. The regions within the Western Ghats, such as these hilly districts, are particularly susceptible to torrential rains and subsequent landslides. Notable post-2018 incidents include the Kavalappara landslide in 2019, which took 50 lives, the Puthumala landslide in 2019, resulting in 15 deaths, and the Pettimudi landslide in 2020, which claimed 66 lives.

The most recent and devastating event occurred on July 30, 2024, when Kerala experienced three of its deadliest landslides. These landslides struck the villages of Punchirimattam, Chooralmala, and Mundakkai in the Meppadi Grama Panchayat of Wayanad district. Over 350 people were killed, with more than 200 feared trapped under debris. The landslides, which occurred along the fragile Western Ghats, led to the complete destruction of the affected villages. The densely populated areas were swept away by a rapid downslope flow of debris, boulders, and earth, while the inhabitants were asleep (see Figure 1).

This tragic event mirrored the historical devastation of the Mundakkai region in 1984 but on a much larger scale. The severity was underscored by the discovery of bodies and body parts found 20-50 km downstream in the Chaliyar River, indicating that many were swept through waterfalls such as Soochipara Waterfalls. The Wayanad landslides of 2024 are reported to be the worst ever in Kerala in terms of both casualties and damage intensity.

Kerala has tragically become increasingly prone to landslides, with frequent occurrences of mass downslope movements across the state, especially in the hilly districts of Wayanad and Idukki since 2018 (Frontline 2024; National Remote Sensing Centre 2023). According to Kuriakkose et al. (2009) and Sreekumar (2019), 13 out of 14 districts in Kerala are prone to landslides, with 13% of the state's land area being extremely susceptible. The Western Ghats regions, including Idukki, Palakkad, Malappuram, Pathanamthitta, and Wayanad, are identified as highly vulnerable. Recent studies and reports highlight the need for improved landslide mitigation strategies, including a forthcoming mobile app for landslide management (The New Indian Express, 2024). Wayanad ranks 13th among the most landslide-prone districts in India, with 10 out of 30 highly susceptible districts being located in Kerala (National Remote Sensing Centre, 2023).

Figure 1: Wayanad Landslide Terrain: Before and After



1. Chooralmala town before landslides (Courtesy: The New Indian Express)
2. Satellite image of Punchirimattam-Mundakkai-Chooralmala: Before landslides (Courtesy: Google Map)
3. Satellite image of Punchirimattam-Mundakkai-Chooralmala: Close view-before landslides (Courtesy: Google Map)
4. Drone view of Wayanad landslides (Courtesy: The Hindu)
5. Drone view of Chooralmala after landslides (Courtesy: Mathrubhumi)
6. Rescue operations at Chooralmala-Bailey bridge (Courtesy: Facebook)

Research on landslide impacts in India is sparse, but several regional studies provide useful insights. For instance, Prabhath et al. (2023) studied the experiences of landslide survivors and emphasized the importance of community-based disaster management planning in Karnataka's Kodagu District. In Kerala, Hao et al. (2022) examine the relationship between land use changes and landslides in Idukki, revealing that while landslides often occurred in densely vegetated areas, short-term land use changes were not the main cause of the 2018 disaster. Jones et al. (2021) use advanced modelling techniques to assess landslide susceptibility in Idukki, finding that both natural and human factors play significant roles. The ecological sensitivity of Kerala, particularly in the Western Ghats, is highlighted by Kuriakkose et al. (2009), who note that most landslides occur on steep slopes. *The Week* (2024) points out that plantation areas and deforestation contribute to landslides, exacerbated by high population density. Ramasamy et al. (2020) and Gadgil (2011) agree on Kerala's vulnerability, while Gadgil (2024) links rock

quarries and cloudbursts to increased landslide risks, with aerosols from quarries potentially amplifying rainfall and landslide hazards. Wadhwan et al. (2020) conducted an in-depth study on the causes of landslides in Kerala, linking heavy monsoon rainfall to landslide occurrences in Kavalappara and Puthumala. Their research highlights that structurally weakened bedrocks and compromised residual materials, exacerbated by excessive rainfall, significantly contribute to landslides. This finding is corroborated by data from the India Meteorological Department (IMD), which reported a dramatic increase in rainfall in Wayanad from 9 mm to 141.8 mm in a single day before the landslide event, highlighting the region's heightened susceptibility to landslides during extreme weather conditions.

However, discussions on the socio-economic and ecological impacts, as well as the effectiveness of risk management systems in India and Kerala, remain limited. In the context of the Wayanad landslide disaster, these theoretical and empirical insights are vital for grasping the full extent of the disaster's impact and shaping an effective response. The region's vulnerability to landslides is intensified by its continuous rainfall, challenging topography, climatic conditions, and increasing human encroachment.

3 Socio - Economic and Ecological Impact of Wayand Landslide

Socio-Economic Background of the Victims: The Wayanad region, especially the landslide-affected areas, is predominantly inhabited by working-class families, most of whom are employed as plantation workers. A smaller portion of the population consists of migrants engaged in small businesses and various other jobs. Nearly every household in the region is connected to the 'Harrisons Malayalam' plantations, with many family members working there. Many of those trapped in the Mundakkai landslides were plantation workers living in 'layams.' These workers, originally migrants from neighboring districts in Kerala and the Nilgiris in Tamil Nadu, had settled in the area in search of stable employment and shelter.

Migration to the Wayanad plantations began largely in the 1920s, influenced by the political conditions following the 'Malabar Rebellion' of 1921 and economic conditions of that period. This migration was driven by the demand for labor on one side and the need to escape starvation on the other. Migrants, compelled by economic necessity, sought livelihood opportunities in Wayanad to escape the deprivation in their home districts. This mass migration from neighboring districts continued into the early 1970s. During this period, plantation workers endured harsh conditions until labor unions, emerging from community organizations like reading and football clubs, began advocating for better wages and improved working conditions (Najeeb, 2020).

Despite these improvements, the workers and their families remained in 'layams,' where they received limited, yet free, facilities from the plantation companies. According to Yazir

(2024), the second generation of plantation workers continued in the same jobs in the 1990s due to a lack of alternative employment opportunities and limited education. Many who left the plantations returned, unable to find better options elsewhere. The bonds formed within the 'layams,' along with the free basic facilities and lack of opportunities, have kept these families tied to plantation work, perpetuating a cycle of poverty across generations (Yazir, 2024, as reported in MediaoneTV Live).

An illustrative example of this dynamic is provided by one of the faculty members at Kerala's arts and science colleges (name withheld upon request), whose family lived in the 'paddies' of the Achoor Tea Estate for several decades. His mother, employed there since 1972, only recently secured their own land and house. Their ancestors had arrived at the Wayanad plantations in a state of absolute deprivation following the Malabar Rebellion of 1921. Even today, the family has not fully transitioned away from plantation life; they maintain strong ties to the community and traditions associated with it, and one of the family members still relies on the plantations for livelihood. Nevertheless, his family exemplifies progress in breaking the cycle of poverty, as he and two of his brothers earned doctorates in different fields and work in various colleges in Kerala. However, another brother remains a plantation employee, indicating that every family is still connected to the plantation economy, even if newer generations pursue other means of livelihood. This suggests that education and diverse livelihood opportunities are crucial for breaking the cycle of poverty in the plantation regions of Wayanad and Idukki.

Since the 1990s, a gradual shift has begun, with some families benefiting from Gulf migration and remittances, allowing them to purchase land and build homes. Moreover, new job opportunities in nearby towns have enabled a few residents to pursue non-plantation livelihoods. Yet, the region remains heavily dependent on plantations, and significant improvements in living standards will require diversifying the local economy beyond traditional plantation jobs.

Socio-Economic Consequences: The landslide-hit regions of Wayanad have seen a complete disruption of normal socio-economic life. Restoring pre-landslide conditions for the survivors will require a long period of effective, permanent rehabilitation. From an economic perspective, it is evident that the well-being of the survivors has significantly diminished, even becoming negative, due to the loss of loved ones, extensive material damage, cessation of local economic activities, and the psychological trauma from narrowly escaping and witnessing the severity of Kerala's worst-ever disaster.

This loss of well-being has both immediate and long-term impacts. The immediate impacts of the Wayanad landslides include the loss of lives (over 400 inhabitants, and a few inter-state migrants and tourists), property and infrastructure devastation, disruptions to daily life, and loss of livelihoods. The long-term effects extend to changes in socio-economic conditions, health, and mental well-being. Survivors can potentially recover their well-being over time as they adapt, undergo rehabilitation, and regain their livelihoods.

The cost of the loss of lives in this disaster, the deadliest in Kerala's history, is beyond estimation. According to new satellite images of the Wayanad landslide disaster area published by the National Remote Sensing Centre, the size of the main scarp of the landslides is approximately 86,000 square meters, equivalent to 21 acres. Additionally, much larger areas along the debris flow route may have become uninhabitable, apart from the obliterated 86,000 square meters area.

Reports indicate that over 600 houses were situated on the hill slopes and valleys of Vellarimala hill, an area within or close to the disaster zone. According to media reports, entire settlements with around 400 houses were washed away by multiple massive debris flows in the early hours of July 30, while people were asleep. More than 100 other houses were partially destroyed or have become uninhabitable. The entire landscape of the landslide-hit villages has become desolate, rendering the area uninhabitable.

Restoring and recovering the disaster-stricken land will be a herculean task, enormously expensive, and might even necessitate abandoning the area due to the risk of future disasters. Besides the destruction of houses, properties, commercial buildings, and public infrastructure, the losses in tourism and damage to plantations must be considered to assess the full extent of livelihood losses. The revenue loss in the plantation sector, due to the loss of farm area and the complete disruption of the entire plantation economy, has been substantial. Moreover, the Punchirimattam-Mundakkai-Chooralmala belt, a picturesque area often referred to as the 'Munnar of Wayanad,' is home to several resorts and homestays that regularly host tourists. The loss or infrastructural damage to these resorts, combined with the inevitable, prolonged, and complete disruption of tourism activities, will significantly impact Wayanad's economy. The Kerala state government reportedly sought a financial package of Rs.2,000 from the Centre for a comprehensive rehabilitation for Wayanad, indicating the scale of the disaster.

The landslide's impact extends beyond the immediate devastation to encompass the destruction of individual assets, commercial wealth, and public infrastructure. Nearly 500 houses, farmland, vehicles, and other personal assets have been lost, along with commercial establishments in the affected towns. Public infrastructure, including roads, bridges, schools, and healthcare centres, has been extensively damaged. In addition to the physical losses, the disaster has fragmented social networks and community bonds, which are crucial for emotional support and collective recovery efforts. The loss of social cohesion further complicates the rebuilding process, leaving the region facing a long and challenging path to recovery.

The landslide disaster highlights the critical need for economic diversification in the region. The persistent dependence on plantations has rendered the local economy highly susceptible to shocks, with few alternatives for livelihoods outside the plantation sector. As the ILO (2019) suggests, diversifying rural economies is essential for improving livelihood security and mitigating the impact of livelihood-shocks. The Wayanad landslide serves as a stark reminder of the importance of building resilient and diversified local economies that can better withstand

future challenges.

Ecological Consequences: The recent landslides in Wayanad have resulted in profound ecological consequences, significantly disrupting the local environment. The immediate impacts of the disaster include widespread destruction of vegetation and the disruption of wildlife habitats, which are critical components of the region's biodiversity. The alteration of natural waterways due to the landslides has led to flooding in adjacent areas, further compounding the environmental damage. The Wayanad landslides have been catastrophic from an ecological perspective, affecting the earth's surface topography, water bodies, and groundwater flow, forest coverage, and natural wildlife habitats, including rivers and streams, all of which contribute to Wayanad's environmental character and quality, as suggested by Geertsema et al. (2009). The deadly landslides claimed the lives of numerous species, including pets, livestock, invertebrates, and small animals found in human habitats, all of which play critical roles in maintaining ecological stability.

Kerala's soil in general, and Wayanad's soil in particular, is highly prone to landslides, according to the Landslide Atlas of India 2023. Gadgil (2011) has identified all three talukas in Wayanad, which are located within the sensitive Western Ghats, as Ecological Sensitive Zone 1 (ESZ1), requiring stringent measures to protect the environment. The steep hill slopes in Wayanad make its soil especially susceptible to devastating landslides, as faster and more extensive debris flow can lead to significant damage over larger areas.

In the long term, the affected areas have been transformed into barren landscapes, with rocks and debris scattered across the once-fertile land. The loss of topsoil, a crucial element for plant growth, means that the restoration of the landscape will be a slow and challenging process. Landslide deposits have a significant long-term impact on stream morphology and can destroy fish habitats in the short term (Geertsema et al., 2009). It can have a more significant impact on Kerala, where the population density remains among the highest in the country, as changes in stream morphology could lead to the loss of habitable land. The altered topography has had a significant impact on rivers, streams, and groundwater systems, leading to long-lasting changes in the region's hydrology. The damage to forests, which serve as vital ecosystems for both flora and fauna, has further exacerbated the ecological impact, leading to the displacement of wildlife and a reduction in biodiversity.

The sedimentation resulting from the landslides has led to a decline in water quality, adversely affecting aquatic habitats and the species dependent on them. Landslides can introduce suspended sediment and organic materials into water sources, negatively impacting drinking water and potentially reducing the habitable area in the disaster zone. The loss of forest cover, a common consequence of landslides, further disrupts the ecological balance, impacting wildlife and the broader environmental health of the region. Additionally, massive debris flows in areas like 'Wayanad's Munnar' can diminish the scenic beauty and tourism value of what was once a highly sought-after destination (Geertsema et al., 2009).

Although the Gadgil Report (2011) and the Kasturirangan Report (2013) were submitted to the government to protect the ecologically sensitive Western Ghats, Kerala's political landscape strongly opposed both reports due to significant pressure from various groups concerned about potential loss of livelihoods. Paradoxically, Kerala is now experiencing natural disasters, such as landslides, which are impacting livelihoods, lives, and property mainly due to the state's failure to implement ecologically sustainable development initiatives. The state must reconsider its development policies for the ecologically fragile regions of the Western Ghats to address these emerging challenges.

Landslides are often regarded as purely destructive events, yet they play a composite role in transforming ecosystems. In Wayanad, the landslide has contributed sediment and coarse woody debris to aquatic habitats, which can enhance biodiversity over time. The creation of diverse soil conditions and the introduction of new sites within the forested landscape may, in the long term, contribute to ecological diversity. According to Geertsema and Pojar (2007), landslides contribute to biodiversity in three main ways: by altering the site, soil, and vegetation (habitat), which can create increased habitat diversity. However, these potential ecological benefits are overshadowed by the immediate and extensive damage caused by the landslide, which has left the Wayanad ecosystem severely compromised. The road to ecological recovery will be long and arduous, requiring sustained efforts in conservation and rehabilitation.

4 Kerala's Resilience in Disaster Response

Kerala's efforts in immediate rescue and search operations during natural disasters have received widespread acclaim. However, the state significantly lags in implementing permanent and effective rehabilitation and mitigation measures. The government and public have consistently demonstrated a strong commitment to rescuing stranded individuals and providing facilities in disaster relief centers. The critical role played by Kerala's NGOs and various volunteer groups, alongside multiple government agencies, in rescuing individuals during natural disasters is well-documented, as evidenced by media reports following disasters such as Cyclone Ockhi in 2017.

The role of NGOs extends beyond rescue operations to include providing essential resources and facilities to survivors in relief camps and supporting rescuers in disaster zones. Despite these efforts, Kerala struggles with effectively rehabilitating survivors permanently, helping them achieve a pre-disaster quality of life with dignity. Achieving a pre-landslide standard of living may not be feasible in the near future, even with comprehensive rehabilitation efforts, due to the loss of loved ones, psychological instability, adverse health conditions, and significant individual, institutional, and infrastructural losses.

The pre-landslide life of Wayanad disaster survivors was already economically and ecologically vulnerable, considering factors such as employment profiles, income levels, landholding sizes, limited access to higher education, limited opportunities for better-paying jobs, and

the presence of ecologically fragile locations. While material losses can be rebuilt, the profound emotional losses from Kerala's worst disaster can only heal with time.

The current landslides have been particularly devastating, as merely building houses and providing monetary compensation will not suffice to "Rebuild Wayanad," as was attempted in previous landslides in the Wayanad, Idukki, and Malappuram districts. Efforts should focus on rehabilitating people in livable and safer locations within a familiar environment. The Kerala government reportedly plans to build a township comprising nearly 500 houses in a safer location, equipped with public infrastructure and commercial complexes. In the short term, it is essential to provide temporary shelters that allow survivors to live with dignity. The government should establish a mechanism as part of the "pre-township" project to house survivors in rented accommodations in livable locations and take care of these families until their livelihoods are secured. Thus, it is crucial to help survivors regain their livelihoods in addition to providing other forms of compensation. Although NGOs have played a phenomenal role in Kerala's rescue operations during massive natural disasters, the government must devise a dedicated and legitimate executive mechanism to accomplish the proposed township project. Financing this project should not create a significant fiscal burden, as substantial offers and donations have been flowing into the Chief Minister's Distress Relief Fund of Kerala (CMDRF), according to media reports.

Rehabilitating landslide-affected people, the environment, and livelihoods poses numerous challenges due to Kerala's demographic features, ecological fragility, fiscal issues, past rehabilitation experiences, and extensive governmental formalities. Rehabilitating 400-500 households in the densely populated state of Kerala, with a population density of 860 people per square kilometer according to the 2011 Census, presents significant challenges. The affected individuals, forced to live on ecologically fragile hill slopes and valleys due to the unavailability of safer locations, highlight the difficulty of finding suitable resettlement areas amidst high population density and ecological fragility. Wayanad's land, prone to landslides, exacerbates this challenge, as much of it is controlled by tea, coffee, and cardamom planters, with 59% of Kerala's landslides occurring in these areas along the Western Ghats.

Fiscal challenges, attributed to fiscal mismanagement and insufficient revenue sources, further hinder the proposed township project, which cannot be accomplished without Central government assistance and public support. While Kerala's past rehabilitation experiences cannot be deemed complete failures, efforts should focus on minimizing complaints during both temporary and permanent rehabilitation processes to support the complete restoration of pre-disaster living quality. Most complaints about the rehabilitation of the recent landslide survivors (in Kavalappara, Pettimudi, and Puthumala) concerned the livability of the rehabilitated locations, access to compatible livelihoods, adequacy of compensation for those who lost farmlands, and the quality of constructions, as per media reports including Malayala Manorama reports on 07-08 August 2024. Additionally, bureaucratic delays and complexities suggest that a new administrative framework is necessary for the successful rehabilitation of those affected

by the 2024 Wayanad landslides.

Addressing the psychological trauma faced by people in the landslide-hit area is paramount and extends beyond monetary estimation. According to Catapano (2001), the psychological state of landslide victims depends on the severity of material and emotional loss. This includes factors such as the loss of loved ones, homes, employment/livelihood vulnerability, neighborhood, and geographical premises. Catapano (2001) also notes that the psychological trauma of a deadly landslide is not limited by time. Long-term psychological trauma can be exacerbated by inadequate support from public institutions and a lack of information on the causes of the event and its probability of recurrence. Therefore, every effort must be made to stabilize the mental strength of victims through effective and sufficient government intervention. This includes permanently rehabilitating the affected individuals, providing all basic facilities, initiating landslide mitigation measures, and communicating progress at different phases of the recovery stage of disaster management theory.

5 Enhancing Disaster Preparedness and Mitigation in Kerala

Recent evidence of climate change and climate change-induced disasters indicates that Kerala faces significant challenges due to its high population density and geographical vulnerabilities. As climate change continues to heighten the frequency and severity of natural disasters in the future, it is crucial to implement robust institutional mechanisms that ensure the safety and security of residents. The National Disaster Management Authority (NDMA) of India devised a detailed landslide risk management plan in September 2019, aiming to minimize damage from landslides. This comprehensive plan includes landslide hazard zonation, monitoring and early warning systems, awareness programs, capacity building, stakeholder training, preparation of mountain zone regulations and policies, stabilization and mitigation of landslides, and the creation of a special purpose vehicle (SPV) for landslide management. Unfortunately, this plan has remained largely theoretical and has not been effectively implemented at the state level, remaining uninitiated at the micro-level.

In February 2023, the National Remote Sensing Centre (NRSC) conducted landslide mapping and zonation across the country, including Kerala. However, experts believe that Kerala's existing mapping data is insufficient for mitigating landslide risks and requires frequent updates due to uneven climatic events. Additionally, the absence of a reliable early warning system—with only rainfall prediction and an inadequate number of competent sensors — has hindered disaster preparedness. The failure to detect and effectively respond to the Wayanad landslide disaster, despite an 'orange alert' from the India Meteorological Department (IMD), underlines the need for a complete overhaul of the landslide risk management system in India.

As cited in the literature, structural interventions like slope stabilization, drainage systems, and vegetation management, which aim to prevent landslides by altering the physical environment, may not be as effective in Kerala due to its geographical disadvantages. Therefore,

non-structural strategies become crucial for the state. These include land use planning, early warning systems (EWS), and public awareness campaigns. EWS can provide timely alerts, enabling communities to prepare for and respond to imminent landslide threats. Community-based mapping can enhance local risk perception and response capabilities. Additionally, sustainable forest management and afforestation can significantly reduce landslide risks by stabilizing slopes and preventing soil erosion, integrating environmental management with disaster risk reduction for a sustainable and cost-effective solution.

Effective disaster management necessitates the empowerment of local self-government bodies, supported by geological experts and equipped with accurate sensors to monitor soil water saturation levels. Strengthening local institutions, as suggested by Hadžić et al. (2020), is essential for successful landslide risk management. This involves amending laws and bylaws to facilitate an effective institutional framework. Sustained collaboration between science and policy-making, as recommended by Alcántara Ayala and Sassa (2023), is crucial for managing landslide disaster risks.

Kerala can draw valuable lessons from Bangladesh's effective management of landslide risks, which is anchored in a robust institutional framework that integrates both expert input and local-level administration. Bangladesh's 'Disaster Management Regulatory Framework' features the National Disaster Management Council (NDMC) and the Inter-ministerial Disaster Coordination Committee (IMDMCC) at the national level, with local disaster management committees operating at district, sub-district, and local administrative levels. This comprehensive approach, as highlighted by Sultana and Tan (2021), has proven successful in managing landslide disasters and could serve as a model for Kerala.

Similarly, Hong Kong has successfully implemented a comprehensive approach to landslide prevention and mitigation, addressing both man-made and natural terrain hazards. Recognizing the high risk associated with its hilly terrain and dense urban development, Hong Kong initiated the Landslip Preventive Measures (LPM) Programme in 1977 to address substandard man-made slopes and retaining walls. Following significant landslide incidents, this program was accelerated and expanded into the Landslip Prevention and Mitigation (LPMit) Programme in 2010. The LPMit Programme focuses on ongoing maintenance and risk management for both man-made and natural slopes. Techniques such as soil nailing, rock bolting, and advanced debris mobility modeling are used to enhance slope stability and mitigate risks. Moreover, innovative solutions like flexible debris-resisting barriers have been explored to minimize environmental impact. Hong Kong's approach also involves managing public expectations through education and incorporating aesthetic considerations into slope design to ensure that it blends with the natural environment.

In Brazil, landslide prevention is approached through a combination of technological and community-based strategies. The Alerta-Rio system employs a network of rain gauges and Doppler radar to monitor precipitation levels and assess landslide risk in real-time. Addition-

ally, the Community-Based Alert and Alarm System (A2C2) utilizes a tiered warning system, including sirens and SMS alerts, to communicate imminent threats to residents. Brazil's government also undertakes efforts to map risk areas, invest in slope stabilization projects, and implement emergency evacuation protocols, all of which contribute to a multifaceted approach to landslide prevention.

Recent advancements in landslide prediction have significantly enhanced the capacity to assess and manage landslide risks. Remote sensing technologies, such as satellite imagery and LiDAR, have become instrumental in detecting terrain changes and identifying potential landslide zones. These technologies provide detailed and accurate information on topographical variations that can indicate increased landslide susceptibility. Complementing these remote sensing tools, ground-based systems— including GPS, inclinometers, and piezometers— offer real-time data on slope movement and soil conditions, thereby facilitating immediate assessment and response to potential hazards.

Improved data analysis and modelling techniques significantly enhance the accuracy of landslide predictions. For example, in 2024, the village of Brienz, located in Switzerland, narrowly averted a catastrophic landslide thanks to its advanced predictive model. This model, which utilized sophisticated data analysis, provided timely warnings that were crucial for mitigating the disaster. This case highlights the critical role of integrating advanced predictive models into landslide risk management strategies, emphasizing the need for ongoing advancements in data analysis and modelling to effectively manage and mitigate landslide risks.

Government policies and regulations are critical in mitigating landslide risks. Effective land-use planning, stringent building codes, and robust environmental protection laws play a vital role in preventing construction in high-risk areas and ensuring that development projects incorporate appropriate mitigation measures. Governments are also pivotal in funding research, monitoring systems, and early warning mechanisms, all of which contribute to reducing landslide risks. Current land-use planning strategies can be particularly effective when they include comprehensive hazard assessments, enforce zoning regulations, and promote sustainable development practices. However, the success of these strategies hinges on their proper implementation and enforcement. To maintain their effectiveness, it is essential for land-use plans to be continuously updated and improved based on emerging data and technological advancements. This iterative process ensures that strategies remain relevant and effective in addressing evolving landslide risks.

6 Conclusion

While Kerala's immediate response to natural disasters has been commendable, a shift towards long-term rehabilitation and mitigation strategies is essential for enhancing resilience against future events. In advancing the permanent rehabilitation of the hundreds of victims affected by the 2024 Wayanad landslides, it is imperative to prioritize the provision of access to suitable

livelihoods alongside housing and monetary compensation. Diversifying the local economy in the plantation areas of Wayanad and Idukki can significantly enhance residents' access to improved livelihoods and help break the vicious cycle of poverty. While careful consideration is necessary when implementing post-event responses, it is equally important to emphasize pre-event measures to strengthen the resilience of plantation communities and other residents in these ecologically fragile regions. Adopting successful disaster management frameworks from other countries, such as strengthening local institutions, regularly updating landslide hazard maps, and educating communities through public awareness campaigns and educational programs, is crucial. Additionally, training local officials and developing effective early warning systems and evacuation plans will further bolster preparedness. The role of international organizations, such as the United Nations and the World Bank, in providing funding, technical assistance, and capacity-building is vital. By integrating these measures, Kerala can improve its ability to safeguard residents from the increasing threats of natural disasters driven by climate change.

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