

LANDSLIDE DISASTER MANAGEMENT PLAN FOR NAGALAND

*A Thesis Project
submitted in partial fulfillment of the requirements for the
award of the degree of*

Bachelor of Planning

By

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DECLARATION

I, **SUNGYENO KIKON**, Scholar No. **2211002139**, hereby declare that the thesis, **Landslide Disaster Management Plan for Nagaland**, submitted by me in partial fulfilment for the award of the degree of Bachelor of Planning, at Maulana Azad National Institute of Technology, Bhopal, India, is a record of bonafide work carried out by me. The matter/result embodied in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma.

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This is to certify that the declaration made by **SUNGYENO KIKON** is true to the best of my knowledge and that the student has worked under my guidance for one semester in preparing this thesis.

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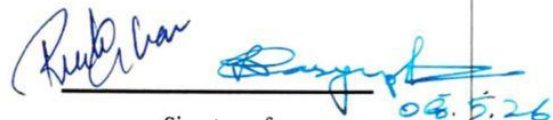

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ABSTRACT

Nagaland, situated in the northeastern hill belt of India along the Indo-Myanmar border, is among the most geologically fragile and landslide-prone states in the country. Characterized by steeply dissected terrain, highly fractured geological formations, and a monsoonal precipitation regime that routinely exceeds 2,000 mm annually, the state presents a compound risk environment where geological susceptibility, climatic intensity, and growing anthropogenic pressure converge. The National Highway 29 (NH-29) corridor, connecting Dimapur to Kohima across a dramatic elevation gradient from approximately 200 m to 1,500 m, constitutes the state's singular lifeline infrastructure and its most vulnerable artery.

This thesis presents a systematic, GIS-integrated Landslide Disaster Management Plan developed through multi-criteria spatial analysis, engineering assessment, and policy evaluation. The study employs a weighted overlay methodology incorporating eight physical and socio-environmental parameters—slope gradient (22%), lithology (18%), annual rainfall (16%), land use (14%), drainage density (12%), structural lineaments (8%), road proximity (6%), and seismic susceptibility (4%)—to generate a Landslide Susceptibility Index (LSI) for the study area. The resultant susceptibility mapping delineates five risk zones, revealing that approximately 42% of Nagaland's mapped area falls within High or Very High susceptibility categories, exposing an estimated 4.2 lakh persons and 387 villages to elevated hazard.

The proposal is structured around the NDMA-mandated 3M+3R framework (Mapping, Monitoring, Mitigation; Response, Recovery, Resilience) and addresses four interconnected intervention domains: (1) an AI-powered Early Warning and Monitoring System (EWMS) based on MEMS sensor networks and Automated Rain Gauges (ARG) along NH-29 hotspots; (2) slope stabilization through Self-Drilling Anchors (SDA), gabion retaining walls, geosynthetic reinforcement, and native bioengineering species; (3) phased disaster preparedness protocols including temporary evacuation shelter standards, SDRF training, and SOP formalization; and (4) a comprehensive Implementation Framework aligned with NDMP 2019, NLRMP 2025, and the Disaster Management (Amendment) Act, 2025. The study draws upon Indian case studies from Uttarakhand, Himachal Pradesh, and Manipur, as well as international best practices from Nepal, Japan, and Hong Kong.

The findings demonstrate that coordinated institutional action, combined with spatially targeted engineering interventions and community-based preparedness, can significantly

reduce landslide fatalities and infrastructural losses in Nagaland. The thesis concludes with policy recommendations for land-use regulation, mandatory resettlement from Zone I areas, and the integration of real-time monitoring into district administration emergency protocol.

सार

नागालैंड, भारत के पूर्वोत्तर पहाड़ी क्षेत्र में भारत-म्यांमार सीमा के साथ स्थित है, और यह देश के सबसे भूगर्भीय रूप से नाजुक और भूस्खलन-प्रवण राज्यों में से एक है। अत्यधिक विच्छेदित भू-भाग, अत्यधिक खंडित भूवैज्ञानिक संरचनाओं, और एक मानसूनी वर्षा व्यवस्था जो नियमित रूप से 2,000 मिमी वार्षिक से अधिक होती है, द्वारा विशेषीकृत, यह राज्य एक मिश्रित जोखिम वातावरण प्रस्तुत करता है जहाँ भूवैज्ञानिक संवेदनशीलता, जलवायु तीव्रता और बढ़ता मानवजनित दबाव एक साथ मिलते हैं। राष्ट्रीय राजमार्ग 29 (NH-29) गलियारा, जो दीमापुर से कोहिमा को लगभग 200 मीटर से 1,500 मीटर तक के नाटकीय ऊँचाई प्रवणता के पार जोड़ता है, राज्य का एकमात्र जीवन रेखा बुनियादी ढाँचा और इसकी सबसे कमज़ोर धमनी है।

यह शोध प्रबंध एक व्यवस्थित, GIS-एकीकृत भूस्खलन आपदा प्रबंधन योजना प्रस्तुत करता है जिसे बहु-मापदंड स्थानिक विश्लेषण, इंजीनियरिंग मूल्यांकन और नीति मूल्यांकन के माध्यम से विकसित किया गया है। अध्ययन में आठ भौतिक और सामाजिक-पर्यावरणीय मापदंडों को शामिल करते हुए एक भारत ओवरले पद्धति का उपयोग किया गया है — ढाल प्रवणता (22%), शैलविज्ञान (18%), वार्षिक वर्षा (16%), भू-उपयोग (14%), जल निकासी घनत्व (12%), संरचनात्मक रेखाएँ (8%), सड़क निकटता (6%), और भूकंपीय संवेदनशीलता (4%) — अध्ययन क्षेत्र के लिए एक भूस्खलन संवेदनशीलता सूचकांक (LSI) उत्पन्न करने के लिए। परिणामी संवेदनशीलता मानचित्रण पाँच जोखिम क्षेत्रों को चित्रित करता है, जो यह दर्शाता है कि नागालैंड के मानचित्रित क्षेत्र का लगभग 42% उच्च या अत्यधिक उच्च संवेदनशीलता श्रेणियों में आता है, जिससे अनुमानित 4.2 लाख व्यक्ति और 387 गाँव उन्नत खतरे के संपर्क में हैं।

प्रस्ताव NDMA-अनिवार्य 3M+3R ढाँचे (मानचित्रण, निगरानी, शमन; प्रतिक्रिया, पुनर्प्राप्ति, लचीलापन) के इर्द-गिर्द संरचित है और चार परस्पर जुड़े हस्तक्षेप क्षेत्रों को संबोधित करता है: (1) NH-29 हॉटस्पॉट के साथ MEMS सेंसर नेटवर्क और स्वचालित वर्षा मापकों (ARG) पर आधारित AI-संचालित प्रारंभिक चेतावनी और निगरानी प्रणाली (EWMS); (2) स्व-ड्रिलिंग एंकर (SDA), गेबियन रिटेंनिंग वॉल, जियोसिंथेटिक सुदृढ़ीकरण, और देशी जैव-इंजीनियरिंग प्रजातियों के माध्यम से ढाल स्थिरीकरण; (3) अस्थायी निकासी आश्रय मानकों, SDRF प्रशिक्षण और SOP औपचारिकीकरण सहित चरणबद्ध आपदा तैयारी प्रोटोकॉल; और (4) NDMP 2019, NLRMP 2025, और आपदा प्रबंधन (संशोधन) अधिनियम, 2025 के साथ संरेखित एक व्यापक कार्यान्वयन ढाँचा। यह अध्ययन उत्तराखंड, हिमाचल प्रदेश और मणिपुर के भारतीय केस अध्ययनों के साथ-साथ नेपाल, जापान और हांग कांग की अंतर्राष्ट्रीय सर्वोत्तम प्रथाओं पर आधारित है।

निष्कर्ष यह प्रदर्शित करते हैं कि समन्वित संस्थागत कार्रवाई, स्थानिक रूप से लक्षित इंजीनियरिंग हस्तक्षेपों और समुदाय-आधारित तैयारियों के साथ मिलकर, नागालैंड में भूस्खलन से होने वाली मौतों और बुनियादी ढाँचे के नुकसान को काफी हद तक कम कर सकती है। शोध प्रबंध भू-उपयोग विनियमन, क्षेत्र I क्षेत्रों से अनिवार्य पुनर्वास, और जिला प्रशासन आपातकालीन प्रोटोकॉल में रियल-टाइम निगरानी के एकीकरण के लिए नीति सिफारिशों के साथ समाप्त होता है।

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INTRODUCTION

One of the most common and destructive natural disasters that impact hilly and mountainous areas worldwide is landslides. Due to their delicate geology, steep slopes, heavy rainfall, and growing human interference, India's Himalayan and northeastern regions are especially vulnerable. One such state that frequently has landslides each year, particularly during the monsoon season, is Nagaland, which is in northeastern India.

Landslides are the third most important natural disaster in the world, occurring at a variety of speeds. Furthermore, landslides typically occur suddenly, leaving people with little time to flee. Consequently, throughout the seven years from 2007 to 2013, 2620 non-seismic, fatal landslides were reported globally, resulting in a total of 32,322 recorded. Additionally, between 2004 and 2016, landslides killed approximately 4,000 people globally on average per year. A few researchers examined how human activity affects the formation of landslides in a case study of Slovakia and gave examples of how slope loading occurs most commonly during the building of new roads, demonstrating that landslides are caused by human activity.

The downward movement of rock, soil, or debris caused by gravity is known as a landslide. Heavy rains, earthquakes, weathering, and human activities including slope cutting, deforestation, haphazard construction, and inadequate drainage systems can all cause this movement.

Landslides have become a constant problem in Nagaland, causing property damage, interfering with transit routes, and posing a major risk to human life. One of the most destructive and common geohazards facing India's Himalayan and sub-Himalayan regions is landslides. They pose a constant threat to human lives, livelihoods, and vital infrastructure throughout the northeastern states, with mass-movement events of all sizes and types frequently occurring during the monsoon season. The National Disaster Management Authority (NDMA, 2019) estimates that 0.42 million square kilometers of India's landmass—nearly 12.6% of the country's total area—are considered landslide-prone. The northeastern states bear a disproportionate amount of this vulnerability due to their unique geological and climatic features

At the intersection of the Naga Hills fold-thrust belt and the Indo-Burman Ranges, Nagaland, the focus of this study, is situated in a structurally complex tectonic context. Highly worn and fractured sedimentary and ophiolitic rocks with low shear strength and high susceptibility to moisture-induced failure make up the majority of the state's geology. An intense and concentrated rainfall regime, with the monsoon providing between 1,500 and 2,500 mm of precipitation annually throughout most of the state and some hillside catchments recording episodic rainfall events far exceeding these averages, exacerbates this geological fragility. The devastating monsoon season of 2024, which saw rainfall in certain areas 393% over average, was a striking example of the extent of precipitation-triggered risk.

The state's most landslide-prone infrastructural corridor and economic lifeline is the National Highway 29 (NH-29), which spans the Dimapur-Kohima corridor over a horizontal distance of around 74 km and a relief gradient of over 1,300 m. Slope failures that cause frequent road closures, often lasting days or weeks, lead to severe economic disruption, a shortage of food and fuel, and the loss of access to emergency medical care. Therefore, socioeconomic vulnerability and systemic infrastructure resilience are also issues, in addition to geotechnical hazard.

The majority of the state is hilly, with limited valleys and steep slopes. Shale and sandstone, which make up the majority of geological formations, are very prone to weathering and erosion. Slope collapses are caused by increasing pore-water pressure in soil and rock masses during prolonged and heavy rainfall, which lowers shear strength. Human activities like road widening, settlement growth, and insufficient slope-protection measures worsen these problems.

1.1 BACKGROUND AND CONTEXT

The geological setting of Nagaland within the Indo-Myanmar Mobile Belt represents one of the most complex and unstable terrains in the Himalayan-Alpine system. As a geologically "young" mountain range, the rock mass has not yet reached a state of equilibrium, leaving the lithology, primarily comprised of Disang and Barail groups, highly susceptible to weathering. The dominance of disintegrated shales and fine-grained sandstones creates a stratigraphic nightmare; these rocks possess inherently low shear strength and tend to degrade into clayey, impermeable materials when exposed to the elements. This structural fragility is exacerbated

by the region's intense tectonic activity, which has introduced a network of faults, folds, and joints that act as ready-made failure planes for sliding masses.

When this precarious geological framework is subjected to the extreme hydrometeorological conditions of the Northeast monsoon, the risk of mass wasting escalates from a possibility to a seasonal certainty. During the peak months of June through September, the terrain is bombarded by high-intensity rainfall that far exceeds the infiltration capacity of the soil. As water percolates through the overburden, it fills the interstitial spaces between soil particles, leading to a dramatic spike in pore-water pressure. From a geotechnical perspective, this increase in pressure effectively "lifts" the soil particles apart, neutralizing the frictional resistance that holds the slope together. Consequently, the effective stress of the slope material drops to a critical threshold, triggering a diverse spectrum of failures. These range from high-velocity debris flows in the upper catchments, which gain destructive momentum as they descend, to massive, deep-seated rotational slides that can displace entire sections of mountainside, permanently altering the landscape and devastating any infrastructure in their path.

The recurring nature of these landslides in Nagaland transcends mere geological concern, effectively transforming seasonal natural hazards into protracted socio-economic crises that paralyze the region's development. This systemic vulnerability is most acutely felt along National Highway-2 and National Highway-29, which function as the primary commercial and humanitarian arteries connecting Nagaland with the neighboring states of Manipur and Assam. When these critical lifelines are severed, the immediate consequence is a total collapse of the supply chain, leading to acute shortages of essential commodities, including food grains, petroleum products, and life-saving medical supplies. Because Nagaland and Manipur are geographically landlocked, there are few viable alternative routes capable of handling heavy commercial tonnage, meaning a single major slide can trigger a localized inflationary spike and a humanitarian bottleneck that persists long after the debris is cleared.

This physical instability also breeds a state of chronic economic stagnation, as vast portions of the state's developmental budget are diverted toward emergency restoration rather than the construction of new infrastructure. Organizations such as the Border Roads Organisation (BRO) and the National Highways and Infrastructure Development Corporation Limited (NHIDCL) are forced into a cycle of "sunk-cost" engineering, where high-frequency maintenance and repetitive slope clearing drain resources that could otherwise be used for long-term modernization. Beyond the balance sheets of government agencies, the human cost of these disruptions is manifested in the profound isolation of rural communities. The sudden

severance of road connectivity acts as a barrier to fundamental human rights, frequently denying villagers access to emergency obstetric care or tertiary hospitals during the height of the monsoon. This enforced seclusion not only disrupts the academic calendar for students who must travel to urban centres but also erodes the resilience of the local economy by preventing farmers from transporting perishable agricultural produce to market, thereby cementing a cycle of poverty and regional underdevelopment.

The persistence of landslide disasters in Nagaland highlights a fundamental flaw in the regional disaster management framework, which remains anchored in a reactive paradigm rather than a preventive one. Current interventions are predominantly characterized by "firefighting" tactics, where engineering resources are mobilized only after a failure has occurred to focus on immediate debris clearance and the application of temporary, often superficial, slope stabilization measures. This tradition of post-event recovery creates a deceptive sense of security; while the road may be reopened quickly, the underlying geological instability is rarely addressed, leading to a repetitive cycle of damage and repair that exhausts state exchequers. This approach is increasingly viewed as economically unsustainable, as the cumulative cost of annual emergency restorations far exceeds the projected investment required for robust, long-term mitigation projects.

Technically, the efficacy of these reactive measures is undermined by a significant data vacuum, specifically the absence of high-resolution Landslide Susceptibility Mapping at the corridor level. Without granular maps that identify high-risk zones based on lithology, slope angle, and land cover, infrastructure development and urban expansion continue to encroach upon hazardous terrain without the necessary geotechnical safeguards. This lack of spatial intelligence means that critical decisions—such as the alignment of new highways or the expansion of settlements—are made without a scientific understanding of the ground's carrying capacity. Consequently, the state finds itself in a perpetual loop of vulnerability, where new construction inadvertently creates the conditions for future failures, further emphasizing the urgent need to transition toward a proactive strategy that prioritizes rigorous mapping and risk-informed planning.

The escalation of landslide risk in Nagaland is significantly intensified by anthropogenic pressures that disrupt the fragile equilibrium of the natural hill slopes. Unplanned urbanization has led to the vertical expansion of settlements on steep gradients that were never geotechnically assessed for such heavy structural loads, while widespread deforestation for timber and shifting cultivation has stripped the terrain of its natural vegetative reinforcement. This loss of root cohesion, combined with archaic or non-existent drainage management,

allows surface runoff to infiltrate the slope unchecked, lubricating potential failure planes and accelerating mass movement. To move toward long-term resilience, the state must transition from a reliance on ad-hoc engineering fixes toward a sophisticated framework of Environmental Planning-Based Disaster Management that treats the slope as a dynamic ecosystem rather than a static wall of earth.

Central to this transition is the institutionalization of risk zoning, which mandates the use of landslide hazard maps to regulate land-use and prevent high-density construction in inherently unstable zones. By codifying these maps into municipal and rural planning bylaws, the state can ensure that development only occurs where the terrain can safely support it. This systemic shift is further bolstered by the integration of Nature-Based Solutions, or bio-engineering, where deep-rooted indigenous vegetation is strategically planted alongside traditional geotechnical structures like gabion walls or rock bolting. This hybrid approach not only provides immediate mechanical support but also offers a self-sustaining method of moisture regulation and soil anchoring that grows stronger over time. Ultimately, achieving regional stability requires a move away from "one-size-fits-all" engineering in favor of corridor-specific strategies. These localized mitigation frameworks recognize that the landslide triggers along a specific stretch of NH-29 may differ vastly from those in the interior districts, requiring customized interventions that account for the unique micro-climates, specific lithology, and local community needs of each individual site.

1.2 PROBLEM STATEMENT

The landslide crisis in Nagaland is not a series of isolated geological accidents but rather a systemic manifestation of a complex interplay between tectonic instability, extreme hydrometeorological triggers, and a historical lack of risk-informed planning. This confluence of variables has rendered the state one of the most hazardous terrains in the Northeast region. The geological foundation, situated within the high-seismic zone of the Indo-Myanmar Mobile Belt, consists of "soft" sedimentary lithology—predominantly splintery shales and weathered sandstones—that possesses a low threshold for failure. When these inherently weak rock formations are subjected to the state's rugged, steep-angled topography, the natural factor of safety for most slopes remains precarious at best. The situation reaches a breaking point during the monsoon season, as high-intensity rainfall saturates the overburden, causing a spike in pore-water pressure that effectively lubricates internal failure planes. This process is exacerbated by widespread deforestation and unplanned urbanization, where the removal of natural vegetative

anchors and the introduction of heavy structural loads onto uncompacted soil have turned once-stable slopes into active disaster zones.

The socioeconomic repercussions of this instability are devastating and multi-layered, beginning with the most tragic outcome: the recurrent loss of human life and the traumatic displacement of families. Beyond the immediate casualties, the destruction of public infrastructure—including schools, government buildings, and community housing—places an immense financial strain on an already capital-constrained state. Perhaps the most crippling effect is the disruption of the transportation and communication backbone; because Nagaland relies almost exclusively on a few primary highway corridors like NH-2 and NH-29 for the movement of food, fuel, and medical supplies, a single landslide can effectively cut off entire districts. For the rural population, this results in a state of chronic isolation, where the inability to access markets leads to the rot of perishable crops and the loss of livelihoods, while the severance of emergency road access frequently leads to preventable medical fatalities during the peak monsoon months.

Despite the predictable and seasonal nature of these occurrences, the current disaster management framework in Nagaland remains trapped in a reactive "clearing-and-repairing" cycle. State agencies primarily focus on post-disaster response—prioritizing the rapid deployment of excavators to clear debris rather than investing in long-term mitigation and structural prevention. This strategic imbalance is both technically insufficient and economically unsustainable, as it fails to address the root causes of slope failure, leading to the repeated collapse of the same "sinking zones" year after year. There is a glaring absence of integrated planning at the regional and corridor levels, particularly the lack of high-resolution Landslide Susceptibility Mapping (LSM) that should ideally guide the alignment of infrastructure.

To bridge this gap, Nagaland requires a paradigm shift toward an all-encompassing landslide catastrophe management plan that moves beyond temporary engineering fixes. This new approach must prioritize scientific risk zoning to ensure that developmental activities are diverted away from high-hazard areas. Furthermore, the state must adopt sustainable and site-specific mitigation techniques, such as the integration of bio-engineering, using indigenous deep-rooted plants to stabilize soil—alongside advanced sub-surface drainage systems. By incorporating rigorous environmental evaluations into the planning process and developing localized strategies for critical highway stretches, Nagaland can finally move toward a future of long-term resilience, breaking the costly and dangerous cycle of seasonal disaster.

1.3 AIM AND OBJECTIVE

The primary aim of this study is:

To assess how environmental conditions and changes influence landslide occurrences in Nagaland and to develop practical disaster mitigation strategies for high-risk corridors and settlements.

The specific objectives of the study are:

- To identify and analyse the major natural and anthropogenic causes of landslides.
- To critically review existing literature, policies, and planning frameworks on landslide disaster mitigation in hilly regions, with a focus on identifying key approaches and research gaps relevant to Nagaland.
- To evaluate the physical and environmental factors influencing landslide occurrence in Nagaland - specifically slope, drainage, and rainfall patterns - and to delineate landslide-prone hotspots along selected transport and settlement corridors.
- To develop landslide susceptibility and risk zoning for the study area and to formulate a planning-based landslide mitigation and disaster management framework for Nagaland.

The primary aim of this investigation is to conduct a systematic and multifaceted assessment of how environmental dynamics, geomorphological conditions, and anthropogenic interventions synergistically influence landslide occurrences within the specific landscape of Nagaland. By evaluating these intersecting variables, the study seeks to transition beyond traditional engineering perspectives to develop scalable, practical, and planning-oriented disaster mitigation strategies. These strategies are specifically designed for high-risk transportation corridors and vulnerable human settlements, ensuring that the research outcomes serve as a blueprint for enhancing infrastructural resilience and safeguarding the socio-economic stability of communities that are currently trapped in a cycle of seasonal disaster and reactive repair.

To achieve this, the study first focuses on a diagnostic investigation into the complex web of natural and anthropogenic causative factors that destabilize the region's slopes. On the natural side, this involves a deep dive into the geologically "young" and fragile lithology of the Indo-Myanmar Mobile Belt, characterized by splintery shales and weathered sandstones that inherently lack structural shear strength. This natural vulnerability is analyzed in conjunction

with human-induced pressures, such as the unregulated cutting of hill slopes for road expansion, widespread deforestation, and the systemic absence of organized drainage systems in urbanizing areas. By quantifying the relationship between these factors, the study establishes a baseline understanding of how human activity accelerates natural mass wasting processes.

A critical component of this study involves a rigorous review of existing literature, policies, and planning frameworks to identify why current landslide management in hilly regions often fails to achieve long-term success. This objective focuses on analyzing national and international guidelines, including those from the National Disaster Management Authority (NDMA), to expose the operational gaps in Nagaland's current disaster framework. This review highlights the historical over-reliance on post-event recovery and the lack of integrated land-use regulations, providing the academic and policy-level justification for a shift toward an environmental planning-based model that prioritizes prevention over cure.

The research further utilizes advanced Geospatial Technologies and Remote Sensing to evaluate the physical and environmental triggers that act as the immediate catalysts for slope failure. This phase involves the isolation and spatial analysis of critical variables, specifically slope geometry, aspect, drainage density, and temporal rainfall distribution patterns during the peak monsoon. By correlating historical landslide records with high-resolution spatial data, the study delineates critical landslide-prone hotspots along vital transport lifelines like NH-2 and NH-29. This localized analysis ensures that the proposed mitigation efforts are strategically directed toward the specific geographic sectors that exhibit the highest levels of geomorphological stress and infrastructural vulnerability.

Finally, the study culminates in the development of a comprehensive landslide susceptibility and risk zoning framework for the study area. This involves the application of multi-criteria decision-making models to categorize the terrain into distinct risk zones, which serves as a scientific foundation for future land-use planning and infrastructure development. Based on these findings, the research formulates an integrated disaster management framework for Nagaland that blends conventional geotechnical engineering with sustainable, planning-based techniques. This includes the proposal of nature-based solutions and bio-engineering to reinforce soil naturally, alongside the development of localized mitigation frameworks that move away from "one-size-fits-all" engineering in favor of site-specific, resilient environmental planning.

1.4 STUDY AREA

Instead of the entire state, the study concentrates on a few districts and corridors in Nagaland that are prone to landslides. The study will be limited to the districts of Dimapur, Chumoukedima, and Kohima as they are the prime urban areas of the state. Critical transportation corridors that are frequently disrupted by landslides receive particular attention.

One of the most significant road connections in the state, the NH-29 length from Chumoukedima to Kohima, serves as the main study corridor. This section is extremely susceptible to landslides since it traverses steep slopes, unstable geological formations, and regions with heavy rainfall. The study area was chosen due to its strategic significance for the state's economy and connections, historical landslide incidents, and the availability of secondary data.

The study region includes Nagaland's Dimapur and Kohima districts, with an analytical focus on the NH-29 corridor. Dimapur, the state's only railhead and commercial center, is located in the western lowlands at an elevation of around 200 meters above mean sea level (AMSL). The state capital is Kohima, which is situated at around 1,500 meters above sea level in the eastern highlands. A corridor of tremendous topographic complexity is created as the Dimapur plateau grades quickly through the Zubza-Medziphema transition zone into the steep slopes of the Kohima district. The intervening topography comprises a compressed yet extremely diversified landscape.

Geologically, the study region includes the Eocene-Oligocene flysch and ophiolitic mélange phases of the Naga Hills as well as Holocene alluvial deposits in the Dimapur plains. Failure pattern direction and drainage organization are fundamentally controlled by the existence of north-south running structural lineaments, which are thought to be manifestations of the deep-seated Naga Thrust. The majority of the soils in the study region are residual and colluvial, and their weathering patterns range in depth. Primary forest on ridge crests, degraded secondary scrub and slash-and-burn agricultural land (jhum) on slopes, and more dense peri-urban habitation in valleys are examples of the varied vegetation cover.

1.5 SCOPE OF WORK

The scope of this study includes:

- The focus of the study is only on the urban areas of the selected districts – Dimapur, Chumoukedima, and Kohima.
- Identification of landslide-prone areas, zoning and mitigation will be based on slope conditions, drainage patterns, rainfall intensity, and anthropogenic activities.
- Thematic mapping will be done with the help of GIS; however, the analysis will be limited to GIS-based findings and available secondary spatial data, without advanced geotechnical modelling or extensive primary data validation.

For certain urban areas in the districts of Dimapur, Chumoukedima, and Kohima, this study aims to evaluate landslide vulnerability and provide mitigating solutions. The main goal of the study is to comprehend the connection between these hill and foothill settlements' growing susceptibility to landslides and their rapid urbanization. The project intends to assess the spatial distribution of landslide hazards and determine appropriate planning and mitigation strategies to improve urban resilience as Nagaland's urban growth continues to spread into unstable slopes and environmentally sensitive areas.

The study's focus is limited to urban areas in the districts that were chosen. The full assessment excludes isolated mountainous areas outside of municipal or urban development boundaries, rural areas, and forest interiors. The chosen urban centers were picked due to their growing populations, expanding infrastructure, frequent landslide accidents during monsoon seasons, and road cutting activities. Slope instability and environmental deterioration result from the considerable interaction between natural terrain characteristics and manmade actions in these key zones.

Through the examination of numerous physical and man-made elements affecting slope stability, the study includes the identification and delineation of landslide-prone locations. Slope gradient, elevation, drainage density, rainfall intensity, land use and land cover patterns, road network expansion, vegetation cover, and settlement concentration are important factors taken into account in this study. Together, these elements will be examined to see how they contribute to or exacerbate landslide incidents in the research region. Anthropogenic activities that contribute significantly to slope failure in rapidly urbanizing hill towns, such as hill cutting, unplanned development, deforestation, and inadequate drainage systems, will receive special attention.

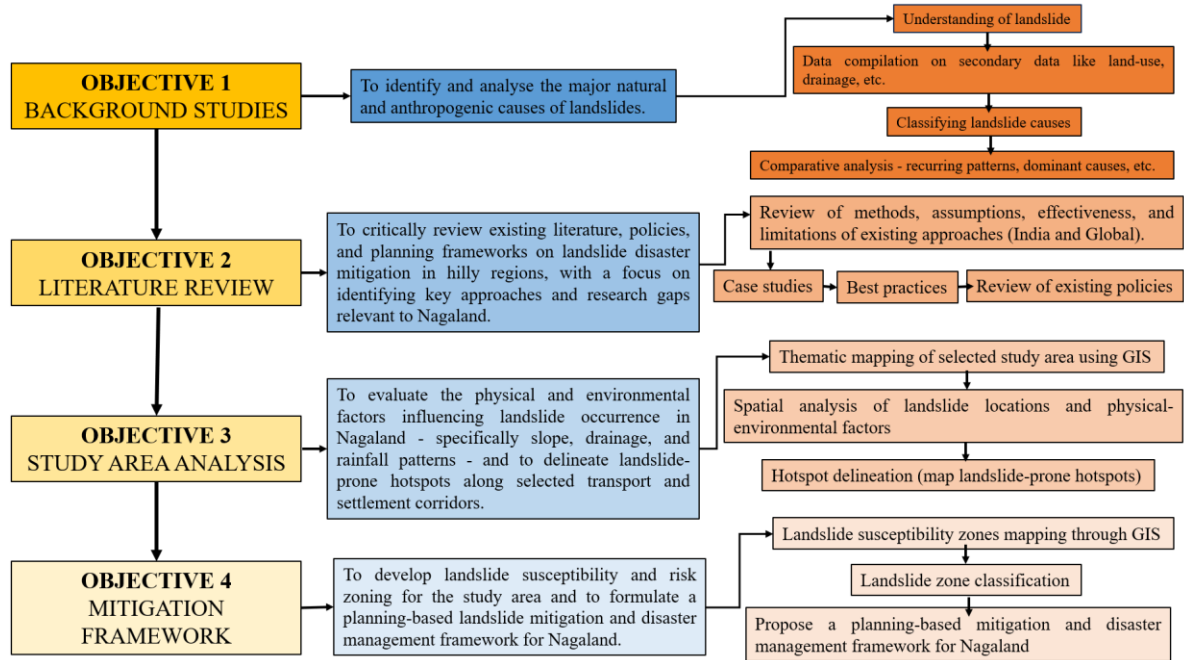
The primary analytical framework of the study is a Geographic Information System (GIS)-based methodology. Using GIS tools and remote sensing techniques, thematic maps pertaining

to infrastructure, hydrology, land use, hazard zones, and terrain characteristics will be created and merged. The study area will be divided into various landslide risk zones, including low, moderate, high, and extremely high susceptibility regions, using spatial overlay analysis and weighted parameter assessment techniques. Vulnerable settlements, important infrastructure routes, and environmentally sensitive slopes that need quick attention can all be found with the aid of the mapping and zoning process.

In order to lower the risk of landslides in urban settings, the study also develops design recommendations and mitigation techniques. Slope stabilizing techniques, green infrastructure solutions, better drainage management, restricted development laws, afforestation programs, and frameworks for disaster preparedness are some examples of suggested interventions. In order to guarantee safer and more sustainable growth in the chosen districts, recommendations will concentrate on incorporating hazard-sensitive planning techniques into urban development strategies.

However, the study's scope is restricted to GIS-based spatial analysis and the interpretation of secondary data that can be found in published literature, government reports, topographic maps, satellite imagery, and meteorological datasets. Due to time, resource, and accessibility constraints, the study does not involve sophisticated geotechnical studies such soil strength testing, subsurface geology analysis, or numerical slope stability modeling. at a similar vein, comprehensive primary surveys and field-based validation at every identified area are outside the purview of the study. Despite these drawbacks, the study intends to offer a thorough geographical understanding of landslide susceptibility and provide insightful information for sustainable development, catastrophe risk reduction, and urban planning in Nagaland's urban settlements.

1.6 METHODOLOGY



The methodology adopted for this study is designed to systematically understand the causes of landslides, analyse the physical and environmental conditions of the study area, identify landslide-prone zones, and formulate suitable mitigation and planning strategies for the urban areas of Dimapur, Chumoukedima, and Kohima. The methodology primarily relies on GIS-based spatial analysis, thematic mapping, literature review, and interpretation of secondary data sources to assess landslide susceptibility and support planning-based disaster mitigation approaches.

Understanding the type and frequency of landslides in the chosen districts is the first step in the study. To determine the primary anthropogenic and natural factors causing slope instability and recurrent landslide episodes, preliminary background research is conducted. Government reports, published research papers, satellite imagery, remote sensing datasets, topographic maps, and meteorological records are the sources of secondary data on topography, slope conditions, drainage networks, rainfall patterns, land use, vegetation cover, settlement growth, transportation corridors, and infrastructure development. To create a thorough understanding of the environmental and developmental characteristics of the research area, these datasets have been assembled and arranged.

To categorize the causes of landslides and spot recurrent trends in the area, the gathered data is analyzed. Examined in connection with landslide incidents include natural elements such

steep topography, heavy monsoonal rainfall, soil erosion, poor geological conditions, and insufficient drainage. In order to comprehend their role in slope failure and land degradation, anthropogenic activities such as hill cutting, road widening, unplanned urban growth, deforestation, quarrying, and poor construction techniques are simultaneously examined. The primary causal elements and spatial correlations between environmental conditions and landslide incidents in the chosen urban regions are determined through comparative analysis. To comprehend current methods and planning techniques for landslide hazard management and disaster prevention, a thorough examination of the literature is conducted. To analyze approaches used in landslide-prone areas, a number of national and international case studies, government policies, planning rules, scholarly publications, and disaster management frameworks are critically examined. The evaluation focuses on evaluating the efficacy, presumptions, constraints, and suitability of various planning interventions and mitigation strategies. In order to find gaps and opportunities pertinent to the study region, current policies concerning land use control, slope management, environmental protection, infrastructure development, and disaster preparedness are also studied. To develop planning strategies appropriate for Nagaland's urban setting, best practices from areas dealing with comparable topographical and climatic issues are examined.

Thematic mapping and geographical analysis using Geographic Information Systems (GIS) and remote sensing techniques constitute the methodology's central analytical component. To evaluate the environmental and physical factors affecting landslide susceptibility, several theme layers are created utilizing the spatial information that are currently accessible. Slope, elevation, drainage density, rainfall intensity, land use and land cover, transportation networks, vegetation cover, and settlement distribution are some of these thematic layers. The link between these variables and the frequency of landslides in the research area is investigated using spatial analysis techniques.

Hotspots that are prone to landslides are identified and delineated using overlay analysis and weighted evaluation techniques. Highly vulnerable areas are those with steep slopes, inadequate drainage, substantial built-up development, plant loss, and large rainfall concentrations. Thematic maps produced by GIS aid in understanding the impact of anthropogenic and physical causes on slope instability as well as the spatial distribution of hazard-prone locations. Landslide susceptibility zoning maps, which categorize the research region into low, moderate, high, and extremely high susceptibility zones, are created based on the combined analysis of all thematic characteristics.

A planning-based framework for disaster management and landslide mitigation is developed for the chosen districts using the results of spatial analysis and hotspot identification. To lessen the risk of landslides and increase urban resilience, appropriate mitigation strategies and planning interventions are suggested. Slope stabilizing techniques, drainage enhancement systems, afforestation and green infrastructure development, controlled development laws, hazard-sensitive land use planning, and disaster preparedness plans are some of these recommendations. The goal of the recommendations is to include catastrophe risk reduction concepts into infrastructure development and urban planning procedures.

This study's methodology mostly relies on secondary data interpretation and GIS-based analysis. Due to time, accessibility, and resource constraints, detailed field validation, numerical slope stability modeling, and advanced geotechnical studies are outside the purview of this work. Nonetheless, the chosen approach offers a methodical and scientifically supported framework for comprehending landslide susceptibility, identifying urban areas that are at risk, and suggesting sustainable design solutions for disaster mitigation in Nagaland.

1.7 LIMITATIONS OF THE STUDY

- The study is limited to three districts of Nagaland i.e; Dimapur, Chumoukedima, and Kohima.
- The analysis largely depends on secondary data sources such as government reports, GIS datasets, news, and previous research studies. Limited availability of high-resolution and long-term primary data on rainfall, soil properties, and slope stability may affect the precision of susceptibility and risk assessment.
- Field verification is constrained due to difficult terrain, dense vegetation, and adverse weather conditions during the monsoon season, which restricts extensive on-site investigations. Additionally, the dynamic nature of environmental factors such as land-use change, infrastructure development, and climate variability may influence landslide behaviour over time, limiting the long-term applicability of the findings.
- Time and resource constraints restrict the use of advanced geotechnical testing and real-time monitoring, and the study therefore emphasizes planning-based and environmental mitigation strategies rather than detailed engineering design solutions.

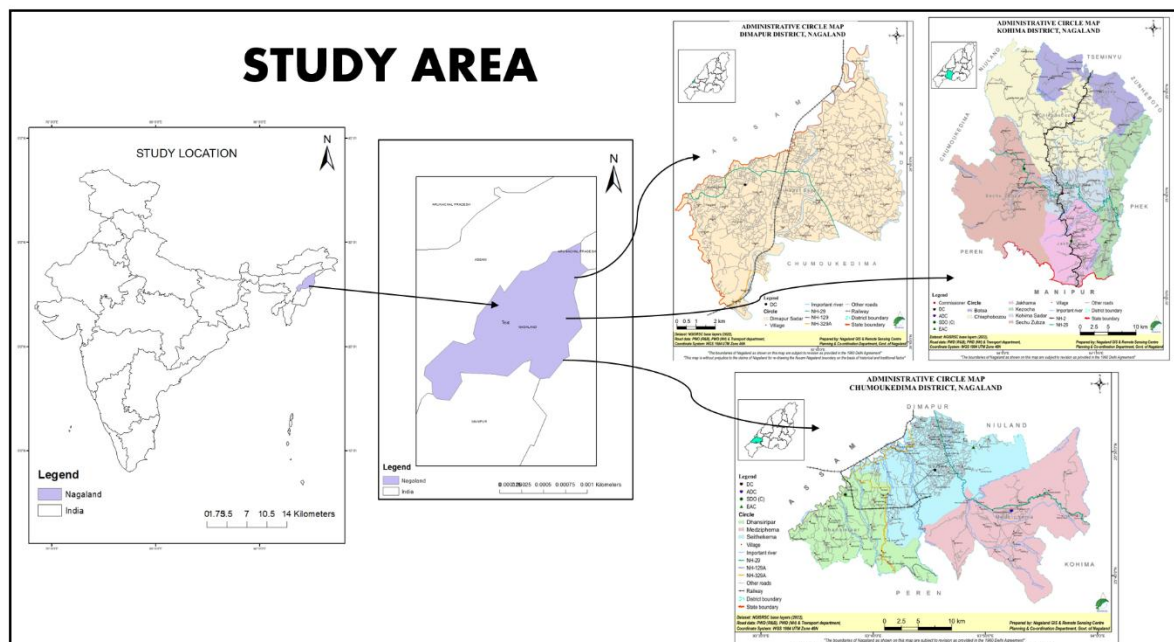
1.8 EXPECTED OUTCOMES

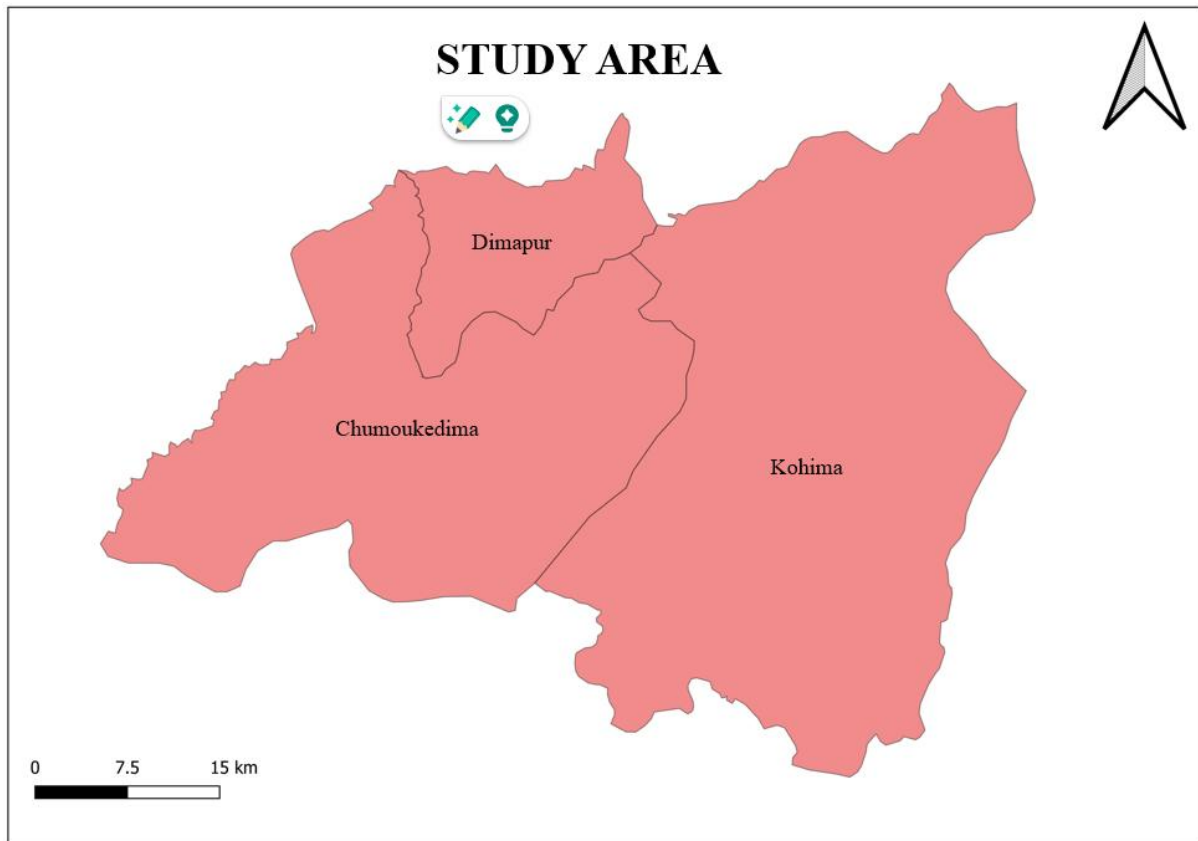
The study is expected to identify landslide-prone hotspots along selected corridors in Nagaland, particularly the NH-29 stretch between Chumoukedima and Kohima. It will improve knowledge of important environmental and human-caused elements that lead to landslides, such as road cutting, drainage failure, slope conditions, rainfall intensity, and geological features.

Landslide susceptibility and risk zoning maps that categorize regions into high, moderate, and low-risk zones will be produced by the study. There will also be an identification of several landslide typologies, such as drainage-related landslides, road-cut failures, and slides caused by rainfall.

The results will be used to provide planning-oriented and corridor-specific mitigation methods, with an emphasis on land-use management, drainage enhancement, and slope stabilization. All things considered, the study will help create a useful framework for managing landslide disasters that promotes safer infrastructure planning, wise decision-making, and sustainable development in Nagaland's mountainous areas.

1.9 MAP





1.10 BACKGROUND STUDY

1.10.1 Geographic and Geological Profile

Nagaland covers an area of 16,579 sq. km with elevations ranging from 194 m to 3,840 m above mean sea level. The state is part of the Indo-Myanmar orogenic band, which is defined by intricate fold structures, shear zones, and thrust faults. Shale, phyllite, schist, sandstone, and limestone are the most common rock types; many of these are extremely vulnerable to weathering and mass movement when saturated. Lateritic and colluvial soils with low cohesion, high flexibility, and weak bearing capacity on steep slopes often make up the soil profile.

1.10.2 Climate and Rainfall

The state experiences a humid subtropical monsoon climate with most rainfall concentrated between May and October. Districts like Tuensang, Phek, and Zunheboto receive 2,500–3,500 mm a year. Debris flows, deep-seated rotational failures, and shallow translational slides are frequently caused by intense rainfall events of more than 100 mm per day. By 2050, intense

rainfall intensity in northeast India is expected to increase by 10–15% due to climate change (Krishnan et al., 2020), increasing the danger of landslides in the future.

1.10.3 Seismicity

According to the Bureau of Indian Standards, Nagaland is completely contained inside Seismic Zone V, which is the greatest hazard zone in India (BIS IS 1893:2016). Because seismic shaking reduces soil cohesiveness and pore-water pressure stability, it can result in co-seismic landslides even during dry intervals. Both the 2011 Sikkim earthquake and the 1988 Bihar-Nepal earthquake showed how similar geological regimes are affected by cascading landslides.

1.10.4 Human Factors

Four major anthropogenic drivers exacerbate landslide risk in Nagaland:

- **Road Cutting:** Every monsoon, thousands of roadside slopes are caused by more than 14,000 km of roads, the majority of which were built using improper cut-and-fill techniques with insufficient slope stability.
- **Deforestation:** Over the past three decades, encroachment, wood extraction, and jhum (shifting) cultivation have reduced the amount of forest cover in certain districts by 25–40% (Forest Survey of India, 2023).
- **Unplanned Settlements:** Without a geotechnical study, urban growth in Kohima, Dimapur, Mokokchung, and other places has forced people to live on steep, unstable hillsides.
- **Agricultural Terracing:** Soil saturation and slope instability are increased by poorly built terraces lacking subsurface drainage.

1.10.5 Socio-Economic Impact

Excluding long-term productivity loss from agricultural land degradation and displacement, landslides in Nagaland are expected to inflict yearly economic losses of INR 200–500 crore. Every year, hundreds of people are displaced and between 30 to 40 people die as a result of landslides. Records from the Nagaland State Disaster Management Authority (NSDMA)

show a steady rise in the frequency of landslides over the previous ten years, which is correlated with increased rainfall and growing road networks.

2. LITERATURE REVIEW

One of the most destructive natural disasters in the world, landslides cause a great deal of property damage, infrastructure disruption, and fatalities each year. A complex interaction of topographical, hydrological, geological, and human variables determines their existence. Particularly in emerging nations, the quick spread of settlements into hilly and mountainous areas has increased exposure to and vulnerability to landslide threats.

Strong frameworks for mitigation, a methodical grasp of the processes, and a trustworthy evaluation of susceptibility and hazard are all necessary for the effective management of landslide risk. Geographic Information Systems (GIS), Remote Sensing (RS), and sophisticated statistical and machine learning methods have revolutionized the discipline over the last thirty years, making it possible to create previously unfeasible large-scale susceptibility and hazard maps.

The results of papers covering foundational classification frameworks, regional and national susceptibility mapping, GIS and RS-based inventory techniques, rainfall-induced landslide analysis, early warning systems, and integrated risk management guidelines are summarized in this review of the literature. Given the severe landslide issue in the area, studies concentrating on the Indian Himalayan context receive particular attention. In order to emphasize methodological evolution, scale issues, important contributing elements, and research gaps, the review is arranged thematically.

A hierarchy of causative components, roughly categorized as preparation, triggering, and governing variables, is identified in the scientific literature on landslide initiation. Over geological timeframes, the preconditions for instability are created by preparatory elements such as land usage, soil type, slope gradient, and geological structure. The initial impetus for failure is imposed by triggering conditions, which are mainly heavy or prolonged rainfall and seismic ground motion. The relative weight of preparation and triggering variables is modulated by controlling elements including slope geometry, vegetation cover, and drainage infrastructure.

The current study's weighted overlay results, which give slope a 22% relative weight in the susceptibility model, corroborate Bhushan and Sah's (2010) findings that slopes greater than 35° in lithologically weak formations represent the highest-order preparatory condition in the Indian Himalayan context. The NDMA's Technical Guidelines on Landslide Hazard Zonation (2009) and Sengupta et al. (2010) have provided significant documentation on the function of rainfall intensity thresholds in causing shallow translational slides in the northeastern Indian hills. The Early Warning System's suggested alert thresholds are directly influenced by these studies' identification of 24-hour antecedent rainfall over 100–150 mm as a crucial threshold for debris-flow onset in colluvial slopes.

A statistically significant spatial link between mapped failure locations and proximity to structural lineaments was found when geological control on landslide occurrence in the Naga Hills was investigated. This result is in keeping with both the observed north-south linear corridors of high susceptibility in the LSI map and the current study's 8% weighting of lineament density in the susceptibility model.

2.1 National and International Case studies

2.1.1. Uttarakhand Landslide Response and NH-58 Slope Management (India)

The most important impetus for comprehensive landslide disaster management reform in India was the 2013 Kedarnath tragedy in Uttarakhand, which killed over 5,000 people and devastated vital infrastructure in the Mandakini and Alaknanda valleys. Extreme rainfall, deforestation, uncontrolled construction in valley floors, and the lack of early warning infrastructure all played compounding roles in turning a geological event into a humanitarian disaster, according to post-event analysis conducted by the Geological Survey of India and NDMA (NDMA, 2014; GSI, 2014). The direct institutional response to this incident was the creation of the National Landslide Risk Mitigation Programme (NLRMP) and the installation of MEMS-based monitoring devices at 23 locations in Uttarakhand.

A technically relevant case study for the NH-29 measures suggested in this thesis is the slope management program along NH-58 (Rishikesh-Badrinath Highway) carried out by the NHIDCL and Border Roads Organization (BRO) between 2015 and 2022. A 58% decrease in road closure incidents due to slope collapses was recorded as a result of the program's installation of gabion retaining walls at 47 places, deployment of SDA systems at 12 high-risk

cut slope faces, and establishment of drainage improvements throughout a 210 km corridor (NHIDCL, 2022). The implementation framework's cost-benefit assumptions are informed by these performance results.

2.1.2 Manipur NH-37 and NH-53 Landslide Management (India)

The geological and institutional backdrop of Manipur's Imphal-Jiribam Highway (NH-37) and Imphal-Moreh Highway (NH-53) is very similar to that of Nagaland's NH-29 corridor. Both roads cross the Indo-Burman fold-thrust area, which has similar rainfall patterns, flysch and ophiolite cycles, and a similar socioeconomic reliance on road communication. The 2019 Landslide Disaster Management Plan (SDMA Manipur, 2019) of the Manipur SDMA offers a directly applicable policy reference for the recommendations of the current study, especially with regard to the establishment of pre-positioned SDRF nodes along crucial corridors and the integration of District Disaster Management Authority (DDMA) coordination in emergency road management.

The identification of 24-hour rainfall thresholds of 80–120 mm as evacuation triggers for cut slopes above settlements (consistent with ARG alert thresholds proposed in Chapter 5); the documented efficacy of Bhutan grass (Vetiver) intercropping with timber species in slope revegetation programs; and the experience that community-based awareness programs, when carried out in collaboration with village councils, achieve significantly higher compliance with evacuation advisories than top-down government communications alone.

2.1.3 Himachal Pradesh MEMS Early Warning System (India)

The most technically advanced domestic precedent for the monitoring system suggested in this study is the installation of MEMS-based landslide monitoring nodes in the Kinnaur-Spiti corridor and along the Manali-Leh Highway (NH-3) by IIT Mandi in cooperation with NDMA between 2018 and 2023. released a thorough technical analysis of 15 installed nodes, revealing mean warning lead durations of 4.2 hours for slow-moving rotating slides and 23 minutes for debris-flow incidents. The system architecture is exactly the same as the system specification in Chapter 5. It consists of MEMS accelerometers, soil moisture sensors, piezometers, and tipping-bucket rain gauges connected via a cellular IoT gateway to a cloud-based dashboard. Crucially, the institutional difficulties in maintaining systems in remote areas, such as high staff turnover rates among technical operators, GSM connectivity gaps in deep valley

topography, and battery failure during monsoon power outages. The maintenance guidelines and GPRS/4G redundancy requirements included in the suggested monitoring system design for Nagaland are directly influenced by these difficulties.

2.1.4 Nepal: Community-Based Landslide Early Warning (International)

Developed under the National Society for Earthquake Technology-Nepal (NSET) and funded by UNDP, Nepal's community-based landslide early warning program offers a globally recognized model for combining technical monitoring with community response capability. The initiative uses a hybrid strategy that combines automated rainfall threshold notifications with low-cost wire extensometers and visual slope monitoring by trained village observers in 16 watersheds in the districts of Jajarkot and Karnali. According to Petley et al. (2007) and UNDP Nepal (2014), over a five-year period, the program achieved zero landslide fatalities in monitored catchments, compared to a national background rate of 40–80 deaths annually per catchment. The village-level preparedness elements of the Disaster Preparedness Framework closely relate to the community ownership model and the function of village-level disaster management committees as first responders.

2.1.5 Japan: Multi-Hazard Early Warning and Slope Monitoring (International)

The integrated approach to slope management on national highways in Japan, which is managed by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), should be contrasted with the proposed NH-29 monitoring system. The Japanese method combines fixed sensor networks (such as rain gauges, tensiometers, and borehole inclinometers) and InSAR satellite surveillance with centralized data administration at prefectural disaster protection centers. The Tokyo Metropolitan Government's experience of a 67% reduction in slope-failure fatalities over two decades of systematic monitoring investment provides the best proof of the long-term advantages of the monitoring infrastructure recommended in this study (Tokyo Metropolitan Government, 2019).

The Japanese approach also emphasizes how important institutional continuity—maintaining monitoring mechanisms and retaining skilled operators—is to a system's long-term effectiveness.

2.1.6 Hong Kong Slope Safety System (International)

Hong Kong's Geotechnical Engineering Office (GEO) has one of the largest slope safety management systems in the world, with approximately 57,000 registered man-made slopes under a systematic risk management framework (GEO, 2021). A site-specific quantitative risk assessment for high-consequence slopes, a required slope maintenance catalogue, and a 24-hour alert and monitoring system linked to the Hong Kong Observatory's rainfall warning service are all part of the program. This study is particularly relevant to Hong Kong's experience with bioengineering slope cover restoration: GEO's documentation of hydroseeding and native species planting programs demonstrates measurable reductions in the frequency of shallow slides on restored slopes as opposed to bare cut slopes, providing empirical support for the bioengineering recommendations.

2.2 Classification of Landslides

A solid classification system is essential for any landslide investigation. Cruden and Varnes created the most widely used process-based categorization technique, classifying mass movements based on the type of material (rock, debris, earth) and the type of movement (fall, topple, slide, spread, flow). This methodology helps identify landslides induced by earthquakes and precipitation, facilitates the creation of systematic inventories, and supports hazard zonation. It also established activity states and velocity classes to help planners and legislators understand risk.

Furthermore, D.J.'s study on Slope Movement Types and Processes provides a global and conceptual scale viewpoint covering the range from slow creep to catastrophic failures.

This study supports GIS-based thematic and hazard mapping by guiding the appropriate choice of mitigation strategies based on movement type—a component that is still critical in contemporary practice.

2.2 Hazard Evaluation Frameworks

Operating at local, basin, and regional sizes spanning vast geographies and pilot basins, Guzzetti offered one of the most significant multi-scale frameworks for landslide hazard assessment. The study advocated affordable, non-structural disaster management strategies and developed the conceptual foundation for GIS-based hazard zonation. It highlighted how crucial it is to identify temporal and spatial variation in hazard evaluations, a problem that still exists in contemporary research.

Landslide Hazard Evaluation and Zonation Mapping in Mountainous Terrain examined macro-zonation at regional scales (1:25,000–1:50,000), with a particular focus on hill routes and towns. The methods used in highway corridor studies and urban fringe mapping are directly influenced by this work, which provides a methodological foundation for GIS-based inventory and hazard mapping in steep terrain.

2.3 Geomorphological Approach

Geomorphology, Natural Hazards, Vulnerability, and Prevention of Natural Disasters in Developing Countries offers a worldwide comparative viewpoint that is especially pertinent for countries such as India. It highlights that geomorphological mapping by itself is inadequate until combined with evaluations of social, economic, and political vulnerability by articulating the equation: Hazard + Vulnerability = Disaster. The study is a vital resource for comprehensive risk assessment in developing-country contexts since it integrates physical and socioeconomic components using geomorphological inventory, GIS, and remote sensing.

2.4 Statistical Approaches: Logistic Regression and Information Value

GIS-based Logistic Regression, Kakuda-Yahiko Mountains, Japan shows how logistic regression and bivariate statistics can be used to map landslide susceptibility at a regional scale (~105 km²) in mountainous terrain using a medium-resolution DEM (10×10 m). Slope, aspect, lithology, roadways, and lineaments are among the GIS layers used. The result is a five-class probability-based susceptibility zonation that provides a repeatable quantitative methodology

that has been extensively used in later regional investigations. Using a 25 m × 25 m grid and the Information Value (IV) statistical model, GIS Based Landslide Susceptibility Mapping expands this method to a ~549 km² regional area. Using DEM and IRS LISS-II satellite data, the analysis takes into account variables such as lithology, slope, aspect, drainage density, faults, and land use. Most importantly, the results are field-validated, highlighting the significance of ground-truthing in susceptibility evaluations. The approach can be easily applied to comparable physiographic environments in the Indian peninsula and the Himalayas.

2.5 Advanced Models: LPI, SVM, and Gaussian Process

In India's Darjeeling Himalayas, landslide susceptibility mapping is a methodological improvement above traditional statistical models. The study uses a weighted Landslide Prediction Index (LPI) model in conjunction with a GIS overlay method at a regional size (~201 km² with a 25 m × 25 m grid). Slope gradient, rainfall, seismicity, lithology, land use, and other conditioning factors are all included. Particle Swarm Optimization-Support Vector Machine (PSO-SVM) and Gaussian Process (GP) classifiers are used to validate the model. This multi-model validation strategy is a cutting-edge benchmark for Indian Himalayan research and significantly increases forecast accuracy.

2.6 Multi-Scale and Multi-Temporal RS-GIS Inventories

By working across several scales (1:25,000–1:50,000), From Landslide Inventories to Landslide Risk Assessment fills the gap between inventory collection and complete risk assessment. It uses multi-temporal, object-based RS-GIS inventories that have been tested in the Western Ghats and Himalayas. In addition to explicitly accounting for geographical, temporal, and magnitude probability—the three components of landslide hazard probability as specified by international guidelines—the methodology incorporates heuristic, statistical, and deterministic models. One of the few articles that provide a comprehensive, end-to-end approach from inventory to risk is this one.

A critical infrastructure corridor viewpoint at the national level is the main emphasis of Remote Sensing and GIS Applications in Managing Landslides along National Highways, Himalayan Regions. Using inventory analysis, danger maps, and the frequency ratio model—a bivariate

statistical method especially well-suited to settings with sparse data—it performs an event-based examination of multi-year landslide cases. The study directly relates to infrastructure resilience planning because of its focus on highway corridors.

2.7 Landslide Atlas of India

A historic national contribution, the Landslide Atlas of India uses remote sensing and GIS-based inventory mapping to include 17 states and two Union Territories. The Atlas records multi-temporal landslide events over a 24-year period (1998–2022) using high- to very-high-resolution satellite imagery, UAV data, and InSAR technology. It includes route-wise, seasonal, and event-based inventories that cover Northeast India, the Western Ghats, and the Himalayas. This thorough national baseline serves as the spatial basis for regional studies and is essential for policy-level decision-making.

2.8 NDMA Guidelines

The formal policy and operational framework for India's approach to landslide risk management at the national and local levels is provided by the National Disaster Management Authority Guidelines. It outlines a comprehensive process that includes inventory compilation, risk assessment, hazard classification, and mitigation. The guidelines place a strong emphasis on capacity building, land use regulation, and monitoring and early warning systems. The contents of this document, which is the required reference for any thesis or study in line with India's institutional framework for disaster risk reduction, support field-level implementation in all landslide-prone areas of the nation.

2.9 Rainfall-Induced Landslides in the Indian Himalayan Region

Using multi-decadal datasets from 1990 to 2019, Rainfall Induced Landslide Studies in the Indian Himalayan Region offers a thorough region-wide analysis covering the whole Indian Himalayan belt. Rainfall thresholds, landslide inventory, real-time monitoring, and early warning system (EWS) design are the main topics of the study. It provides important insights into the dependability and limitations of rainfall-threshold-based triggering models, an area of

active research given the rising frequency of extreme precipitation events linked to climate change. It does this by comparing various models, conditioning factors, and data quality issues.

2.10 Darjeeling Himalayan Studies

It demonstrates the applicability of hybrid machine learning models (PSO-SVM, GP) in the complex geological setting of the Darjeeling Himalayas—an area marked by high rainfall, seismicity, steep terrain, and intense land use pressure—and offers the most methodologically sophisticated susceptibility mapping study in an Indian context. This study's 12 conditioning elements provide a repeatable model for comparable areas.

2.11 Susceptibility → Hazard → Risk Progression

The gradual analytical framework from susceptibility mapping to hazard evaluation and finally to risk quantification is a recurring feature in the studied literature. Together, the publications provide the clearest explanation of this hierarchy. With a case study in Tegucigalpa, Honduras, Spatial Data for Landslide Susceptibility, Hazard, and Vulnerability Assessment uses GIS, remote sensing, GPS, and DEM analysis to illustrate this framework at various scales (regional to detailed). It demonstrates that all three levels of analysis are supported by the same spatial data infrastructure and integrates the susceptibility–hazard–risk continuum.

The most thorough methodological reference for practitioners is Guidelines for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning, which covers a range of minor to major landslides and artificial slopes using both qualitative and quantitative methodologies. Importantly, it integrates the four pillars of rigorous risk zoning - probability, intensity, vulnerability, and validation - and immediately links the results to land use planning, linking government and science.

2.12 National Guidelines and Institutional Framework

The institutional and operational foundation of landslide management in India is made up of the NDMA Guidelines and the risk assessment framework found in Landslide Risk Assessment

and Management. It operates at multi-scale, site-specific levels and uses GIS-based statistical and deterministic models to develop site-specific risk assessments. Among the assessed articles, it is the most comprehensive risk management reference since it incorporates monitoring, early warning, and planning controls.

2.13 Vulnerability and Social Dimensions

It explicitly include vulnerability as a component of disaster risk, expanding the analysis to take into account social, economic, and political aspects in addition to physical hazards. This is especially important for developing nations since underprivileged populations in high-risk areas are less able to adapt. shows, through a global comparison analysis, that in order for risk reduction efforts to be successful and equitable, vulnerability mapping must be used in addition to physical hazard mapping.

2.14 Key Conditioning Factors

Slope gradient, lithology, land use/land cover, rainfall/precipitation, aspect, drainage density, distance to faults, distance to roadways, and DEM-derived morphometric parameters are among the conditioning elements that consistently appear in all susceptibility and hazard mapping investigations. The study is unique in that it quantifies the relative weights of 12 factors and tests them explicitly, making it a valuable resource for factor selection in related research. As the main triggering mechanism in the Indian Himalayan Region, rainfall-related phenomena are given particular attention.

2.15 Data Sources and Technology

All of the studied studies show a distinct technological progression. Previous research mostly used medium-resolution DEMs, geological surveys, and topographic maps. More recent research makes use of multi-temporal datasets, InSAR-derived displacement data, and high-resolution satellite images (IRS, UAV). The integration of PSO-SVM and Gaussian Process models in Paper 11 and the move toward object-based image analysis (OBIA) signify a

movement toward AI/ML-assisted susceptibility mapping, which is fast becoming the industry standard.

3.DATA COLLECTION AND MAPPING

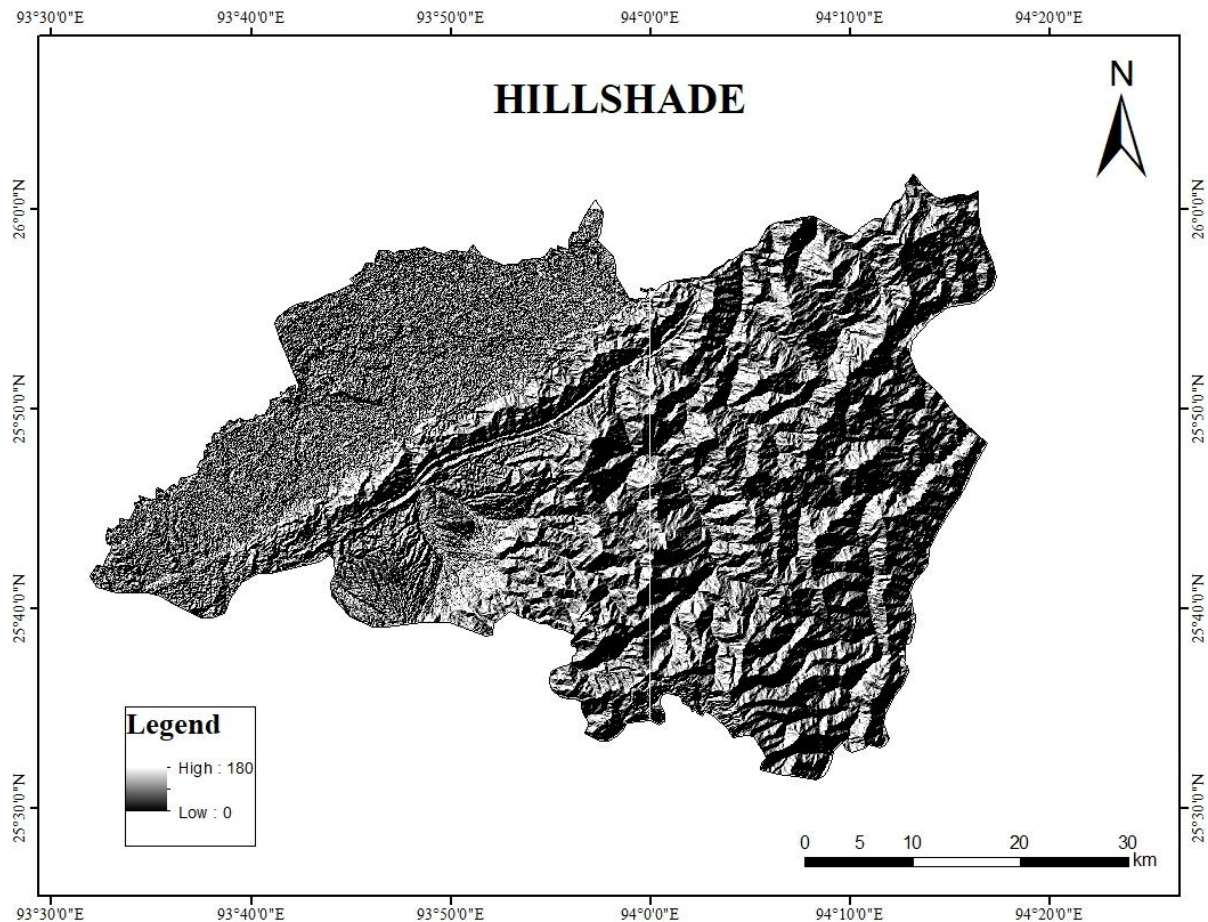
3.1 Analysis of Physical and Environmental Factors

With a focus on the NH-29 corridor, this chapter provides a thorough GIS-based analysis of the environmental and physical elements influencing landslide susceptibility throughout the study area, which includes the districts of Dimapur, Chumoukedima, and Kohima. Hillshade (terrain morphology), slope aspect, slope gradient, terrain curvature, surface contour, and yearly rainfall distribution were the six theme factors that were examined. The multi-factor basis for the landslide susceptibility evaluation is comprised of these parameters.

3.1.1 Hillshade Map

In order to recreate the illumination of terrain from a fixed sun angle and provide a three-dimensional visualization of surface morphology throughout the study region, hillshade analysis was carried out using a Digital Elevation Model (DEM). The western and eastern halves of the research region have quite different topography characteristics, according to the investigation.

LANDSLIDE DISASTER MANAGEMENT PLAN FOR NAGALAND



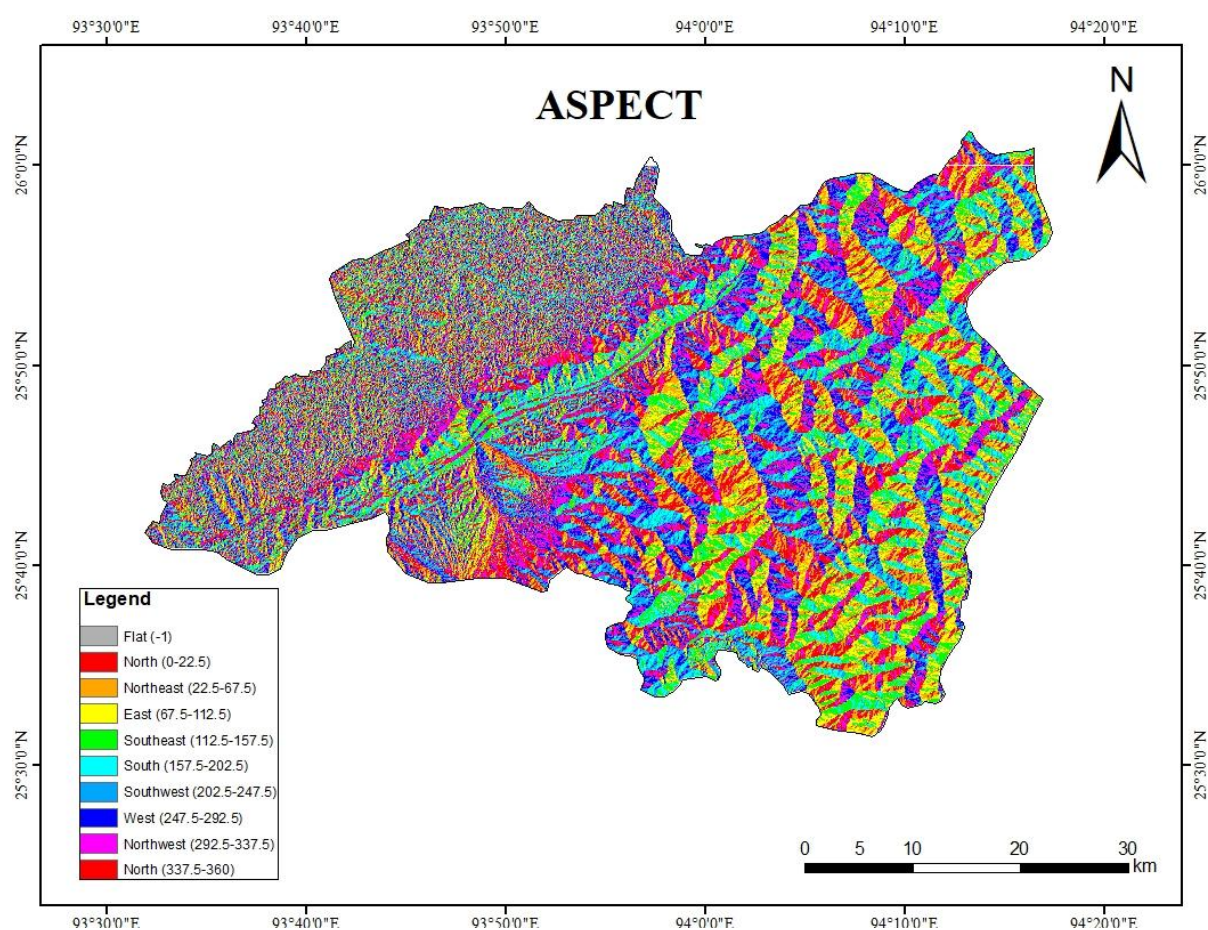
Parameter	Observation	Implication for Landslide Risk
Western Study Area (Dimapur)	Relatively flat elevated plateau with low hillshade variation	Lower mass-movement susceptibility; risk limited to drainage-related hazards
Eastern Study Area (Kohima)	Tightly packed parallel ridges; the highest topographic complexity in the study area	Maximum susceptibility zone; multiple simultaneous failure mechanisms possible
Valley Systems	Elongated valley systems cutting through terrain — natural drainage corridors	Susceptible to channelised debris flows and high-velocity runoff concentration
North/NW-facing slopes	Dark zones indicate slopes facing away from the sun — minimal solar exposure	Moisture retention enhanced; persistent saturation increases pore-water pressure
Relief Gradient	Terrain elevates steeply west to east: Dimapur ~200 m to Kohima ~1,500 m	Maximum gradient along NH-29; highest road-cut failure risk in the transition zone

The relatively benign western Dimapur plateau and the highly complicated, high-relief Kohima zone are the two separate danger domains identified by the hillshade analysis within the research region. NH-29 travels across the most morphologically active and, hence, the most hazardous terrain as it crosses the entire elevation gradient between these zones.

3.1.2. Aspect Map

Slope aspect, or the direction a slope faces on the compass, is a crucial factor in determining how much solar radiation is received, how quickly evapotranspiration occurs, and ultimately how much soil moisture is retained. North and northwest-facing slopes are especially important in landslide susceptibility studies because they get less direct solar radiation, which results in consistently higher moisture content and weaker soil.

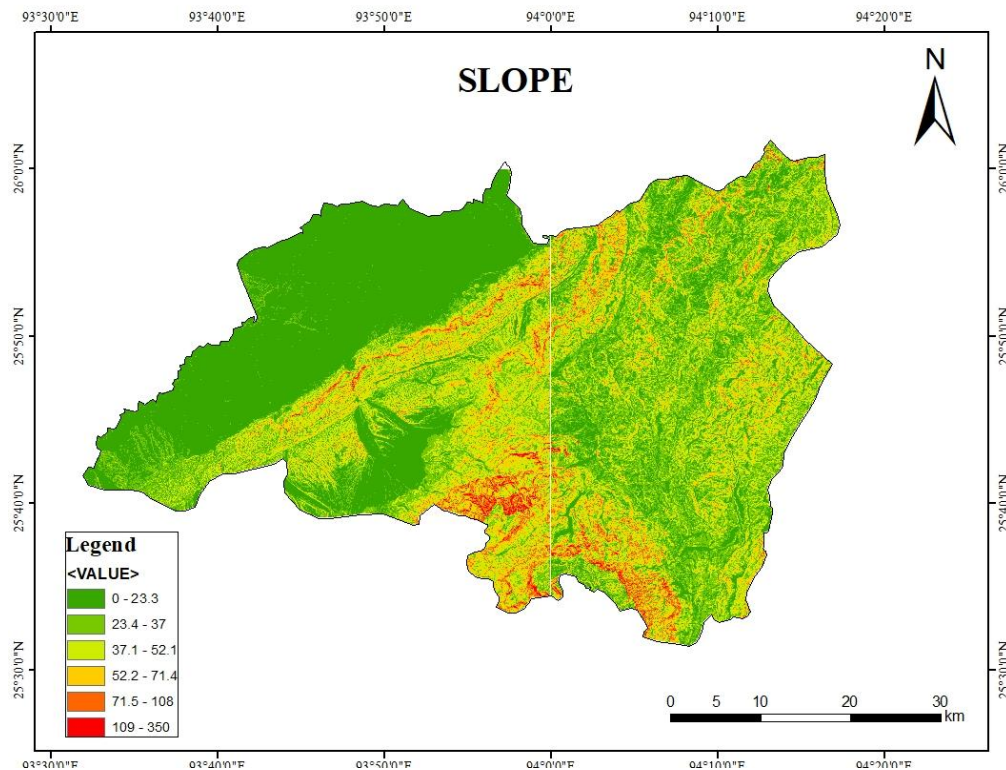
The research area's aspect distribution map confirms complicated, fragmented topography with no dominant stable orientation by displaying a highly varied, mixed pattern of aspect directions. North, Northwest, and Southwest are the predominant aspects in the Kohima district to the east, exhibiting several vulnerable orientations at once. North-facing slopes must be regarded as primary risk zones requiring priority intervention, according to this conclusion, which directly affects risk zoning.



Aspect Direction	Solar Radiation	Moisture Regime	Landslide Risk Level
North / Northwest	Low	High moisture retention; reduced evapotranspiration	High — prioritise in risk zoning
South / Southeast	High	Higher evaporation; drier slopes	MODERATE — lower wet season risk
East / Northeast	Moderate (morning sun)	Moderate moisture patterns	Moderate
West / Southwest	Moderate (afternoon sun)	Moderate to variable	Moderate

3.1.3. Slope Gradient Map

The most basic factor influencing landslide risk is slope gradient. The type of probable landslide and the necessary mitigation strategy are determined by the link between slope angle and failure type. Using DEM data, GIS-based slope analysis was carried out throughout the study region, dividing the topography into five gradient groups.



Slope Class	Gradient Range	Dominant Landslide Types	Typical Locations in Study Area
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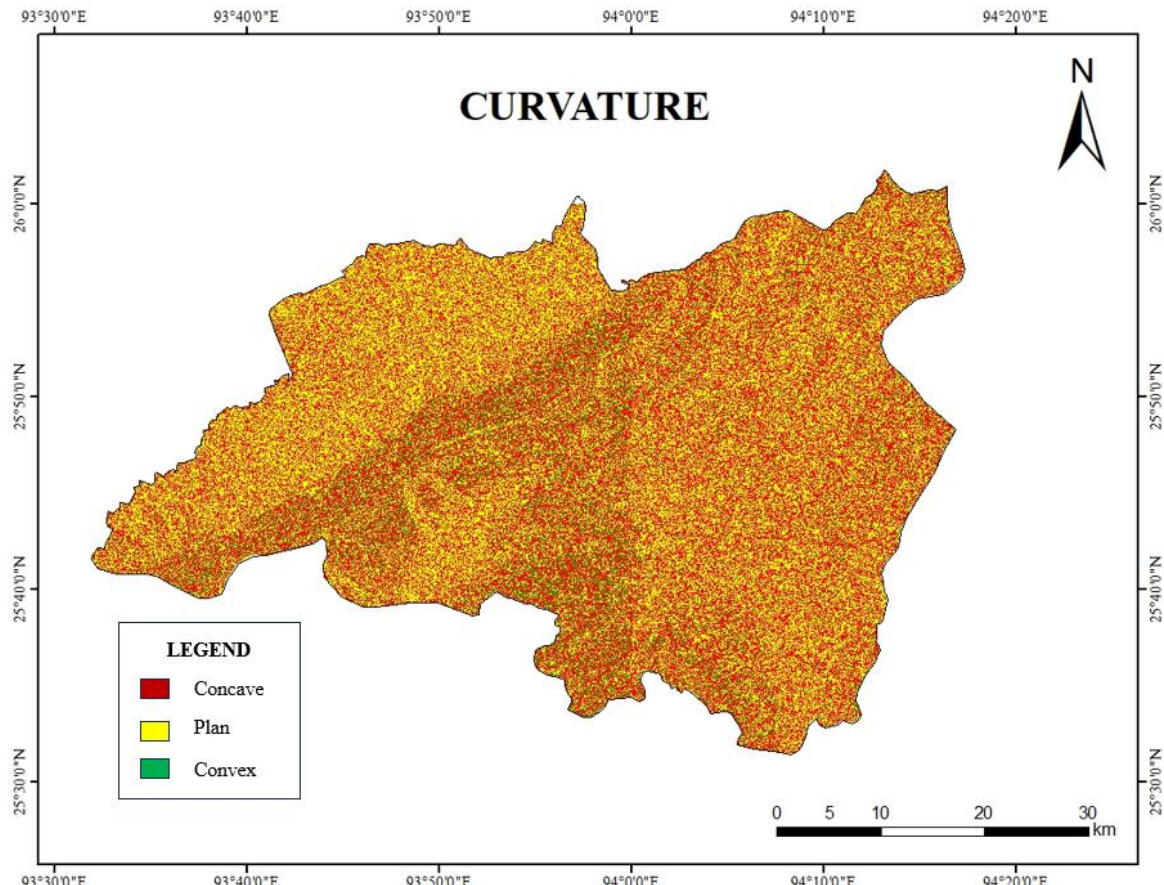
Gentle	0° – 23°	Earth flows, slumps, translational slides where drainage is impeded	Dimapur plateau; valley floors
Moderate	23° – 37°	Debris slides, translational failures, shallow rotational slumps	NH-29 lower section; lower Chumoukedima slopes
Steep	37° – 52°	Complex failures; rotational slumps; debris avalanches	NH-29 transition zone; mid-Kohima slopes
Very Steep	52° – 71°	Rockfalls, toppling; wedge failures — common on highway cut slopes	Upper Kohima; exposed cut slopes along NH-29
Near-Vertical	>71°	Free-fall rockfalls; toppling of rock blocks	Cliff faces; bridge approach cuts

The bulk of the NH-29 corridor is located in moderate-to-high susceptibility terrain, with 68–72% of it passing through slopes more than 23°, according to a crucial GIS finding from the slope research. Complex multi-mechanism failures can occur in the elevation transition zone between 200 and 1,500 meters along the roadway, which shows the fastest slope gradient changes. In all planning and zoning choices, steep contour zones that indicate gradients more than 30° should be designated as high-priority risk areas.

3.1.4. Terrain Curvature Map

Terrain curvature describes the rate of change of slope gradient across the landscape and is a critical parameter for understanding surface and subsurface water flow concentration — a primary driver of landslide initiation. Three curvature types were mapped across the study area.

LANDSLIDE DISASTER MANAGEMENT PLAN FOR NAGALAND



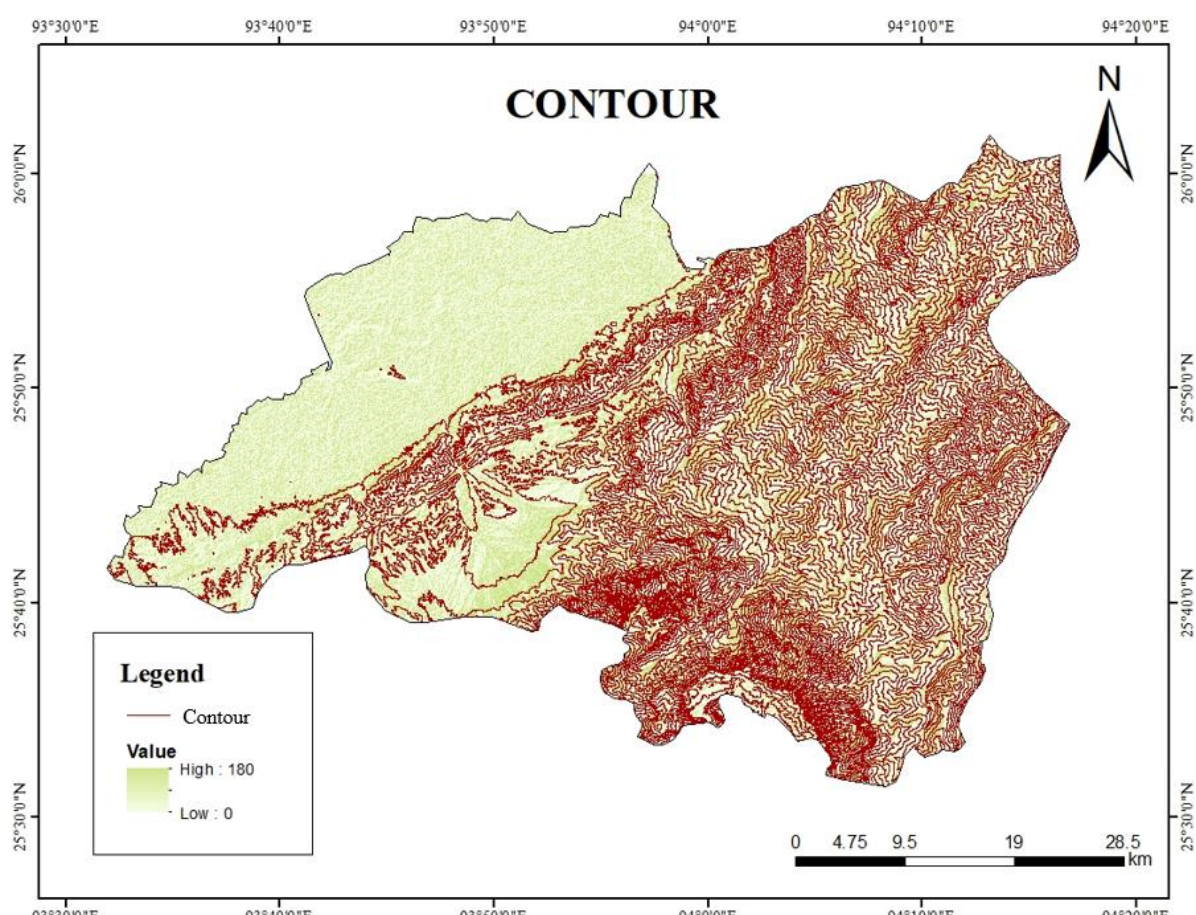
Curvature Type	Description	Hydrological Behaviour	Landslide Hazard Implication
Concave	Hollows and valley forms; terrain curves inward	Water and debris converge — high erosion and flow accumulation	Very high — debris flow initiation zones; drainage failure critical
Planar	Neutral slopes; uniform gradient	Flow moves linearly without concentration or dispersal	Moderate — failure risk depends primarily on slope gradient and geology
Convex	Ridge crests and noses; terrain curves outward	Water disperses away from the crest; less accumulation	Moderate — instability risk at ridge edges and convex break-of-slope

There are no consistently stable topography zones throughout the study area, and the curvature map shows a distinctive speckled red-yellow pattern suggestive of significant surface complexity. This is a crucial discovery because it demonstrates that danger must be viewed as ubiquitous throughout the environment rather than limited to discrete "hotspot" areas.

Throughout the studied area, valley channels contain areas with intense concave curvature. These are locations where runoff, silt, and slope failures from upslope regions come together to form debris flow accumulation corridors. Priority drainage infrastructure intervention is needed in these zones. The NH-29 transition zone is the area with the highest risk of slope failure along the highway since it has the greatest curvature fluctuation of any corridor stretch.

3.1.4. Contour Map

Contour mapping from DEM data provides a direct visualisation of terrain gradient and its spatial distribution. The contour analysis reveals two distinctly different terrain characters within the study area and defines the critical elevation transition zone that NH-29 must negotiate.



Zone	Contour Character	Gradient Implication	Risk Assessment
Dimapur Plateau (West)	Wide contour spacing	Gentler terrain; lower slope gradient risk	Low to Moderate — drainage

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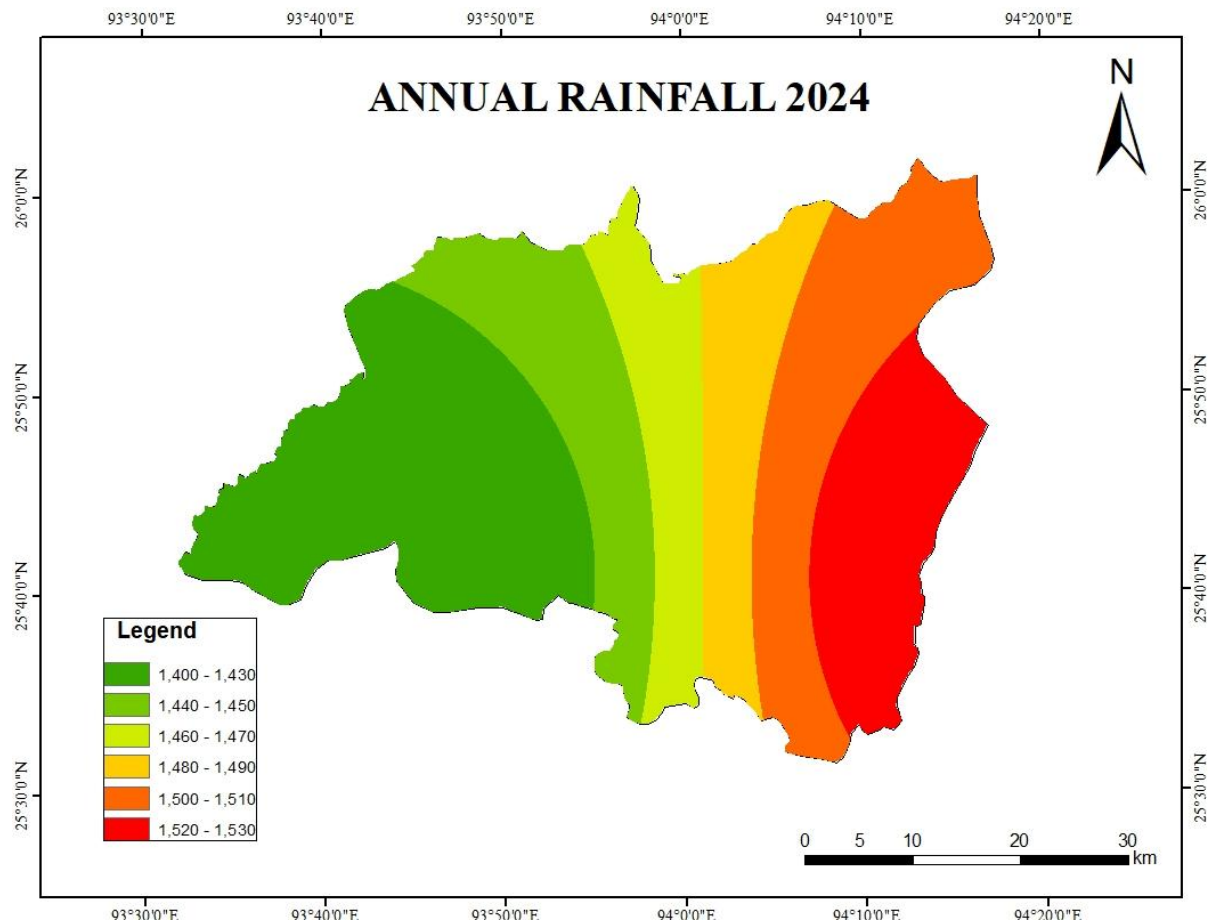
			management primary concern
Chumoukedima (Central)	Transition from wide to narrow spacing	Increasing gradient; beginning of high- risk zone	Moderate to High — road-cut management critical
Kohima District (East)	Tightly packed contours; V-patterns at valley incisions	Very steep slopes; sharp valley incision — water concentration zones	High — maximum susceptibility; priority intervention zone
NH-29 Corridor	Traverses critical elevation transition — maximum gradient change zone	68–72% of corridor on slopes > 23°	Very high along full transition from 200m to 1,500m

Sharp valley incisions—water concentration and erosion zones where surface runoff and groundwater convergence accelerate slope destabilization—are indicated by the V-shaped contour patterns prevalent throughout the Kohima zone. When planning a drainage intervention, these zones must be given top priority.

3.1.5. Annual Rainfall Map

Rainfall is the dominant triggering factor for landslides in Nagaland. Annual rainfall distribution data for 2024 were mapped across the study area, revealing a pronounced orographic gradient consistent with the topographic transition from west to east.

LANDSLIDE DISASTER MANAGEMENT PLAN FOR NAGALAND



Rainfall Class	Annual Total (mm)	Zone	Risk Implication
Class 1 (Low)	1,400 – 1,430	Western Dimapur plateau and leeward valleys	Baseline risk — other factors dominate
Class 2	1,440 – 1,450	Lower Chumoukedima	Moderate — combined slope-rainfall risk begins
Class 3	1,460 – 1,470	Mid-elevation transition zone	High rainfall combines with steep gradients
Class 4	1,480 – 1,510	Windward Kohima slopes	Very High — orographic enhancement of rainfall on steep terrain
Class 5 (High)	1,520 – 1,530	Upper Kohima — windward faces of Naga Hills	Extreme — highest combined rainfall-slope-geology risk

In several areas of Nagaland, the highest rainfall class (1,520–1,530 mm) indicates precipitation that is higher than the usual annual average, which typically falls between 1,500 and 2,500 mm in high-rainfall zones. The monsoon in 2024 was remarkable, with peak intensities that were 393% higher than usual. This extraordinary anomaly is closely related to the terrible events that occurred in July and August of 2025.

The Naga Hills' windward faces receive the most precipitation (Classes 4–5), while leeward valleys and lower plateaus receive relatively smaller totals (Classes 1–2). This geographical distribution of rainfall supports a strong orographic influence. As a result, the highest-risk areas combine maximum rainfall exposure with maximum slope steepness and most vulnerable geology; this triple convergence is centered in the upper NH-29 corridor and Kohima zone.

3.2. Key Findings from Analysis

- The Kohima district, which makes up the research area's maximal susceptibility zone, has the highest topographic complexity with closely spaced ridges and deep concave valley systems.
- The state's worst road-cut failure risk conditions are created by the NH-29 corridor's passage through an elevation transition zone (200 to 1,500 meters) with fast slope gradient change.
- The high-risk zones are dominated by slopes facing north and northwest, which hold more moisture because of lower solar radiation and evapotranspiration.
- Concave zones located along valley channels are identified by curvature analysis as pathways for debris flow accumulation, necessitating priority drainage infrastructure.
- The NH-29 corridor is categorized as moderate-to-high susceptibility terrain since 68–72% of it runs through slopes higher than 23°.
- The highest-risk areas receive 1,520–1,530 mm of rain annually; the severity of the 2024 monsoon was 393% over average.
- Because of the corridor's block-jointed, erosion-prone geology, sandstone zones are particularly vulnerable to rockfalls and debris slides.

3.3 Identification of Key Planning Issues

The analysis reveals a compounding set of planning failures that amplify the already high physical vulnerability of the study area:

Planning Issue	Evidence from Analysis	Consequence
Construction in high-susceptibility terrain	Road widening and settlement expansion continue on slopes > 30° without geotechnical assessment	Fresh, unsupported cut slopes are continuously created in maximum-risk terrain
No pre-positioned emergency response	August 2025: 72 hours for debris clearance alone at Dzüdza bridge	Complete isolation of Kohima; all supply chains disrupted
Zero mitigation planning on NH-29	Highway traverses the highest-risk elevation transition zone with no retaining walls, drainage diversion, or bioengineering	Maximum exposure on the most critical transport corridor
Absence of engineered drainage	No drainage network designed around natural flow paths identified by curvature analysis; valley channels and concave zones have no intervention	Unmanaged debris accumulation in highest-risk convergence zones
No land-use controls	No risk zoning, no slope-based building controls, no land-use restrictions in any district	Unregulated settlement encroachment into hazard zones continues unchecked
Deforestation and jhum cultivation	Steep slope deforestation reduces root cohesion and increases surface runoff velocity	Accelerated erosion and increased shallow failure frequency

3.4 Methodology: Weighted Overlay Analysis

The Weighted Linear Combination (WLC) methodology is used in a GIS system to generate the Landslide Susceptibility Index (LSI) for the research region. WLC is a type of multi-criteria evaluation (MCE) that generates a composite susceptibility score for each grid cell by multiplying separately classified and standardized parameter rasters by their corresponding analytical weights and adding the results. The mathematical formulation of the LSI is as follows:

$$LSI = \sum (W_i \times X_i)$$

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Where W_i is the normalized weight assigned to the i th parameter and X_i is the standardized value (reclassified to a uniform 1–5 scale) of that parameter at a given grid cell. The assignment of parameter weights is based on a synthesis of published literature from the Himalayan and Indo-Burman ranges, modified through expert consultation and calibration against the GSI's available landslide inventory for Nagaland.

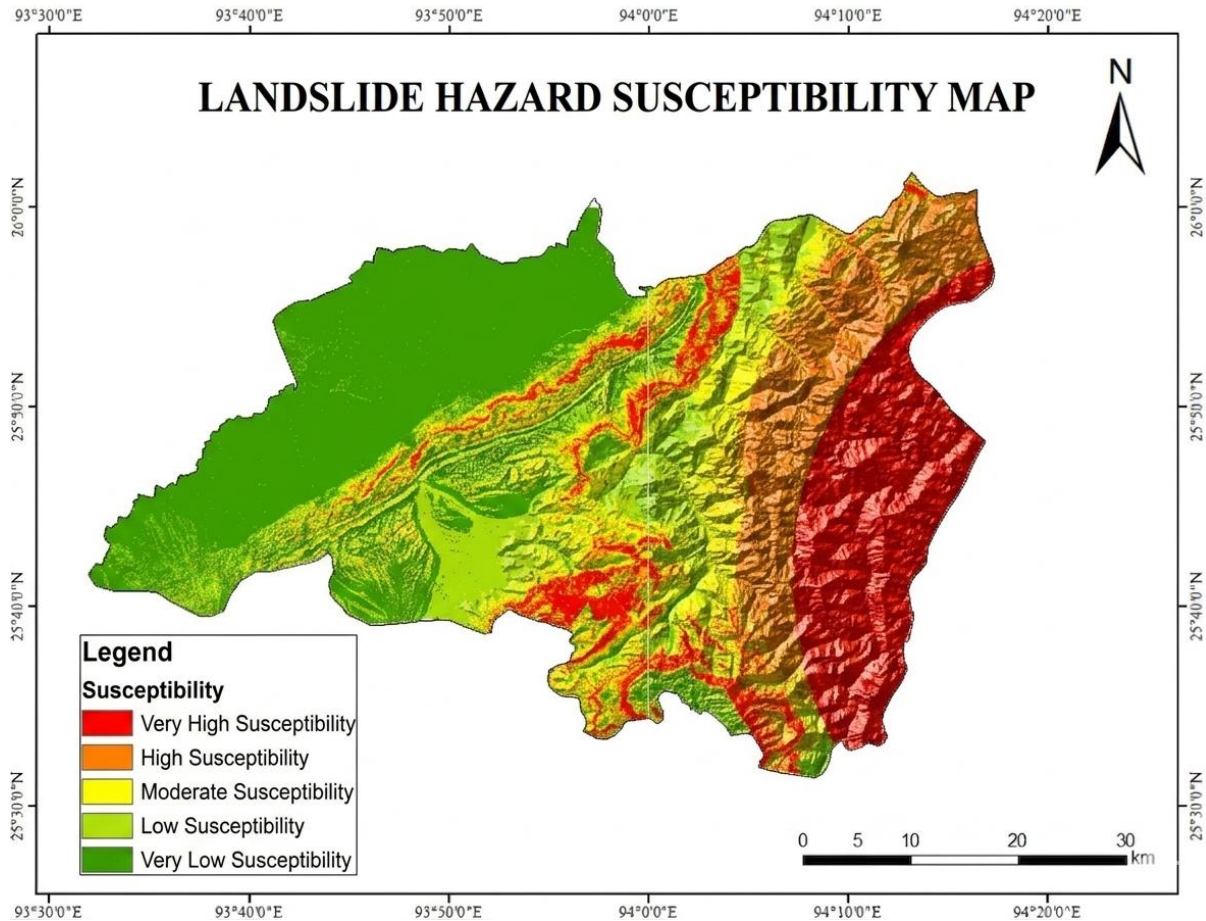


Table: Parameter Weightage for Landslide Susceptibility Index (LSI) Computation

Criteria / Parameter	Weightage (%)
Slope Gradient	22%
Geology / Lithology	18%
Annual Rainfall	16%
Land Use / Land Cover	14%
Drainage Density	12%
Structural Lineaments	8%
Road Proximity	6%
Seismic Susceptibility	4%
TOTAL	100%

Slope gradient is given the largest weight (22%), which reflects the overwhelming consensus in the literature and empirical evidence that slope angle is the main physical control on the frequency and size of mass movements in the context of the research region. Second place goes to geology and lithology (18%), which recognizes the critical role that weathering intensity and rock type play in affecting both infiltration characteristics and shear strength parameters. Annual rainfall (16%) ranks third, reflecting the triggering primacy of precipitation in the monsoon-dominated climate of Nagaland. While drainage density (12%) indicates the impact of stream incision and channel closeness on slope undercutting and lateral erosion, land use/land cover (14%) captures the important function of vegetation cover in slope hydrological and mechanical stability.

Road closeness (6%) and structural lineaments (8%), which are predisposing factors that concentrate stress and decrease slope stability margins in their immediate vicinities, are given lesser but substantial weights. While conceding that earthquake-triggered slope failures have occurred in the larger northeastern region, seismic susceptibility (4%) receives the least weight, reflecting the study area's comparatively lower seismicity in comparison to the Main Himalayan Thrust zone.

3.5 Susceptibility Zone Characterization

The application of the WLC methodology to the study area produces a continuous LSI surface that is subsequently classified into five discrete susceptibility zones using Natural Breaks (Jenks) classification, which minimizes within-class variance while maximizing between-class variance. The five resulting zones are described in detail below and summarized in the table.

Table: Landslide Susceptibility Zone Characterization and Land-Use Regulatory Framework

Zone	LSI Range	Slope	Rainfall (mm/yr)	Geology	Land-Use Regulation
Zone I (Very High)	0.75 – 1.00	>35°	>2000	Fractured shale/ophiolite	No construction; mandatory resettlement
Zone II (High)	0.55 – 0.75	25° – 35°	1600 – 2000	Weathered sandstone	Only critical infrastructure with geotechnical approval
Zone III (Moderate)	0.35 – 0.55	15° – 25°	1200 – 1600	Mixed sedimentary	Retaining walls + drainage before any excavation

LANDSLIDE DISASTER MANAGEMENT PLAN FOR NAGALAND

Zone IV (Low)	0.15 – 0.35	5° – 15°	800 – 1200	Consolidated alluvial	General development with standard drainage
Zone V (Very Low)	0.00 – 0.15	<5°	–	Stable bedrock/alluvium	No restriction

Zone I (Very High Susceptibility, LSI 0.75–1.00) includes regions where near-continuous marginal stability is created by the convergence of the most important instability conditions, which include slopes more than 35°, annual rainfall exceeding 2,000 mm, and fractured shale or ophiolitic geology. Failure in these zones can be caused by slight changes in slope geometry, slight perturbations in antecedent moisture conditions, or mild seismic events. Zone I must have the strictest land-use regulations, prohibiting new development and requiring the relocation of already-occupied structures over a suitable planning horizon.

High rainfall, steep gradients, and worn sandstone geology combine to provide increased but not extreme susceptibility in Zone II (High Susceptibility, LSI 0.55–0.75). The primary engineering problem zone along NH-29, where highway cut slopes are carved through worn sandstone with varying clay mineral composition, most closely resembles this zone. Only vital national infrastructure may be developed in Zone II, and construction approval is contingent upon the completion of required geotechnical studies, slope stability analyses, and engineering mitigation measures.

Zone III (Moderate Susceptibility, LSI 0.35–0.55) encompasses the transitional terrain between the low-risk western plains and the high-risk eastern hills, making up the biggest aerial extent of the research region (33%). This zone serves as the main location for bioengineering and drainage enhancement operations and is home to the majority of secondary residential and agricultural land use. Installing retaining structures and improving drainage should be a prerequisite for all earthworks and development in Zone III.

The Dimapur region's alluvial floodplains, terrace deposits, and regions of stable bedrock outcrop are located in Zones IV and V (Low and Very Low Susceptibility, LSI 0.00–0.35).

Although they are not immune to flooding and erosion risks from debris flow runoff from upslope high-risk zones, these zones have the lowest chance of slope failure. Standard drainage regulations apply to development in these areas, but no unique geotechnical prerequisites are needed.

3.6 Population and Infrastructure Exposure

The LSI zonation is overlaid with census settlement data, infrastructure network layers, and population distribution grids to quantify the exposure of people, settlements, and critical infrastructure to each susceptibility class. The results, summarized in following table, reveal a stark pattern of concentrated vulnerability in the high-risk zones of the Kohima district.

Table: Population and Village Exposure by Landslide Susceptibility Zone

Risk Zone	Area (%)	Population Exposed	No. of Villages	Key Characteristic
Very High (Zone I)	14%	~1.8 lakh	142	Fractured slopes, >2000 mm rainfall
High (Zone II)	28%	~2.4 lakh	245	Weathered sandstone, steep terrain
Moderate (Zone III)	33%	~6.1 lakh	389	Mixed geology, moderate slopes
Low (Zone IV)	16%	~8.4 lakh	610	Alluvial terrain, gentle gradients
Very Low (Zone V)	9%	~3.5 lakh	180	Stable bedrock, flat topography

The most important exposure finding is that over 42% of the mapped area, which includes Zones I and II, is classified as High or Very High susceptibility. An estimated 4.2 lakh people from 387 villages in Zones I and II are at increased risk of landslides. Due to the exclusion of people living in Zone III areas that are close to Zone I and II boundaries and may be impacted by long-runout landslide deposits, this statistic significantly underestimates actual exposure. From the standpoint of infrastructure exposure, the NH-29 corridor is the state's most critical infrastructure vulnerability, passing across Zone I and Zone II terrain for an estimated 42 km of its 74 km overall length.

The Medziphema-Zubza-Chiephodozou sub-reach, which has the highest density of roadside villages due to slope gradients, geological fragility, and heavy rains, corresponds to the highway stretches most severely exposed. Secondary roads that lead to sub-divisional offices and district headquarters often pass through Zone I terrain and are devoid of slope protection measures.

In line with the structural control of the Naga Thrust and related fault-parallel lineaments seen in the geological mapping, the pattern of susceptibility zones shows a north-south linear direction. Because of this structural alignment, the most dangerous terrain is arranged into

predictable corridors that can be methodically targeted for monitoring and mitigation investments rather than being dispersed at random. The susceptibility model's forecast accuracy is validated by the fact that more than 85% of historical landslide events in the GSI inventory plot fall into either Zone I or Zone II.

4. PROPOSALS

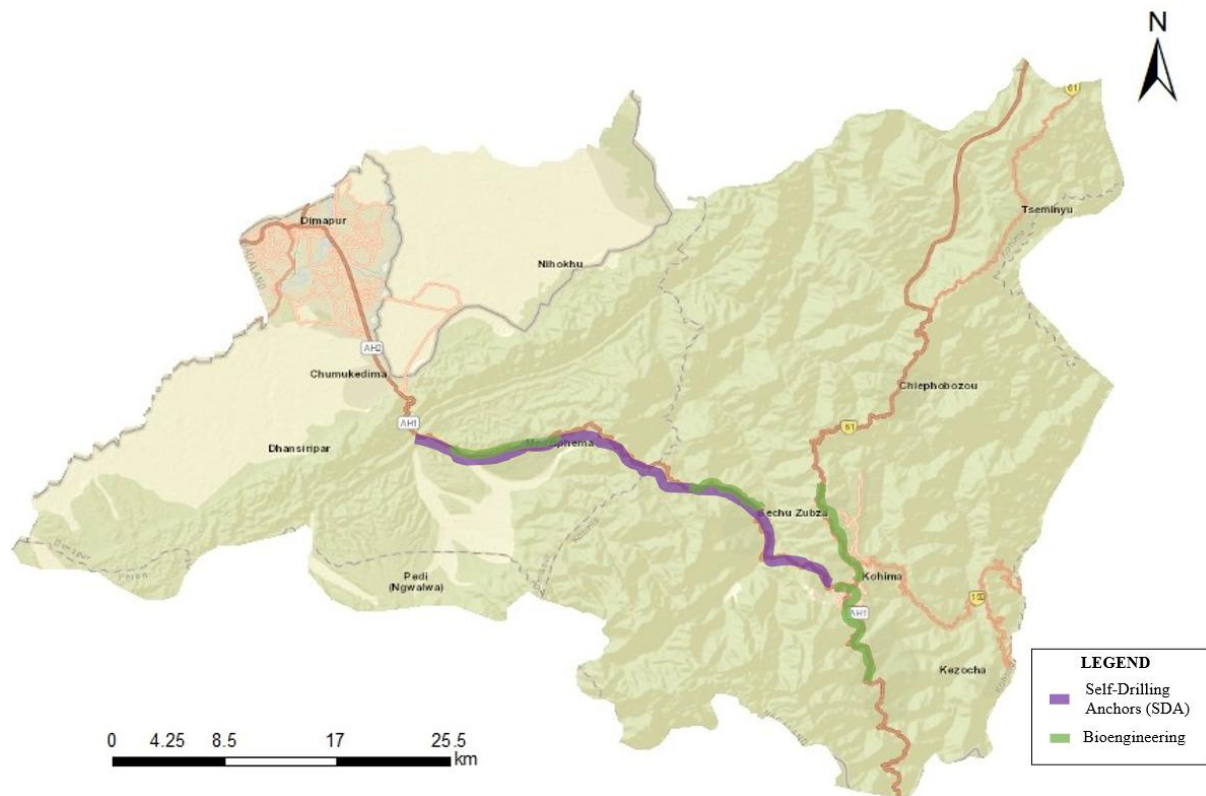
4.1. SLOPE STABILIZATION TECHNIQUES

A multi-tiered engineering and ecological response is necessary for slope stabilization along the NH-29 corridor, matching the type of intervention to the unique failure mechanism, geological substrate, and right-of-way constraints at each site. The study's suggested slope stabilization program combines four complementary methods: geosynthetic reinforcement for embankment reconstruction, bioengineering using native plant species for moderate-risk and revegetation applications, gravity retaining structures using gabion wall systems, and structural anchoring using Self-Drilling Anchors (SDA). The highest-risk cut slope faces directly above the highway carriageway will be given priority as the program is phased over a 24-month period.

A variety of engineering techniques are included in slope stabilization, which aims to raise a slope's Factor of Safety (FoS) against failure. The main methods that apply to Nagaland are: (a) Soil Nailing; (b) Rock Bolting; (c) Ground Anchoring; (d) Slope Regrading (terracing/benching); (e) Geosynthetic Reinforcement; and (f) Micropile Installation.

4.1.1 Geosynthetic Reinforcement

Within compacted fill slopes or new embankments, High-Strength Geogrids (polyester or HDPE, Ultimate Tensile Strength > 50–200 kN/m per ASTM D6637/ISO 10319) are positioned at predetermined vertical intervals. In order to avoid soil migration into drainage layers due to the extremely saturated conditions in Nagaland, geogrids are paired with geotextile separators (non-woven polypropylene, minimum 200 g/m² CBR ≥ 1.5 kN per ISO 12236).



4.1.2 Effectiveness, Advantages, and Limitations

- Effectiveness: Soil nailing and shotcrete have proven ability to raise FoS by 0.3–0.8 in typical cut slopes. Rock bolting prevents kinematic rock failures effectively when discontinuity analysis is accurate.
- Advantages: Minimal disturbance of existing slope geometry; adaptable to complex topography; can be implemented in confined right-of-way (RoW); relatively rapid execution.
- Limitations: Requires skilled geotechnical engineers and specialized drilling equipment (limited in Nagaland); grouted nails may fail if soil is highly organic or contains swelling clays; ineffective against deep-seated rotational failures without integration with drainage.

Along the national and state highway cut slopes in Nagaland, where a narrow RoW precludes other possibilities, soil nailing is very relevant. In Nagaland's colluvial and disturbed soils, where traditional drill-and-grout techniques frequently fail owing to borehole collapse, SDA (Self-Drilling Anchors) technology is particularly well suited. It is possible to mobilize

equipment from Dimapur or Guwahati. Within six to twelve months, local contractors can be trained in basic soil nailing installation.

4.1.3 Approximate Implementation Cost

Technique	Unit	Estimated Cost (INR)	Source/Reference
Shotcrete Facing (fibre-reinforced)	Per sq. meter	INR 1,200–2,500/m ²	IRC:SP:48, contractor rates
Rock Bolting (grouted)	Per bolt (3–6 m)	INR 8,000–18,000/bolt	BRO project data
Geogrid Reinforced Slope	Per sq. meter of face	INR 800–2,000/m ²	Tensar, Tencate market rates
Typical 100 m cut slope treatment	Complete stabilization package	INR 50–120 lakh	Composite estimate

4.1.4 Funding Sources and Government Schemes

- National Highways and Infrastructure Development Corporation (NHIDCL): Capital works on NHs in Northeast India.
- Border Roads Organisation (BRO): Strategic road stabilization under Project Vartak and Project Pushpak.
- State PWD / Nagaland Roads & Bridges Development Corporation (NRBDC): State highway stabilization.
- PMGSY (Pradhan Mantri Gram Sadak Yojana): Rural road stabilization through green technology components.
- NDMA Guidelines on Landslide Hazard Mitigation (NDMA, 2009): Central allocation via State Disaster Response Fund (SDRF) and NDRF.
- World Bank – National Disaster Risk Management Programme (NDRMP): Technical and financial assistance for hazard mitigation DPRs.
- Asian Development Bank (ADB) – North East Road Network Connectivity Improvement Project: Active in Northeast India.

4.1.5 Stakeholders Involved

- Primary: Department of Public Works (PWD), NHIDCL, BRO, Nagaland State Disaster Management Authority (NSDMA)

- Technical: Central Soil and Materials Research Station (CSMRS), National Geotechnical Facility (NGF) Dehradun, IIT Guwahati, NIT Nagaland
- Local: Village Councils (Gaon Burahs), Naga Mothers' Association (NMA), District Disaster Management Committees
- Private Sector: Geotechnical contractors (Maccaferri India, Keller Ground Engineering, Bauer India), materials suppliers.

4.1.6 Maintenance and Long-Term Sustainability

The nail heads, bearing plates, and drainage weepholes of soil nail and anchor systems must be inspected every year. Every two years, shotcrete facing needs to be examined for detachment, spalling, or cracking. Every five years, lift-off testing should be used to confirm the grouting integrity of anchors. 2–5% of the initial capital cost is the estimated yearly maintenance cost. The relevant PWD division is required by IRC:SP:48 to maintain a specialized slope maintenance record.

4.2 RETAINING WALLS AND GEOTECHNICAL STRUCTURES

Retaining structures provide direct mechanical resistance to slope movement by supporting unstable soil or rock masses. The most applicable types for Nagaland's conditions are: (a) Gabion Walls, (b) Reinforced Earth/MSE (Mechanically Stabilized Earth) Walls, (c) Reinforced Concrete (RCC) Retaining Walls, (d) Breast Walls (stone masonry), and (e) Pile Walls (soldier pile or secant pile).

In the challenging geotechnical environment of Nagaland, retaining structures function as the critical mechanical backbone of slope stabilization, engineered specifically to provide direct structural resistance against the gravitational forces that drive mass movement. These structures are designed to support unstable soil or rock masses by counteracting the active earth pressure that develops when a slope exceeds its natural angle of repose. Given Nagaland's unique combination of high-intensity monsoon rainfall and a lithology dominated by weak, splintery shales and weathered sandstones, the selection of a retaining system must prioritize not only lateral strength but also hydraulic efficiency and structural flexibility.

Among the most applicable interventions, Gabion walls remain a cornerstone of hill road engineering in the region. These structures consist of double-twisted hexagonal wire mesh cages filled with durable, locally sourced stone. Their primary advantage in Nagaland is their inherent porosity; unlike rigid structures, gabions allow for the free passage of water, effectively preventing the dangerous buildup of hydrostatic pressure behind the wall—a phenomenon that is the leading cause of retaining wall failure during the peak monsoon. Furthermore, their flexible nature allows them to deform slightly and settle without losing structural integrity, which is essential when dealing with the unpredictable, shifting foundations of the Indo-Myanmar Mobile Belt.

For larger highway projects where significant vertical clearance and load-bearing capacity are required, Reinforced Earth or Mechanically Stabilized Earth (MSE) walls offer a sophisticated alternative. These systems utilize a composite material approach, combining granular backfill with high-tensile reinforcements such as geogrids or metallic strips. By creating a unified, heavy gravity mass, MSE walls can be constructed to much greater heights than traditional masonry and can better accommodate the vibrations and heavy axle loads typical of modern transport corridors. They are particularly favored for their rapid construction time and their ability to be faced with various materials to suit the local environmental aesthetic.

Where the terrain demands absolute rigidity and long-term structural permanence, Reinforced Concrete (RCC) retaining walls are implemented. These are typically designed as cantilever or counterfort structures that rely on the weight of the backfill sitting on a concrete "heel" to maintain stability. However, because RCC walls are impermeable, they must be paired with rigorous drainage engineering, including the installation of weep holes and thick layers of filter media, to ensure that the saturated soils of Nagaland do not exert excessive pressure that could lead to overturning or sliding.

For localized protection at the base of a slope, Breast walls—often constructed from stone masonry—are utilized to prevent the slumping of the weathered overburden. These are generally smaller in scale and are designed to protect the "breast" of the hill from surface erosion and minor shallow failures. Finally, in cases where deep-seated rotational slides threaten critical infrastructure, or where there is insufficient space for a gravity-based wall, Pile walls (including soldier piles or secant piles) are deployed. These piles are bored or driven deep into the stable strata below the failure plane, acting as structural anchors that "pin" the unstable mass to the bedrock. This high-capacity intervention is essential for stabilizing complex "sinking zones"

where the depth of the unstable soil makes surface-level treatments ineffective, providing a robust solution that ensures the long-term safety of Nagaland's most vital lifelines.

4.2.1 GABION WALLS

The engineering success of gabion systems in Nagaland is fundamentally rooted in their ability to function as a mass-gravity structure that maintains a symbiotic relationship with the surrounding hydrological environment. Unlike rigid concrete structures that attempt to resist the immense force of nature through sheer mass and stiffness, gabions succeed through "controlled flexibility." This is particularly vital in the Indo-Myanmar Mobile Belt, where the ground is rarely static. If the subgrade soil undergoes minor settlement or shifts due to seismic activity or moisture fluctuations, the double-twisted hexagonal wire mesh allows the structure to deform and redistribute internal stresses without cracking or losing its retaining capacity. This "self-healing" property ensures that the wall remains functional even under conditions that would cause a reinforced concrete wall to fail catastrophically.

The technical specifications of the wire mesh itself—specifically the 80 x 100 mm aperture and the 2.7 mm core wire diameter—are engineered to balance tensile strength with the need for porosity. The Galfan coating, which is a specialized 5% aluminum-zinc alloy, is crucial for the high-humidity and high-rainfall environment of Northeast India. Unlike standard galvanization that can be brittle and prone to peeling, Galfan forms a dense, passive protective layer that is up to three times more effective at preventing corrosion. This longevity is essential because the stone fill, while sturdy, relies entirely on the integrity of the wire "cage" to remain in place. By ensuring the mesh survives for a design life of several decades, engineers can guarantee that the wall will continue to provide mechanical resistance long after the initial construction phase is completed.

The internal architecture of the wall is further reinforced through the use of diaphragms and stiffeners. Each 2.0-meter-long basket is divided into two 1.0-meter cells by an internal diaphragm, which prevents the stone fill from shifting toward one end of the basket, especially on steep highway gradients. During the filling process, internal "connecting wires" or stiffeners are installed at 330 mm intervals. These wires are crucial; they act as internal ties that prevent the front face of the gabion from bulging outward under the pressure of the rock fill and the external earth pressure. Without these stiffeners, the wall would lose its vertical alignment (its

"batter"), which would shift the center of gravity and compromise the factor of safety against overturning.

The hydraulic management provided by the non-woven geotextile filter at the rear of the wall represents the most critical "invisible" component of the system. In the landslide-prone corridors of Nagaland, the primary cause of failure is often "piping"—the internal erosion of fine soil particles through the gaps in the retaining structure. The 200 g/m² geotextile acts as a sophisticated valve; its high permeability allows water to exit the hill slope at a rate of over 10 cm/s, preventing the buildup of pore-water pressure, yet its pore size is small enough to trap the soil particles in place. This ensures that the hill behind the wall remains structurally sound and that the "effective stress" of the soil is maximized.

Furthermore, for walls designed at heights exceeding 6 meters, the inclusion of a Reno Mattress at the toe is a non-negotiable safety feature. In Nagaland's narrow valleys, high-velocity runoff during the monsoon can quickly scour the soil at the base of a wall. The Reno Mattress, being a thin and highly flexible stone-filled mat, deforms into any scoured holes, protecting the main wall's foundation from being undermined. This holistic design philosophy—integrating material durability, internal structural ties, advanced filtration, and toe protection—transforms a simple pile of rocks into a sophisticated engineering system capable of withstand the extreme geological and climatic stresses of Nagaland.

In Northeast India, gabion walls—wire mesh baskets filled with stone—are the most widely used and reasonably priced retaining structure. Features: gabion baskets with double-twisted hexagonal wire mesh (80 x 100 mm mesh, 2.7 mm wire, 3.7 mm selvedge wire; Galfan-coated (5% aluminum-zinc alloy in accordance with EN 10244-2 Class A, providing better corrosion resistance than simple galvanization). Basket measurements: 1.0 m × 1.0 m × 2.0 m or 1.0 m × 0.5 m × 2.0 m. Fill stone: sturdy, hard rock (quartzite, granite) with a minimum UCS of 50 MPa, a maximum size of 250 mm, and a minimum size of 100 mm (to prevent migration through mesh). stone from authorized quarries in the area. Maccaferri & Officine Maccaferri, TerraFix, or comparable recognized vendors.

Design: In accordance with BS 8006, IRC:SP:14, and IS 9143. Wall height up to 6 m in single-face stepped configuration (batter 6:1 to 4:1, i.e., 1H:6V to 1H:4V setback per course). Reno Mattress toe protection (0.3–0.5 m thick flexible mattresses) is added for heights more than 6 m. To stop soil loss, a geotextile filter (non-woven, 200 g/m² permeability > 10 cm/s) is positioned at the soil-gabion contact.

4.2.2 RCC RETAINING WALLS

In high-density development areas or critical highway segments where the topography is too steep for wide-based gravity structures, Reinforced Cement Concrete (RCC) retaining walls offer the necessary structural rigidity and verticality. These walls operate through a combination of their own self-weight and the weight of the soil resting on the base slab to resist overturning and sliding. For walls of moderate height, a cantilever design is utilized, where the vertical stem and the base slab act as structural members protruding from a central junction. However, as heights increase, counterfort walls become more efficient; these incorporate triangular transverse ribs—counterforts—that tie the stem and the base together, significantly reducing the bending moments and allowing for thinner, more economical concrete sections despite the heavy lateral loads.

The material specifications are stringent to ensure durability in the chemically active soils and humid climate of Nagaland. Utilizing M30 grade concrete provides the necessary compressive strength and impermeability, while Fe-500D reinforcing steel offers high ductility, which is essential for absorbing the energy of minor seismic shifts or tectonic movements without brittle failure. A minimum clear cover of 40 mm is mandated to protect the steel from corrosion caused by the high moisture levels and potential acidic leaching from the surrounding soil. The design, strictly adhering to IRC:78 for bridge and highway structures and IS 456 for general concrete standards, ensures that the wall can withstand both the static earth pressure and the dynamic live loads from heavy vehicular traffic on the road above.

Hydraulic management is the most critical factor in preventing the structural failure of an RCC wall. Unlike permeable gabions, concrete is inherently impermeable, meaning that water trapped behind the wall can exert massive hydrostatic pressure, effectively doubling the force acting against the structure. To mitigate this, a sophisticated multi-tier drainage system is integrated. The 75 mm diameter PVC weep holes, spaced strategically at 1-2 meter intervals, serve as the primary exit points for groundwater. Each weep hole is encased in a gravel filter to prevent fine soil from clogging the pipe, ensuring a continuous flow path.

Furthermore, the implementation of a vertical drainage geocomposite, such as Enkadrain, represents a modern upgrade over traditional thick boulder backfills. This geocomposite consists of a plastic drainage core fused to a non-woven geotextile filter. It is installed directly against the back face of the RCC wall, acting as a high-capacity conduit that intercepts seepage before it can exert pressure on the concrete. With a flow rate exceeding 5 L/m/s, it rapidly

channels water downward to a longitudinal perforated collector pipe at the base. This systematic reduction of pore-water pressure ensures that the wall only has to resist the weight of the dry or moist soil, significantly increasing the factor of safety and preventing the "bursting" or overturning failures that are common in poorly drained rigid structures during Nagaland's monsoon.

4.2.2.1 Effectiveness and Limitations

The selection of a retaining structure in Nagaland involves a strategic trade-off between structural capacity, environmental adaptability, and long-term maintenance requirements. Understanding the operational boundaries of these engineering solutions is vital for ensuring that the chosen intervention does not become a future failure point due to material fatigue or site-specific constraints.

Gabion walls are often the first choice for the Himalayan-Alpine belt because they harmonize with the environment through the use of locally sourced stone and a highly permeable architecture. Their primary effectiveness lies in their ability to survive the frequent minor ground shifts characteristic of Nagaland's tectonically active zones; their flexible wire-mesh skeleton allows the structure to settle and deform without the sudden, brittle failure seen in rigid masonry. However, their reliance on a thin wire cage is also their greatest limitation. Despite Galvan coatings, the high humidity and constant exposure to oxygenated water within the voids eventually lead to mesh corrosion. Over a period of 20 to 30 years, the structural integrity of the "basket" can weaken, potentially leading to the "bulging" or spilling of the rock fill. Therefore, while they are highly cost-effective for heights up to 6–8 meters, they require periodic monitoring to ensure that the wire diameter has not been compromised by oxidation or abrasion from debris flows.

Mechanically Stabilized Earth (MSE) walls represent a pinnacle of modern hill-road engineering, particularly prized for their exceptional seismic performance. Because the structure is composed of a unified mass of reinforced soil, it can absorb and dissipate the energy of earthquake shocks far more effectively than a monolithic concrete wall. Their ability to reach heights exceeding 15 meters makes them ideal for the massive vertical cuts required by National Highway expansion. The significant limitation in Nagaland, however, is the "backfill paradox." MSE walls demand high-quality, free-draining granular material to ensure the frictional bond between the soil and the geogrid reinforcement. In many districts of Nagaland dominated by splintery shales and clayey silts, such material is absent, necessitating the

expensive importation of stone from distant authorized quarries. Additionally, the polymer-based geogrids, while strong, are susceptible to chemical degradation in the acidic, leaching-heavy soils common in the Northeast, requiring the use of specialized, chemically-stabilized polymers to avoid long-term structural fatigue.

Reinforced Cement Concrete (RCC) walls are the "heavyweight" solution for sites where space is restricted and the lateral loads are immense, such as near urban settlements or bridge abutments. Their primary advantage is their high structural capacity and an extended design life that can exceed 50 years with minimal maintenance. However, this longevity comes with a high price tag and significant technical risks. In the isolated, rugged terrain of Nagaland, transporting the heavy machinery and bulk materials (cement, reinforcement steel, and formwork) required for RCC construction is logistically difficult and expensive. Furthermore, because concrete is impermeable, the wall acts as a dam against groundwater. If the drainage design—including the vertical geocomposite and weep holes—is not executed with precision, the resulting hydrostatic pressure can lead to catastrophic overturning. This necessitates a level of expert formwork and stringent quality control that is often difficult to maintain in remote, rain-lashed construction sites, making RCC a high-performance but high-risk intervention compared to more forgiving flexible structures.

4.2.2.3 Cost Estimates

Structure Type	Height Range	Cost Per Sq. Meter (Face Area)	Notes
Gabion Wall (Galfan-coated)	2–8 m	INR 4,500–9,000/m ²	Including stone filling & geotextile
MSE Wall (geogrid + concrete panel)	4–15 m	INR 8,000–18,000/m ²	Includes backfill, panels, reinforcement
RCC Cantilever Wall	2–6 m	INR 12,000–22,000/m ²	Including drainage geocomposite

4.2.2.4 Funding and Schemes

The financial landscape for landslide mitigation and infrastructure resilience in Nagaland is a complex architecture of state-level allocations, central capital expenditure, and international technical cooperation. These funding streams are categorized by the scale of the intervention, ranging from emergency post-disaster repairs to long-term strategic highway stabilization. Currently, the State Public Works Department (PWD) and the Nagaland Road and Bridges Development Corporation (NRBDC) serve as the primary conduits for routine maintenance and slope protection within the State Annual Plan. However, because these budgets are often

stretched thin across a vast network of hill roads, they are frequently utilized for "minor" masonry works and localized clearing rather than the high-capital engineering required for deep-seated stabilization.

On the scale of major national lifelines, the National Highways and Infrastructure Development Corporation Limited (NHIDCL) provides the most significant capital expenditure for slope stabilization. Unlike state funds, NHIDCL's financial model allows for the implementation of advanced geotechnical solutions, such as high-capacity Mechanically Stabilized Earth (MSE) walls and specialized rock bolting, which are integrated directly into the project cost of highway widening and modernization. Complementing these large-scale investments are localized funds like the Chief Minister's Constituency Development Fund and District Development Funds. These are essential for "micro-mitigation," providing the agility needed to construct small breast walls and drainage channels within village settlements and interior roads where major federal agencies do not operate.

International cooperation plays a pivotal role in shifting the region from a reactive to a proactive engineering culture. The Japan International Cooperation Agency (JICA) has become a key partner in the Northeast, providing not only funding but also technical cooperation for disaster-resistant infrastructure. JICA's involvement is particularly focused on "sustainable slope management," introducing Japanese engineering standards for sediment disaster prevention that are specifically adapted to the young, tectonic mountains of the Indo-Myanmar Mobile Belt. This technical influx helps local engineers move away from temporary fixes toward more durable, site-specific interventions.

Finally, the State Disaster Response Fund (SDRF) acts as the primary financial safety net for "post-event" emergency works. While essential for the immediate restoration of connectivity after a catastrophic slide, the SDRF's mandate is largely restricted to emergency retaining wall works and debris removal. The ongoing challenge for Nagaland's disaster management policy is to find a way to pivot a portion of these emergency-only funds toward "pre-disaster" mitigation. By integrating these diverse funding sources—from the localized district funds to international technical grants—Nagaland can develop a more resilient financial strategy that prioritizes long-term prevention over the costly, repetitive cycle of emergency repairs.

4.2.3 BIOENGINEERING AND VEGETATION-BASED STABILIZATION

Bioengineering, also known as soil bioengineering or biotechnical stabilization, is the use of live plant materials, either by themselves or in conjunction with inert materials, to limit erosion, stabilize slopes, and restore ecological functionality. Given the state's abundant biodiversity, labor pool, and traditional ecological knowledge (TEK), it may be the most economical and contextually suitable long-term solution for Nagaland. Within 12 to 18 months, the canopy and roots will fully mature.

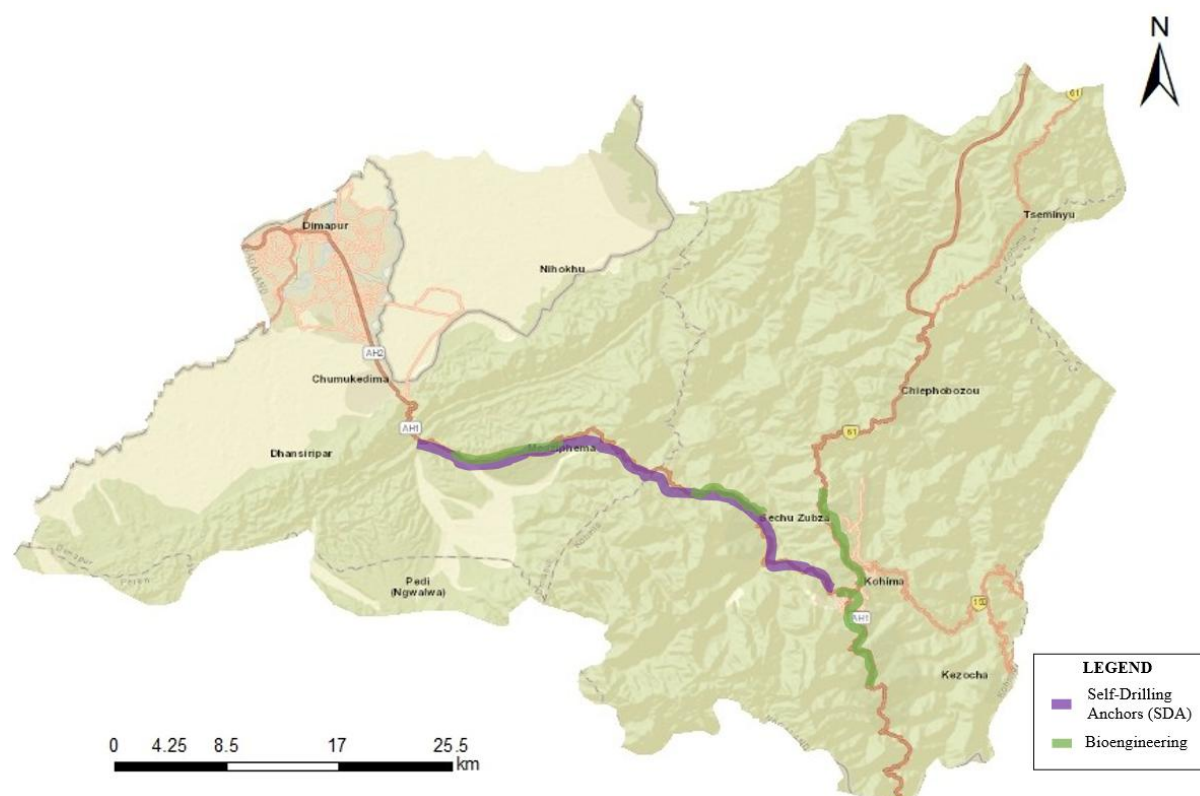
The technical sophistication of bioengineering lies in its ability to transform the top two to three meters of the soil profile—the zone most susceptible to shallow landslides and translational slides—into a reinforced composite mass. This process, known as "vegetative armouring," utilizes the tensile strength of live roots to provide a surcharge of cohesion to the soil. In Nagaland, where the geological strata often consist of highly weathered and fragmented shales, these biological anchors act as a natural structural grid. As roots penetrate through the loose overburden and into the more stable "in-situ" soil or fractured rock below, they effectively "pin" the unstable surface layer to the mountain, significantly increasing the factor of safety against slope failure.

Hydrologically, bioengineering serves as a sophisticated, solar-powered drainage system. During the torrential monsoons characteristic of the Northeast, the primary driver of landslides is the buildup of pore-water pressure, which reduces the friction between soil particles. A mature bioengineered slope mitigates this through "evapotranspiration," where plants actively extract water from the soil and release it into the atmosphere. This biological suction creates a "negative pore-water pressure" or soil suction, which essentially pulls the soil particles together and makes the slope inherently more stable. Furthermore, the foliage and leaf litter provide "interception storage," catching a significant percentage of rainfall before it ever hits the ground, thereby preventing the rapid saturation and subsequent "liquefaction" of the hill slope.

In terms of implementation, Nagaland's traditional ecological knowledge offers a blueprint for specific techniques like "live fascines," "brush layering," and "live staking." Live fascines involve bundling dormant branches of indigenous species—such as *Alnus nepalensis* (Alder), which is already widely used by Naga farmers for its nitrogen-fixing and soil-binding properties—and burying them in shallow trenches along the slope's contours. These bundles act as immediate physical barriers to surface runoff and erosion while they take root. Brush layering goes a step further by placing live cuttings into the slope at a slight downward angle,

providing deep-seated reinforcement that grows as the roots extend horizontally into the hill. Because these methods use live, organic material, the resulting structure is self-repairing; if a minor shift occurs in the soil, the plants simply adjust their growth patterns to compensate, whereas a concrete wall would crack and require expensive manual repair.

The long-term resilience of Nagaland's highway corridors and rural settlements depends on moving away from the "grey" infrastructure of the past toward "green-grey" hybrids. By integrating bioengineering with traditional structures—such as planting deep-rooted grasses and shrubs at the base of gabion walls or on the terraces of RCC walls—engineers can create a multi-layered defence system. The hard engineering provides immediate mechanical support, while the biological component provides long-term stability, erosion control, and ecological restoration. This transition not only addresses the technical requirements of landslide mitigation but also aligns with global climate goals by sequestering carbon and preserving the rich biodiversity of the Indo-Myanmar biodiversity hotspot, ensuring that Nagaland's development is both geologically stable and environmentally sustainable.



4.2.3.1 Native Tree Planting for Deep-Root Stabilization

The implementation of deep-rooted native silviculture for landslide mitigation in Nagaland is a highly specialized form of "biological anchoring" that leverages the structural properties of living organisms. For failure planes occurring at a depth of one to three meters—the most common depth for translational slides in the region's weathered overburden—the selection of tree species is governed by their root architecture and their ability to thrive in the state's acidic, nutrient-leached soils. Research from the Institute of Bioresources and Sustainable Development (IBSD) and the North Eastern Regional Institute of Science and Technology (NERIST) underscores that the most effective stabilizers are those that possess a "heart" or "tap" root system capable of penetrating the soil-rock interface and providing high tensile resistance.

Among the recommended species, *Alnus nepalensis* (Indian Alder) stands out as the primary biological tool for Nagaland. As a pioneer species, it is uniquely adapted to colonize fresh landslide scars where other vegetation might struggle. Its nitrogen-fixing nodules improve the soil chemistry of degraded slopes, while its massive, spreading root system provides immediate mechanical reinforcement. This is complemented by *Schima wallichii* (Needle Wood) and *Toona ciliata* (Red Cedar), which offer high tensile root strength and are resistant to the high

moisture levels of the monsoon. *Prunus cerasoides* (Wild Himalayan Cherry) is particularly valued for its ability to stabilize drier, steeper gradients, while *Ficus* species and *Michelia champaca* (Champak) provide a secondary layer of protection; their dense, interlocking lateral roots create a surface "web" that prevents the initiation of shallow tension cracks, effectively binding the topsoil into a cohesive unit.

The technical implementation of this biological stabilization requires precise spatial planning to ensure maximum soil-root interaction. A planting density of 1,500 to 2,500 stems per hectare is a scientifically calculated requirement to achieve "root closure." This is the critical point at which the root zones of adjacent trees overlap to form a continuous reinforced mat within the soil profile. Staggered row spacing, such as 2 m × 2 m or 2 m × 3 m, is utilized rather than linear grids to break the hydraulic connectivity of surface runoff. This "quincunx" pattern ensures that water flowing down the slope is forced into a meandering path, which significantly reduces its erosive velocity and encourages gradual infiltration into the root zone where it can be managed by the plants' transpiration cycle.

Successful establishment in Nagaland's rugged and often nutrient-poor terrain depends heavily on the quality of the planting pits. Excavating pits to a dimension of at least 45 cm by 45 cm by 45 cm ensures that the sapling's primary roots can expand without physical restriction during the critical first growing season. Because the shaly soils of the region are often deficient in key minerals due to heavy monsoon leaching, the addition of one kilogram of vermicompost and fifty grams of rock phosphate to each pit is a mandatory technical requirement. The vermicompost provides immediate organic carbon and microbial activity to stimulate root hairs, while the rock phosphate offers a slow-release source of phosphorus, which is the primary driver of root elongation and structural lignification (the hardening of wood).

This nutritional "kickstart" ensures that the biological anchors reach the target one-to-three-meter failure depth as quickly as possible. Within three to five years, these trees undergo a transition from simple plants to structural components of the hill, where their roots act as living "soil nails." The cumulative effect of thousands of these anchors across a vulnerable slope creates a resilient, self-maintaining barrier that not only prevents the movement of the soil mass but also restores the ecological health of the corridor. By combining the mechanical strength of deep-rooted timber with the hydrological benefits of a mature canopy, this silvicultural approach offers a permanent solution that grows stronger with time, unlike conventional engineering which begins to degrade the moment it is built.

4.2.3.2 Bamboo-Based Stabilization

The utilization of bamboo species such as *Bambusa balcooa*, *Bambusa tulda*, and *Dendrocalamus hamiltonii* for landslide mitigation in Nagaland represents a high-performance biological engineering strategy. Bamboo is uniquely suited for slope stabilization due to its rapid growth rates and its "leptomorph" or "pachymorph" rhizome systems, which create a dense, interlocking underground network. Unlike traditional trees that may take a decade to provide significant structural support, bamboo establishes a functional biomass within a remarkably short window of three to four years. The scientific advantage lies in the expansive nature of the rhizome network, which can extend 4 to 8 meters horizontally from the primary culm. This network acts as a natural "geogrid," binding the top 1.0 to 1.5 meters of the soil profile into a reinforced monolithic mass that is highly resistant to surface erosion and shallow translational sliding.

In terms of technical placement, the spacing of rhizome cuttings or offset clumps at 3 m by 4 m is designed to optimize "canopy and root closure." By Year 3, the underground mats of adjacent clumps begin to overlap, creating a continuous structural blanket across the slope. This dense mat serves a critical hydrological function: it increases the surface roughness of the hill, effectively intercepting overland flow and forcing the energy of rushing monsoon water to dissipate. This prevents the formation of "rills" and "gullies," which are often the precursors to major slope failures. Furthermore, the high transpiration rate of bamboo helps regulate pore-water pressure by actively pumping water out of the saturated soil layers during Nagaland's heavy rain cycles.

A more advanced application of this technology is the construction of "live crib walls" using bamboo pegs. By utilizing species like *Bambusa vulgaris*, which possess high regenerative capacity, engineers can drive 2 to 3-meter-long pegs (with a diameter of 80 to 100 mm) deep into the slope face, typically reaching depths of 1.0 to 1.5 meters. These pegs act as immediate mechanical "soil nails," providing lateral resistance. Because they are "live," these pegs eventually sprout roots and branches, transforming a temporary mechanical fix into a permanent, living structural element. This hybrid approach—combining the immediate physical support of the peg with the long-term biological reinforcement of the resulting root system—is particularly effective for stabilizing road embankments and the steep fringes of rural settlements.

Beyond the geotechnical benefits, the integration of bamboo into disaster management frameworks provides a vital socio-economic justification that ensures the longevity of the intervention. Unlike concrete walls, which offer no direct financial return to the local community, bamboo is a high-value "green gold" commodity. Once the stabilization project reaches maturity (typically after Year 4), the culms can be sustainably harvested for construction, handicrafts, or paper pulp without compromising the integrity of the underground rhizome network. This "livelihood incentive" encourages local communities to take ownership of the slope maintenance, ensuring that the biological structures are protected from overgrazing or accidental damage. By aligning mechanical slope stability with rural economic development, bamboo bioengineering offers a self-sustaining model for resilience that is perfectly tailored to the cultural and geographical landscape of Nagaland.

4.2.3.3 Hybrid Bio-Engineering: Geocell + Vegetation

The integration of High-Density Polyethylene (HDPE) geocells represents a sophisticated leap in "confinement technology," offering a hybrid solution that bridges the gap between immediate geotechnical stability and long-term ecological restoration. These three-dimensional, honeycomb-like structures are engineered to solve the fundamental problem of slope instability: the loss of shear strength due to lack of lateral confinement. In the rugged terrain of Nagaland, where steep embankment slopes—often at gradients of 1:1 or steeper—are subjected to high-velocity monsoon runoff, traditional topsoil application is nearly impossible. Geocells solve this by creating a series of individual "micro-basins" that mechanically lock the soil in place, preventing the gravitational "creep" and hydraulic "washout" that typically plague road edges and recently failed slopes.

The technical integrity of this system is derived from the high-performance polymers and the geometric design of the cellular web. Conforming to rigorous international standards such as ASTM D5199 for thickness and ASTM D4759 for quality control, these geocells feature a cell depth of 100–200 mm and a seam weld strength exceeding 1,800 N. This high weld strength is critical; it ensures that when the cells are expanded and filled, the "hoop stress" generated by the weight of the infill and the moisture does not cause the structure to unzip or fail. Furthermore, the cell walls are typically textured and perforated. The texture increases the friction between the cell wall and the infill, while the perforations serve a dual scientific purpose: they facilitate rapid lateral drainage to prevent the buildup of hydrostatic pressure

within the cells and allow the root systems of the planted grasses to interlock between cells, creating a monolithic, "living" reinforced mat.

The biological component involves infilling these cells with a specialized growing medium—usually a blend of 80% local topsoil and 20% organic compost—to provide an optimized substrate for rapid vegetative establishment. The selection of native grasses such as *Chrysopogon zizanioides* (Vetiver), *Paspalum conjugatum* (Sour grass), and *Cynodon dactylon* (Bermuda grass) is a strategic choice based on their diverse root architectures. Vetiver, in particular, acts as a biological "soil nail," with roots that can penetrate up to 3 meters deep, effectively pinning the geocell system to the stable subgrade below. While this biological "armoring" typically requires three to six months to reach full structural maturity, the geocells provide instantaneous mechanical confinement from the moment of installation. This "instant stability" is vital in Nagaland's climate, where a single heavy rain event can occur at any time, threatening to sweep away unprotected revegetation efforts.

Commercial systems like the Cellular Confinement Systems (CCS) or Presto Geosystems GEOWEB offer a versatile tool for road engineers in the Northeast. They are especially useful on "raw" slopes created by highway widening or at the edges of hair-pin bends where space for traditional retaining walls is limited. As the grass matures, the HDPE structure becomes completely obscured, protecting the polymer from UV degradation and restoring the natural green aesthetic of the hills. This synergy of "synthetic confinement" and "biological reinforcement" creates a resilient, flexible, and self-maintaining slope protection system. By mimicking the natural root-binding process through a mechanical mesh, geocells provide a sustainable alternative to carbon-heavy concrete paving, ensuring that Nagaland's vital transport lifelines remain stable without compromising the region's ecological integrity.

4.2.3.4 Effectiveness, Advantages, and Limitations

The following analysis evaluates the operational trade-offs, technical limitations, and scientific justifications of various biological and hybrid stabilization methods, specifically within the complex geological and socio-economic context of Nagaland.

The Vetiver System serves as a premier "bio-hydrological" tool, particularly for controlling superficial erosion and shallow failures at depths of less than 1.5 meters. Scientifically, Vetiver grass (*Chrysopogon zizanioides*) is unique because its roots do not grow horizontally; instead, they descend vertically, forming a dense, high-tensile curtain that can reach depths of up to 3 meters. This acts as a living "soil nail" wall that reinforces the soil's shear strength through

increased cohesion. While it is highly inexpensive and environmentally restorative, its effectiveness is strictly limited to the surface and near-surface layers. It cannot mitigate deep-seated rotational slides that occur below the root zone. Furthermore, in the high-growth environment of the Northeast, it requires consistent maintenance cutting to prevent the crown from becoming too heavy; if neglected, the plant can become top-heavy, and the leverage from wind force could inadvertently lead to localized soil loosening or "uprooting" during storm events.

Bamboo stabilization leverages Nagaland's existing natural capital to provide a dual-function solution: geotechnical reinforcement and socio-economic support. The strength of bamboo lies in its expansive rhizome network, which creates a horizontal "mat" that binds the soil particles together, significantly increasing the soil's resistance to surface displacement. This is excellent for preventing the initiation of slides on steep slopes. However, the system requires a high degree of "silvicultural discipline." The scientific risk here is the "decay gap." If the bamboo is harvested incorrectly, or if too many culms are removed at once, the death of the associated rhizomes leads to a loss of tensile strength. As the organic matter decays, it leaves behind voids in the soil that can actually increase permeability and pore-water pressure. Skilled harvesting management is therefore essential to ensure that the underground structural integrity remains intact while the community benefits from the timber yield.

Geocell + Vegetation represents a premium hybrid approach, merging the immediate mechanical benefits of High-Density Polyethylene (HDPE) with long-term biological armoring. This system is technically superior for "at-risk" slopes, such as road embankments or recently failed areas where there is no time to wait for plants to reach maturity. The HDPE cells provide instantaneous confinement, creating a "slab" effect that prevents soil particles from moving even during a heavy downpour immediately after installation. While it is more costly than pure bioengineering due to the need for HDPE sourcing and logistics, it offers a "fail-safe" during the critical first six months of a project. As native grasses eventually colonize the cells, the system transitions into a naturalized, self-maintaining structure. The cells protect the roots from being washed away, and the roots eventually "staple" the cells to the deeper subgrade, creating a multi-layered defense.

Tree Planting is the most effective long-term strategy for failures occurring at depths of 1 to 3 meters. Deep-rooted native species like *Alnus nepalensis* provide a massive surcharge of cohesion to the hill through their primary taproots and secondary heart-root systems. These roots act as biological anchors that bridge the failure plane between the unstable overburden

and the stable bedrock. The primary disadvantage of this method is the "time-lag"; it generally takes 5 to 10 years for the root architecture to reach its full load-bearing capacity. During this establishment phase, the slope remains vulnerable to landslides. Furthermore, in Nagaland, these biological assets face a unique human-made risk: Jhum (shifting cultivation) burning. If the vegetation is scorched, the loss of the canopy leads to immediate hydrological saturation. More dangerously, the eventual decay of the roots in the years following a fire can trigger "delayed" landslides. Protecting these reforestation zones from fire and grazing is as critical as the initial engineering design itself.

4.2.3.5 Cost Estimates

Technique	Unit	Cost Range (INR)	Notes
Bamboo Planting (clumps)	Per hectare	INR 30,000–80,000/ha	Including site prep & irrigation
Native Tree Planting	Per hectare	INR 50,000–1,50,000/ha	Species mix, pits, fertilizer

4.2.3.6 Funding Sources

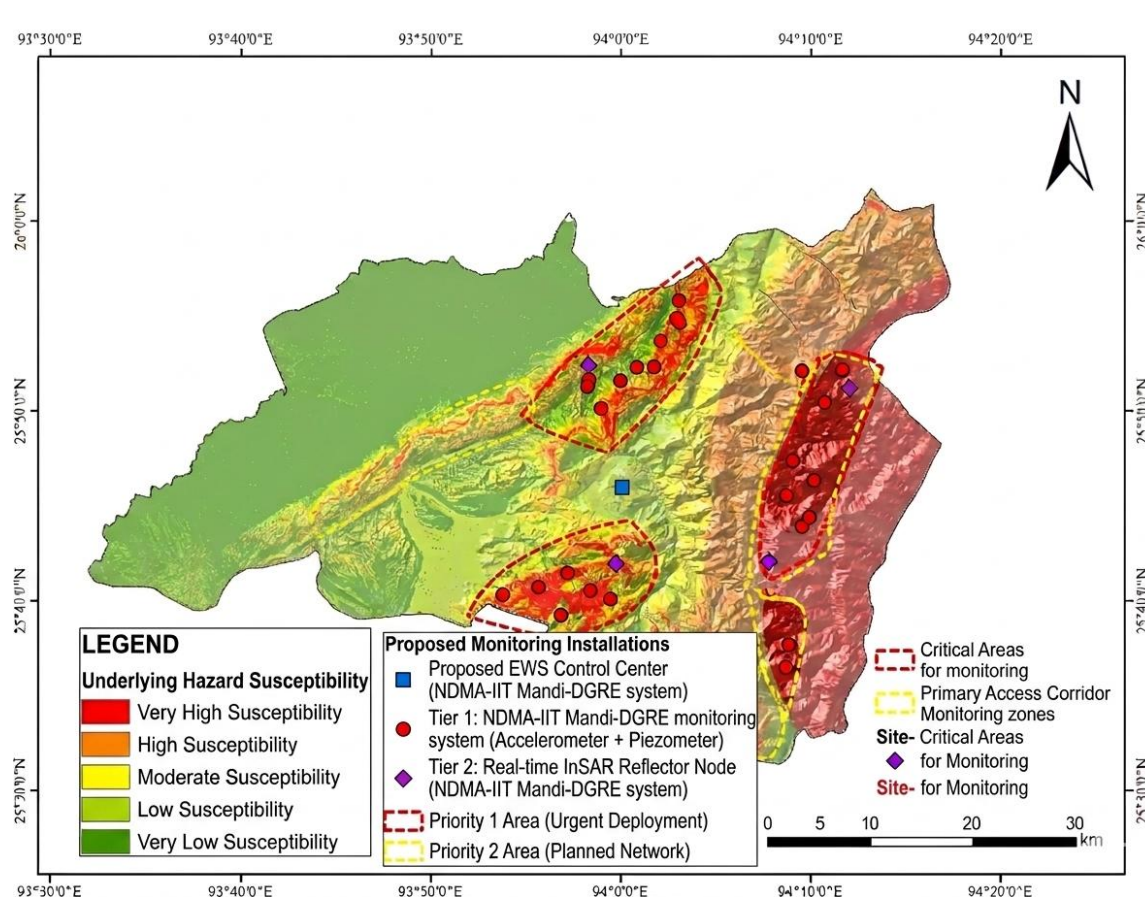
- CAMPA (Compensatory Afforestation Management and Planning Authority): Central funds for afforestation; highly applicable.
- MGNREGS (Mahatma Gandhi National Rural Employment Guarantee Scheme): Bioengineering work is eligible; provides wage employment.
- National Afforestation Programme (NAP) through Forest Department.
- NABARD Watershed Development Fund and Rural Infrastructure Development Fund (RIDF).
- UNDP – Ecosystem-Based Adaptation (EbA) Programme in Northeast India.
- GIZ India – Biodiversity and Ecosystem Services programme (BEST).

4.3 EARLY WARNING AND MONITORING SYSTEMS

Landslide Early Warning System (LEWS) is more than just a network of sensors; it is a life-preserving dialogue between the shifting earth and the people who live upon it. In the steep, rain-soaked terrain of Nagaland, where the difference between safety and catastrophe can be measured in minutes, these systems act as a community's "digital nervous system." By

translating the silent movements of the mountain into actionable intelligence, LEWS empowers residents to move from a state of constant anxiety to one of informed readiness.

The system begins by listening to the mountain through a process of monitoring and instrumentation. Geotechnical sensors are installed at critical "slip surfaces" to detect the earliest signs of distress. Inclinoimeters and tiltmeters measure the slightest physical lean or internal shift of the soil mass, while piezometers track the buildup of pore-water pressure—the invisible force that "lubricates" a landslide. In Nagaland, where rainfall is the primary trigger, these are paired with automated rain gauges. Together, they monitor the saturation levels of the slopes, capturing data on how much water the ground is holding and how close it is to its breaking point.



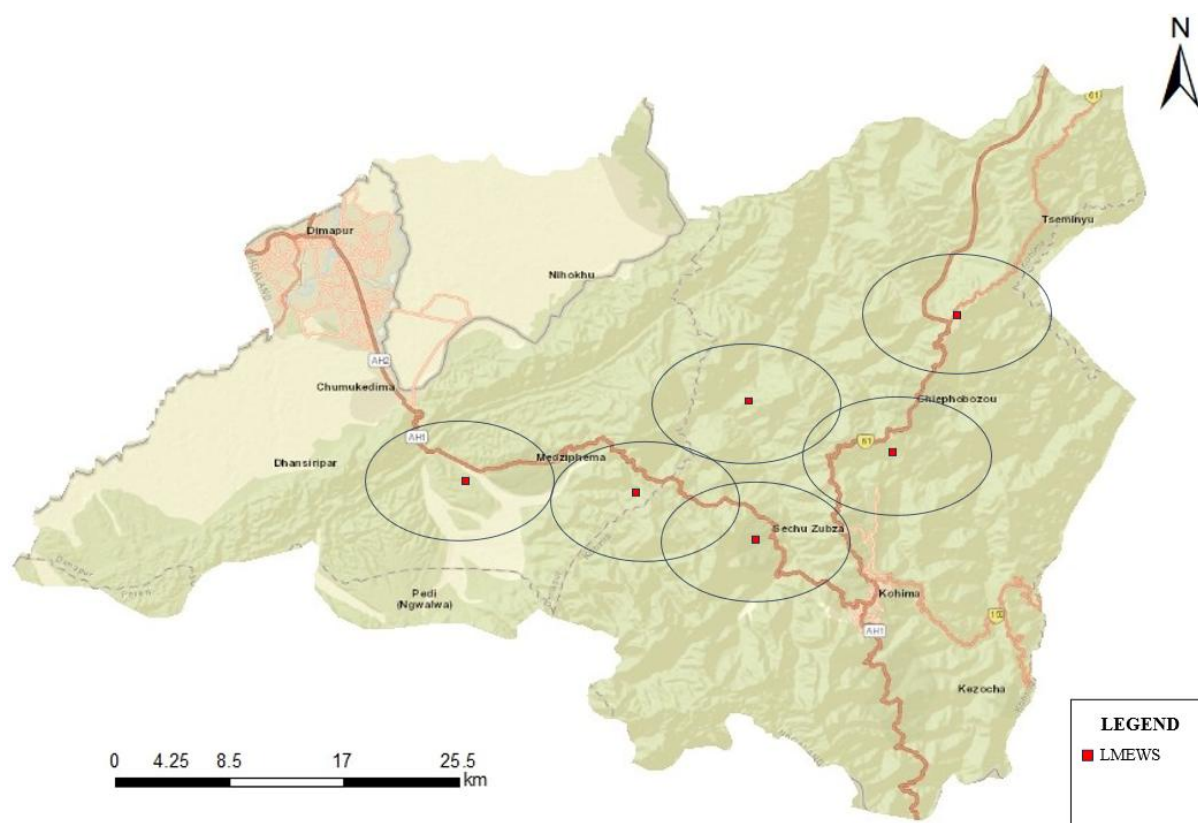
Once the data is collected, it must travel instantly to those who can interpret it via a robust data transmission infrastructure. This requires a redundant communication backbone. In remote Himalayan corridors, this is often a hybrid of cellular networks (GSM/GPRS) and satellite links to ensure that even if a road is cut or a tower goes down, the signal remains unbroken. These "data bridges" push real-time readings to a centralized cloud platform or a district emergency

operations center. This constant stream of information ensures that the mountain is never left unobserved, even in the middle of a monsoon night.

The most critical stage is the "brain" of the operation: threshold analysis and alert generation. Scientists and engineers establish mathematical limits based on historical landslide data and soil mechanics. When rainfall intensity or soil displacement exceeds these pre-defined limits, the system triggers an alert. Modern systems increasingly use Machine Learning to refine these thresholds, learning from every minor tremor or rain event to reduce false alarms. This ensures that when the alarm does sound, the community knows the threat is genuine, preventing "warning fatigue."

Finally, the system finds its "voice" through dissemination and community response. A warning is only successful if it leads to a safe, human reaction. The voice of the system reaches the public through multi-channel alerts: high-decibel sirens for immediate danger, SMS blasts for situational awareness, and community radio for detailed instructions. However, the technology is only half the battle; it must be matched by "Last Mile Connectivity." This involves local "Landslide Volunteers" and Village Disaster Management Authorities who have been trained through evacuation drills. By the time the alert reaches a resident's phone, they should already know their evacuation route and their designated safe zone.

Ultimately, a LEWS transforms the unpredictable threat of a landslide into a manageable risk. It bridges the gap between high-level geophysics and the village doorstep, ensuring that the people of Nagaland can coexist with their rugged landscape with a sense of security and foresight.



4.3.1 NDMA-IIT Mandi-DGRE Monitoring Framework

The collaboration between the National Disaster Management Authority (NDMA), IIT Mandi, and the Defence Geoinformatics Research Establishment (DGRE) represents a landmark shift in how India protects its mountain lifelines. By moving away from "imported, elite" technology toward a locally-engineered, "frugal" innovation, this partnership has created a technical framework specifically tuned to the heartbeat of the Himalayas and the Naga Hills. This is not just an engineering project; it is an effort to democratize safety, ensuring that even the most remote stretches of the NH-29 corridor are under the watchful eye of a system that understands the specific "language" of Indian landslides.

The soul of this system lies in the use of Micro-Electro-Mechanical Systems (MEMS). Traditionally, monitoring a single landslide was a prohibitively expensive endeavor. Standard high-precision tools—like borehole inclinometers that require deep, complex drilling or vibrating wire piezometers that demand surgical installation—can cost between 180,000 and 540,000 per instrument. For a state like Nagaland, with hundreds of active slip zones along a single highway, such costs make widespread protection a financial impossibility. The NDMA-IIT Mandi-DGRE framework breaks this barrier. By utilizing MEMS sensors—the same resilient, miniaturized technology found in smartphones to detect orientation—the team has

developed a "complete monitoring node" for approximately 108,000. This makes it possible to deploy a "safety net" of sensors across the entire NH-29 corridor rather than just guarding a few select spots.

Beyond the hardware, the "intelligence" of the system is what truly humanizes it. These nodes are AI-powered, meaning they don't just record data; they interpret it. In the past, traditional sensors would often trigger "false positives" during heavy monsoons, leading to a "cry wolf" effect that caused communities to ignore warnings. The AI algorithms developed through this partnership are trained on the specific geological signatures of the Northeast—the splintery shales, the high-clay soils, and the extreme rainfall intensities. The system learns to distinguish between a "settling" slope and a "failing" slope, ensuring that when an alert is issued, it is a credible, life-saving call to action.

The operational feasibility of this system is designed with the "boots-on-the-ground" reality of Nagaland in mind. High-end equipment often requires specialized technicians from metropolitan centers for every minor repair; however, the IIT Mandi-led design emphasizes modularity and local maintenance. These units are solar-powered and built to survive the high-humidity, corrosive environments of the North-East. By slashing the cost of deployment and maintenance, the framework shifts the focus from "recovery after the disaster" to "intelligence before the event." It transforms NH-29 from a road of uncertainty into a "smart corridor," where technology serves as a silent, vigilant guardian for every traveler and local resident.

4.3.1.1 Data Transmission and Central Processing

The transition to an IoT-enabled Landslide Early Warning System marks the evolution of Nagaland's disaster management from a reactive stance to a predictive one. At its core, this architecture functions like a digital sentry, ensuring that no matter how isolated a village or road stretch may be, it remains connected to a centralized "brain" at the Nagaland State Disaster Management Authority (NSDMA) in Kohima. By weaving together advanced telemetry and intuitive dashboards, the system ensures that data is not just collected, but actually heard and acted upon.

The true breakthrough in humanizing this technology lies in the use of LoRaWAN (Low-Power Wide-Area Network). In the deep valleys and high ridges of Nagaland, traditional GSM or 4G signals are often swallowed by the terrain or knocked out during the very storms that trigger landslides. LoRaWAN acts as a resilient "long-distance whisper." A single gateway perched on a strategic ridge can "listen" to sensors up to 15 kilometers away, spanning multiple towns

and villages using very little power. This ensures that even the most remote community—where a standard cell phone might show "No Service"—is still under the protective umbrella of the monitoring network.

Once a sensor detects a tremor or a spike in soil moisture, the data travels to a Central Monitoring Station (CMS), where it is housed in a high-speed, time-series database like InfluxDB. This is more than just digital storage; it is a "memory bank" of the mountain's behavior. By recording every minute fluctuation over months and years, scientists can begin to understand the "normal" rhythm of the slope versus the "distressed" signals that precede a collapse. This historical context is vital for reducing false alarms, ensuring that when the community is told to evacuate, they can trust the instruction implicitly.

To make this complex data accessible to decision-makers, the system utilizes Grafana or bespoke web dashboards. These interfaces translate raw numbers and technical jargon into clear, visual stories—green for stable, amber for caution, and red for danger. The system humanizes the response by meeting people where they are. In the event of a breach in safety thresholds, the system doesn't just ping a server; it sends automated, urgent alerts directly to the pockets of local officials and residents via WhatsApp, SMS, and email.

This "last-mile" communication is the most critical link in the chain. It transforms a sophisticated cloud-based operation into a simple, life-saving message for a village elder or a truck driver on NH-29. By providing a real-time window into the mountain's stability, the NSDMA creates a "shared consciousness" of safety, where technology serves as a bridge between the cold data of the laboratory and the warm, lived reality of the people of Nagaland.

4.3.1.2 AI-Based Prediction Integration

The science of landslide prediction has shifted from mere reaction to a sophisticated form of digital foresight. By utilizing machine learning, we are no longer just watching a landslide happen; we are teaching computers to recognize the invisible patterns that precede disaster. In the context of Nagaland's volatile slopes, these models act as an early-warning intuition, providing a critical window of six to twenty-four hours to move families, travelers, and heavy equipment to safety before the earth begins to move.

At the core of this predictive power are two primary types of digital brains: Random Forest classifiers and Long Short-Term Memory (LSTM) recurrent neural networks. A Random Forest acts like a committee of experts, weighing hundreds of different factors—from the

steepness of a hill to the specific type of soil—to vote on the likelihood of a collapse. LSTMs, however, are even more human-like because they possess a memory for sequences. They do not just look at today's rain in isolation; they remember how much it rained five, seven, and ten days ago and how that moisture has been slowly saturating the earth over time. This ability to understand the history of a slope makes them exceptionally good at predicting the exact tipping point when a hillside can no longer hold its own weight.

The intelligence of these models depends on the features or ingredients fed into them, which combine ground-level sensors with an eye-in-the-sky perspective. The system tracks antecedent rainfall to determine if the ground is already "primed" for failure, alongside real-time data on piezometric head and physical displacement rates. To complement this, scientists use Sentinel-2 satellite imagery at a 10-meter resolution to monitor the Normalized Difference Vegetation Index (NDVI). By detecting NDVI anomalies, the model can spot "bruises" on the mountain—subtle changes in vegetation health that suggest the ground beneath is shifting or tilting, even before a crack is visible to the naked human eye.

To teach these models, researchers dive into the vast digital archives of the India Meteorological Department (IMD) and the National Remote Sensing Centre (NRSC/ISRO) landslide inventory. By showing the AI thousands of examples of past landslides in similar Himalayan and North-Eastern terrains, the models learn to identify the unique fingerprints of a disaster. The results are remarkably accurate, with established research reporting a success rate between 80% and 92% Area Under the Curve (AUC). In practical terms, this high degree of precision allows the system to distinguish between a harmless monsoon shower and a life-threatening geological event.

Humanizing this technology means recognizing it as a profound tool for community empowerment. When a model achieves 90% accuracy, it is providing the confidence needed for a local village headman or a district official to order a difficult evacuation in the middle of a dark, rainy night. It transforms the mountain from an unpredictable, looming threat into a landscape that can be understood, respected, and navigated safely. By merging the vast historical memory of ISRO's satellites with the real-time processing of modern AI, Nagaland can move toward a future where the phrase "unforeseen disaster" becomes a relic of the past.

4.3.1.3 Community Alert Dissemination

The Last-Mile Connectivity principle is the most vital pulse of any early warning system; it represents the transition from a technical signal to a human heartbeat. In the rugged landscapes of Nagaland, a warning is only as powerful as the person who hears it and knows exactly what to do. This principle ensures that the gap between a high-tech sensor and a remote kitchen or a mountain road is bridged with clarity, empathy, and speed. It transforms the cold data of a monitoring station into a warm, protective hand for the community.

This human-centric approach is organized into four distinct Alert Levels, designed to guide families through the escalating tension of a storm without causing unnecessary panic. Green signifies a state of regular monitoring—a quiet promise that the mountain is being watched so the community can sleep soundly. Yellow introduces a sense of shared alertness; it is a gentle nudge to the community to pack essential documents, medicines, and warm clothes, preparing for the possibility of movement. Orange is a call for decisive action, requiring the partial evacuation of families living on the most vulnerable "fingers" of the slope. Finally, Red is the highest cry of urgency, signaling a complete evacuation to save every life before the earth gives way.

To ensure these messages reach everyone, from the elderly in a quiet village to a truck driver on a winding pass, the system utilizes a multi-channeled "symphony" of communication. All India Radio Kohima serves as a trusted voice in the corner of the room, broadcasting steady updates in local dialects. For those on the move, the Nagaland Police helpline (100) stands ready as a direct line to safety. In the palm of the hand, WhatsApp community groups managed by Village Development Boards turn neighbors into protectors, allowing for the rapid, viral spread of life-saving information through familiar and trusted networks.

In the physical world, the system speaks through solar-powered hooter systems. These sirens are the modern sentinels of the hillside; their 500-meter audible range pierces through the sound of torrential rain, providing an unmistakable, visceral signal that it is time to move. Because these hooters are solar-powered, they remain vigilant even when the main power grid fails during a storm, ensuring the "voice" of the mountain is never silenced by a blackout.

The final, most personal layer of the system involves direct SMS alerts to a dedicated network of local heroes: Village Disaster Committee members, Anganwadi workers, and ASHA workers. These individuals are the true "last mile." When an ASHA worker receives a red alert on her phone, she isn't just a data point; she is the person who knocks on the door of a pregnant

mother or an elderly neighbor to help them down the path to the evacuation center. By empowering these local leaders with instant information, the system ensures that the "Last Mile" is not just a distance, but a human connection rooted in care and collective resilience.

4.3.1.4 Sensing Integration

- Landslip susceptibility mapping and change detection at the landscape scale are made possible by satellite-based monitoring:
- InSAR (Interferometric Synthetic Aperture Radar): To identify mm-scale slope deformation, Sentinel-1 SAR data (free, 6–12 day repeat, 5 m resolution in IW mode) is analyzed using the SNAP + StaMPS/SBAS methodology. Feasibility: InSAR-based landslide monitoring has been proven in Northeast India by ISRO-SAC, NRSC Hyderabad, and IIT Bombay.
- Slope angle, aspect, curvature, lithology (GSI 1:50,000 geology), land use/land cover (LULC from ISRO Bhuvan 56-band data), soil type (NBSS&LUP soil map), drainage proximity, and historical landslide inventory are all integrated in this multi-criteria GIS analysis (QGIS/ArcGIS). For Northeast Indian settings, machine learning susceptibility mapping with Random Forest, SVM, or CNN on Sentinel-2 derived features obtains $AUC > 0.90$ (Roy & Saha, 2019, Geoscience Frontiers).
- Google Earth Engine (GEE): Pre/post event change analysis, debris flow mapping, automated forest cover loss monitoring (Hansen Global Forest Watch), and a free cloud computing platform for processing multi-decadal satellite images.

4.3.1.5 MEMS Sensor Network Design

The main real-time monitoring layer of the suggested EWMS is the MEMS sensor network. To capture the multi-parameter signature of pre-failure slope behavior, each monitoring node combines several sensor types. The main slope displacement sensor in the system is a MEMS accelerometer, a three-axis device that can detect movements of rock and soil masses as small as 0.01 g. These are supplemented by tilt sensors that track the rotational displacement of instrumented blocks, pore-water pressure transducers that monitor the crucial hydraulic parameter that most directly determines slope stability margins, and MEMS-based soil moisture sensors that measure volumetric water content at multiple depth profiles.

Sensor data from each node is collected by a local microcontroller-based data acquisition system that performs initial time-series processing and anomaly detection before transmitting aggregated data packets to a central cloud-based server via a GPRS/4G cellular gateway. The transmission frequency is adaptive: during quiescent baseline conditions, data transmission occurs at 15-minute intervals to conserve power; during elevated precipitation events or detection of anomalous displacement trends, the transmission frequency automatically increases to 1-minute intervals to maximize warning lead time.

Using machine-learning anomaly detection algorithms trained on past sensor signatures from similar slope failures at NDMA-IIT Mandi deployment sites, the cloud-based data management platform combines real-time data streams from all monitoring nodes with weather radar data from IMD. The system automatically generates tiered alerts—Green (routine monitoring), Amber (watch), and Red (warning/evacuation)—when the combined sensor signal surpasses pre-calibrated warning thresholds. These alerts are distributed via a variety of channels, including SMS to registered community members and road users, siren activation at nearby habitations, LED blinker activation at highway approach signs, and dashboard notifications to the District Disaster Management Authority (DDMA) control room.

4.3.2 Automated Rain Gauge (ARG) System

The second critical layer of the Early Warning and Monitoring System (EWMS) is defined by a network of high-precision Automated Rain Gauges (ARG). These instruments serve as the system's "sensory receptors," providing the raw quantitative data necessary to fuel threshold-based alerts and calibrate the sophisticated algorithms that detect anomalies in MEMS sensors. In the rain-shadowed valleys and cloud-bathed peaks of Nagaland, these gauges do more than just measure water; they provide the mathematical evidence required to predict when a slope will transition from stable to saturated.

At the core of the ARG is a finely balanced tipping-bucket mechanism, a masterclass in simple yet effective mechanical engineering. The system operates on a binary logic: a specialized internal bucket is designed to tip every time it collects exactly 0.2 mm of precipitation. Each tip triggers a magnetic switch closure pulse, which is instantly captured and timestamped by a digital data logger. This allows for a dual-stream data analysis. First, it calculates the immediate rainfall intensity—the "velocity" of the storm in mm/hour—which is critical for identifying

flash flood risks. Second, it tracks cumulative totals over any duration, providing a historical record of the total "water load" the hillside is currently supporting.



Designing an instrument to survive the punishing environment of the Naga Hills requires a deep respect for the elements. The ARG specifications for the NH-29 corridor have been meticulously chosen to balance laboratory-grade precision with rugged operational resilience. The bucket and funnel assemblies are constructed from non-hygroscopic SS304 stainless steel or specialized Fiber Reinforced Plastic (FRP). Unlike standard materials, these do not absorb moisture, ensuring that even in the 90% humidity typical of the region, every drop that enters the funnel is accounted for. Furthermore, the collector ring is designed with a "knife-edge" profile. This sharp geometry is scientifically essential; it breaks the surface tension of water droplets during light mists or low-intensity drizzles, preventing water from "clinging" to the rim and ensuring it is funneled into the measuring mechanism.

This technology involves recognizing the role of the dedicated field technicians who keep these sentinels standing. In a region where the earth is constantly shifting, maintaining a perfectly level instrument is a significant challenge. To address this, each ARG is equipped with an integrated bubble-level installation indicator. This simple, visual tool allows local maintenance teams to quickly verify and adjust the gauge's vertical alignment during routine visits. Even a slight tilt can lead to significant measurement errors, so this feature empowers technicians to ensure the data reaching the Central Monitoring Station in Kohima is always beyond reproach. By combining robust materials with user-friendly maintenance features, the ARG network becomes a reliable, long-term partner in the state's quest for climate resilience.

Table: Automated Rain Gauge (ARG) Technical Specifications for NH-29 EWMS Deployment

Parameter	Specification
Type	Tipping bucket, non-hydroscopic SS304/FRP stabilised
Bucket Capacity	0.2 mm
Accuracy	±1% at 12 in/hr
Output Formula	Rainfall (mm) = B × N; N = logger reading, B = calibration multiplier
Transmission	GPRS / 4G with redundant SIM
Maintenance Cycle	Filter screen cleaning every 30 days; annual full calibration
Placement Density	1 ARG per 100 km ² in high-risk zones; minimum 5 units along NH-29 (Dimapur, Medziphema, Zubza, Chiephodozou, Kohima)

The empirical link between antecedent rainfall and failure frequency reported in the literature for similar geological settings is used to calibrate rainfall threshold alerts for slope failure risk in the research area. The suggested levels for alerts are: Rainfall totaling more than 60 mm over a 6-hour period triggers Amber Alert: 6-hour cumulative rainfall above 100 mm or 24-hour cumulative rainfall surpassing 150 mm results in Red Alert, which requires Zone I settlements within the impacted watershed to be evaluated for evacuation. After every monsoon season, these thresholds are subject to seasonal adjustment and recalibration utilizing the sensor network's actual failure and non-failure event record.

4.3.2.1 Locational Justification and Network Deployment

Based on the convergence of three criteria—high LSI zone classification, documented historical failure incidence from GSI inventory data, and proximity to populated settlements or critical highway sections—the EWMS's spatial deployment strategy ranks five primary monitoring node locations along the NH-29 corridor. The five priority deployment locations are Kohima itself (monitoring the saturated weathered sandstone above the state capital), Chiephodozou (at the approach to the main Kohima ridge system), Zubza (at the midpoint of the steepest highway gradient section), Dimapur (at the transition from the plateau to the foothills), and Medziphema (at the crucial first major escarpment crossing).

Based on their documented failure history, two other high-priority sites are selected for early deployment: Dzudza, where a combination of north-facing slope orientation, high rainfall exposure, and proximity to Zone I settlements creates exceptional risk to habitation rather than just highway infrastructure, and Pagla Pahar, which has seen numerous highway-blocking

failures in recent monsoon seasons and where the geological conditions—ophiolitic melange with clay-rich gouge zones—present exceptional slide susceptibility.

At a total capital cost of about INR 30–35 lakh, the entire network, which consists of the five main corridor nodes plus two more high-priority locations and at least three Automated Rain Gauges (one per 100 km² in the high-risk zone), represents a Phase 1 deployment of ten instruments. In addition to providing rainfall data for the three main catchments supplying slope systems above the highway, this deployment provides monitoring coverage of the most crucial 42 km of NH-29 that crosses Zone I and Zone II terrain.

Table: MEMS Node Cost Estimate per Installation Unit

MEMS Node Component	Estimated Cost (INR)
Sensor node and enclosure	₹1,00,000
Gateway / Communications	₹35,000
Power backup (solar + battery)	₹25,000
Installation and civil works	₹50,000
Calibration and training	₹30,000
Dashboard / maintenance buffer	₹60,000
Total per Node	₹3,00,000

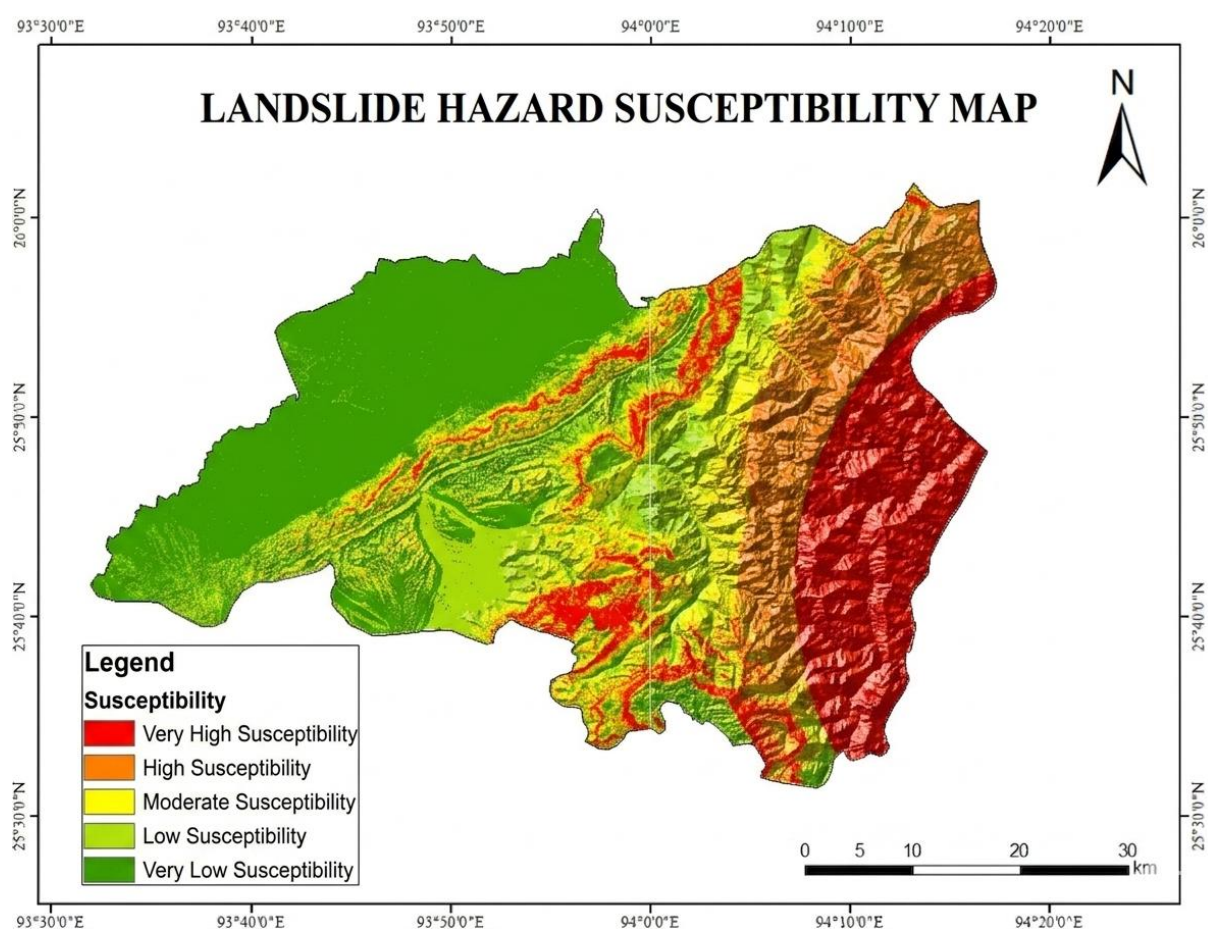
4.4 LAND-USE ZONING AND PLANNING REGULATIONS

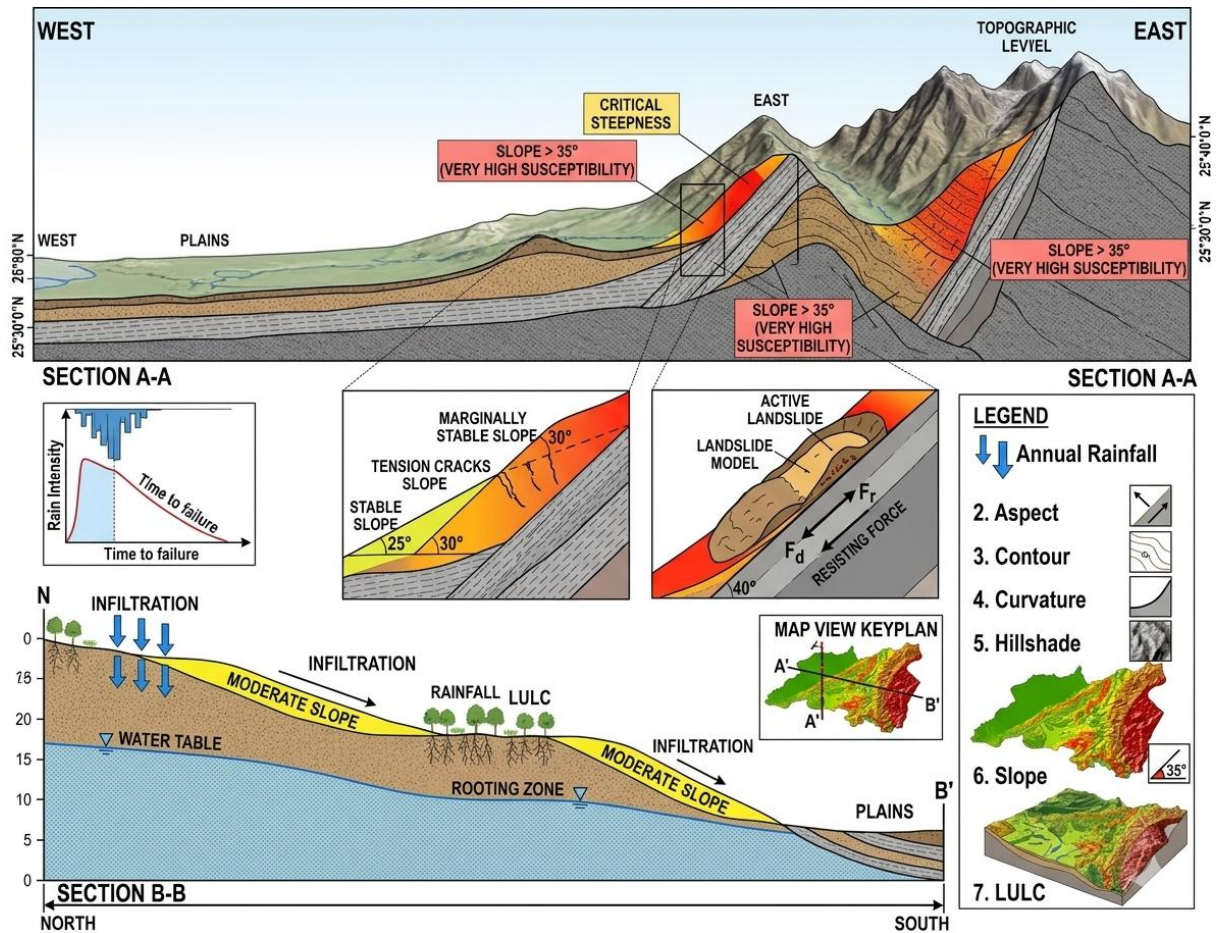
Land-use zoning represents one of the most powerful, yet silent, guardians in a state's disaster resilience toolkit. Unlike concrete walls or steel anchors, which try to fight the mountain once a problem already exists, zoning is a non-structural "preventive" philosophy. It is the art of reading the land's history and potential for movement, then making the compassionate decision to steer development away from its most fragile slopes. By choosing where we build today, we decide who we protect tomorrow, effectively lowering the risk for families and infrastructure before a single spade of earth is even turned.

The core objective of Landslide Hazard Zonation (LHZ) is to create a "social contract" between the geography of Nagaland and its residents. By classifying terrain into high, medium, and low-risk zones, local planners can implement tiered development controls. In the "Red Zones"—those jagged, high-gradient slopes with unstable geology—the policy might restrict heavy construction or large-scale road cutting, preserving these areas as natural buffers or "green belts." In "Yellow Zones," it might mandate specific engineering standards, such as lightweight building materials or mandatory drainage plans, ensuring that if we must build on a slope, we do so with a light and respectful touch.

Currently, the National Disaster Management Authority (NDMA) 2009 guidelines provide a robust technical framework, yet Nagaland faces the challenge of a "policy gap." Without a state-specific, comprehensive LHZ policy, development often happens reactively rather than proactively. Humanizing this policy means recognizing that it isn't about "restricting" growth, but about "securing" it. When a young family builds a home in a newly developed colony around Kohima or Dimapur, they deserve the peace of mind that comes from knowing the ground beneath them wasn't flagged as a high-hazard zone by experts years prior.

Closing this gap in Nagaland requires a marriage of traditional local wisdom and modern geoinformatics. By integrating ISRO's satellite-derived hazard maps with the lived experience of village councils who know every seasonal spring and ancient slip, the state can create a living zoning policy. This document would serve as a roadmap for the future, ensuring that the vital expansion of schools, hospitals, and homes is directed toward stable foundations. Ultimately, land-use zoning is an act of foresight that honors the rugged beauty of the Naga Hills while ensuring that progress never comes at the cost of human safety.





4.4.1 Landslide Hazard Zonation (LHZ) Mapping

The transition from a macro-level 1:50,000 scale to a micro-level 1:10,000 scale in Nagaland represents a fundamental shift from general land-use planning to precise engineering-geological intervention. At the broader scale, the Geological Survey of India provides a foundational understanding of regional susceptibility, but the complex urban fabric of cities like Kohima, Dimapur, and Mokokchung demands a higher resolution to account for the interplay between natural instability and anthropogenic pressure. This micro-level approach is necessary because, in the rugged terrain of the Indo-Myanmar Range, geological conditions can change drastically within a few dozen meters. A slope that appears stable on a regional map may actually be a dormant landslide toe or a zone of crushed rock when viewed through the lens of a 1:10,000 scale analysis.

The methodology utilizing the Analytical Hierarchy Process (AHP) within a GIS environment is particularly effective for this terrain because it allows for the structured weighting of multiple variables that do not contribute equally to slope failure. For instance, in the soft sedimentary

rocks of the Disang and Barail Groups, Lithology and Structural Geology are often assigned higher priority weights than Aspect or Curvature. The presence of faults and lineaments creates zones of high secondary porosity and rock mass fragmentation, which act as primary conduits for groundwater. When this is cross-referenced with the Historical Landslide Inventory, the model gains predictive power, transforming from a static map into a dynamic tool that identifies where future failures are most likely to occur based on where they have happened before.

To enhance this methodology further, the model should incorporate the specific role of the Naga Thrust and other regional tectonic features that have left the rock mass in a highly weathered and "sheared" state. On a micro-scale, the Slope factor must be analyzed in conjunction with the Soil Type to determine the specific angle of repose for different materials. In urban Nagaland, the "Very High" hazard zones are often found where steep slopes intersect with saturated, thick overburden or residual soils. The Curvature factor is critical here because concave slopes act as topographical funnels that concentrate surface runoff, leading to localized pore-pressure spikes during the intense monsoon season. By integrating Drainage Density, the GIS analysis can highlight areas where natural waterways have been constricted by urban encroachment, a common cause of flash floods and subsequent toe erosion that triggers larger slope movements.

Furthermore, the elaboration of Land-Use and Land-Cover (LULC) data at the 1:10,000 scale allows for the identification of specific building clusters that are exerting excessive vertical load on unstable terraces. In cities like Kohima, the weight of multi-story RCC structures often exceeds the bearing capacity of the weathered shale beneath them. An enhanced model would treat the "Weight of Infrastructure" as a distinct causal factor, acknowledging that human activity is no longer just a passive observer of the landscape but an active geological force. The final output, classified into Very High, High, Medium, and Low zones, provides a rigorous framework for the State Disaster Management Authority to enforce specific building regulations. For example, in Very High zones, the policy could mandate a total ban on heavy construction and the implementation of bio-engineering solutions such as the planting of deep-rooted Vetiver grass or the installation of horizontal sub-surface drains.

To ensure the highest level of accuracy, this GIS-based AHP model should be validated using the Receiver Operating Characteristic (ROC) curve to determine the Area Under the Curve (AUC). A high AUC value indicates that the model successfully predicted known landslides, thereby granting the map the legal and scientific weight required for urban zonation. In the final phase, these maps should be integrated into a web-GIS platform, allowing city planners

and engineers to overlay proposed utility lines or road expansions directly onto the hazard zones. This proactive approach moves beyond disaster response and into the realm of disaster risk reduction, ensuring that the growth of Nagaland's urban centers is synchronized with the geological realities of the terrain.

4.4.2 Zoning Regulations

- Zone VH (Very High Hazard): No building is allowed; current residents must leave within five years; reforestation is necessary; and the area is designated as a protected forest under the Nagaland Forest Act.
- Zone H (High Hazard): Only temporary and agricultural constructions are allowed; all construction must include a Site-Specific Geotechnical Investigation Report (SSGIR) and a Slope Stability Analysis, with a minimum setback of 15 meters from the slope crest.
- Zone M (Medium Hazard): Residential construction is allowed as long as it complies with the Building Code (NBC 2016, IS 1893 seismic zone V standards); drainage is required; and the slope angle of the building foundation is limited.
- Zone L (Low Hazard): Standard NBC 2016 compliance and standard construction norms are applicable.

4.4.3 Nagaland Town and Country Planning (TCP) Act Integration

The legal foundation for including LHZ in Master Plans is provided by the TCP Act of 1978 and the Nagaland Municipal Act of 2001. It should be mandatory for Kohima Municipal Council and Dimapur Municipal Council to create Disaster Risk-Sensitive Land-Use Plans (DRS-LUP) with five-year revision cycles that use GSI LHZ maps. A qualified geotechnical engineer should be required to sign off on all building plan approvals in Zones VH and H.

4.5 DISASTER PREPAREDNESS

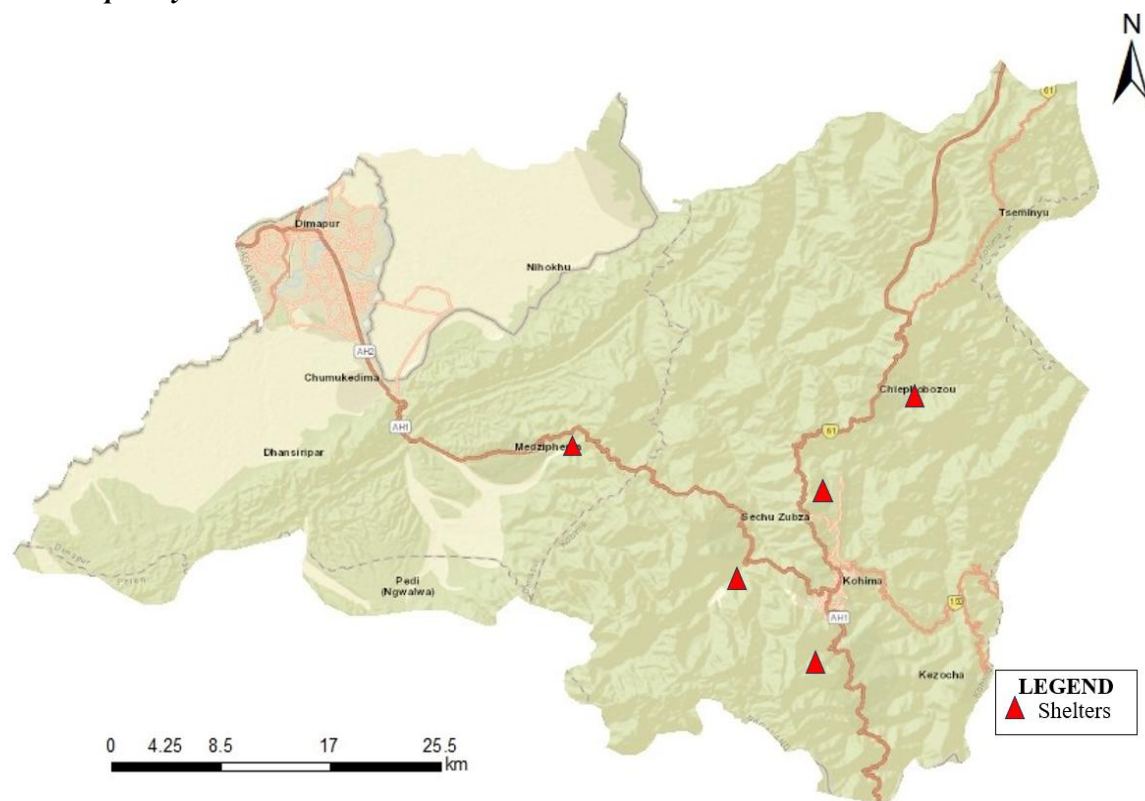
The purpose of this disaster preparedness plan is to establish a structured, three-phase framework for managing landslide disasters across Nagaland, with particular focus on the NH-29 corridor. The three phases — Before, During, and After — address the full spectrum of disaster management: proactive risk reduction and readiness measures; rapid, coordinated

response during active disaster events; and systematic recovery, reconstruction, and institutional strengthening in the aftermath. Together, these phases reflect a holistic approach grounded in national policy frameworks and informed by ground-level realities specific to Nagaland's geography and communities.

4.5.1 Before the Disaster - Preparedness and Prevention

Effective disaster management begins long before a disaster event occurs. The pre-disaster phase focuses on reducing vulnerability through strategic infrastructure development, community engagement, and risk-informed planning. Two primary components form the backbone of this phase: the establishment of temporary evacuation shelters and the formulation of robust policy interventions.

4.5.1.2 Temporary Evacuation Shelters



A network of pre-identified temporary evacuation shelter locations must be developed across low-risk and geologically stable zones in proximity to vulnerable settlements along the NH-29 corridor. Key shelter locations include Medziphema, Zubza, Chiephobozou, and other accessible settlements that lie outside high-risk slide-prone areas.

Each shelter facility should be equipped with a full range of essential services to support displaced persons for extended periods. These include emergency water supply systems, sanitation infrastructure, solar-powered lighting for off-grid resilience, medical kits and first aid facilities, communication equipment for coordination with state and district authorities, and clearly marked evacuation access routes.



4.5.1.3 Minimum Standards for Shelters

The design and construction of these shelters must comply with minimum standards established under national disaster preparedness norms:

- Each shelter must allocate at least seven square meters of floor space per occupant to maintain hygiene and personal safety.
- Safe Assembly Points must be designated a minimum of 300 metres away from slopes identified as slide-prone, ensuring that gathering areas are not themselves at risk.
- Site layouts must guarantee continuous access to potable water, sanitation facilities, electricity connections, and transportation links so that residents can sustain themselves and receive emergency services.
- Structures must be wind-resistant and engineered to withstand wind speeds of up to 120 km/h, and must include robust foundation systems appropriate to local soil conditions.

4.5.1.4 Policy Intervention

The pre-disaster framework is anchored in two key national instruments: the National Disaster Management Plan (NDMP 2019) and the National Landslide Risk Mitigation Programme (NLRMP 2025). Both underscore preparedness, community resilience, and infrastructure planning based on risk assessment data.

Funding mechanisms are available through the State Disaster Response Fund (SDRF) and the National Disaster Response Fund (NDRF). During the 2021-26 period, allocations amounting

to Rs 1,28,122 crore were directed to the SDRF, while Rs 54,770 crore was allocated to the NDRF. In 2025 alone, Rs 10,498.8 crore was disbursed across 24 states through SDRF channels. These funds can legally be applied toward land acquisition, basic amenities, access road construction, and the building of temporary shelter infrastructure as mandated components of disaster readiness.

- SDRF allocations are specifically designated for immediate relief needs, including temporary shelter provisioning.
- Funds are legally available for infrastructure development as part of preparedness activities, provided expenditures align with national norms and state disaster management plans.

4.5.2 During the Disaster - Response and Coordination

When a landslide event is imminent or actively unfolding, the priority shifts to rapid, coordinated response aimed at saving lives, minimizing disruption to critical corridors, and enabling swift evacuation. The central operational strategy for this phase is the training and deployment of local State Disaster Response Force (SDRF) teams, supported by a clear policy framework for assessment and training.

4.5.2.1 Training Local SDRF Teams

A specialized training programme should be developed for SDRF personnel operating along the NH-29 corridor. This programme focuses on rapid response competencies specifically suited to the corridor's terrain, traffic characteristics, and settlement patterns. The overarching goal is to reduce road closure duration during and after landslide events and to enable efficient, safe evacuation of affected populations.

The National State Disaster Management Authority (NSDMA) maintains an Annual Training Calendar for SDRF personnel, providing a structured institutional framework within which corridor-specific modules can be embedded. The NH-29 corridor training module should be developed as an extension of existing SDRF capacity-building initiatives, ensuring coherence with broader state-level preparedness programs.

The Disaster Management (Amendment) Act, 2025, further empowers State Disaster Management Authorities (SDMAs) to develop preparedness strategies specific to their regional needs, creating legal space for tailored, corridor-focused training programs.

Core Training Competencies

Basic search and rescue operations, including techniques for accessing debris-covered areas.

Knotting and rope-based rescue methods applicable to slope and cliff environments.

Fire behavior identification and extinguishing methods for post-landslide scenarios involving utility lines or vehicles.

Safe entry and navigation procedures for structurally compromised buildings.

Evacuation protocols designed to handle high volumes of displaced persons along the NH-29 corridor.

4.5.2.2 Policy Intervention

A structured, multi-layered evaluation framework must be used to assess the operational readiness of trained SDRF personnel. This framework includes pre-training and post-training knowledge assessments, practical skill demonstrations observed by qualified assessors, and scenario-based simulation exercises that replicate real landslide conditions in the NH-29 environment.

Training content must be differentiated to meet the specific needs of distinct target groups. Community volunteers require practical, accessible modules focused on basic rescue and evacuation. Professional SDRF personnel need advanced technical training in search-and-rescue operations, debris management, and emergency communications. Local administrative officers benefit from training in coordination protocols, resource mobilization, and inter-agency communication.

Plans should actively leverage partnerships with National Disaster Response Force (NDRF) battalions. These partnerships enable large-scale training exercises, bring expert instructors with broader field experience, and facilitate the exchange of best practices across state lines, thereby enriching and expanding the capacity-building pipeline for Nagaland's disaster response teams.

4.5.3 After the Disaster – Recovery and Institutional Strengthening

The post-disaster phase addresses both the immediate humanitarian needs of affected communities and the longer-term task of rebuilding more resilient settlements, infrastructure, and governance systems. This phase is structured around three pillars: the development of a comprehensive Standard Operating Procedure (SOP), targeted policy interventions, and a sequenced short-term and long-term recovery plan.

4.5.3.1 Developing a Nagaland Landslide Disaster Management SOP

A formal Standard Operating Procedure document, developed specifically for the Nagaland State Disaster Management Authority (NSDMA), is essential to institutionalizing the lessons and practices accumulated through disaster response operations. This SOP will formalize NSDMA's operational practices, ensure consistency across successive disaster events, and provide a documented reference point for training and auditing purposes.

The National Landslide Risk Mitigation Programme (NLRMP 2025) is an initiative by the National Disaster Management Authority (NDMA) aimed at reducing landslide risks across 15 high-risk states, with Nagaland identified as a priority area. NDMA, working in partnership with the Geological Survey of India (GSI), is implementing the '3Ms' framework — encompassing Mapping, Monitoring, and Mitigation - for landslide-prone areas nationwide. The SOP document under development is intended to guide specifically the Mitigation and Monitoring components of this framework at the state level.

4.5.3.2 Policy Intervention

Under Section 39 of the Disaster Management Act, 2005, the central government is mandated to prioritize capacity-building initiatives, ensure adequate funding allocation for those activities, and formalize plans for training disaster management personnel at the state level. Section 23 of the same Act stipulates that every state must have a functioning disaster management plan in place, providing a legal obligation for Nagaland to maintain and regularly update its landslide management framework.

The Incident Response System (IRS) must be integrated into the phased recovery framework and strictly complied with by all stakeholders participating in post-disaster operations. Additionally, the 3M + 3R framework - Mapping, Monitoring, Mitigation combined with Response, Relief, and Recovery - should be embedded into the phased response structure to provide a comprehensive and systematic operational logic.

Urban Local Bodies (ULBs) are mandated to coordinate their recovery activities with District Disaster Management Authorities (DDMAs), police forces, fire services, the Public Works Department (PWD), the Public Health and Engineering Department (PHED), and health departments. This cross-departmental coordination is particularly vital for pre-monsoon

planning, when anticipatory measures can significantly reduce the impact of the subsequent monsoon season.

4.5.4 Short-term Recovery Measures

Immediately following a disaster event, several critical recovery activities must be initiated without delay to stabilize affected areas and address urgent humanitarian needs:

- Debris clearance operations on roads, residential structures, and drainage channels to restore access and reduce secondary hazard risks.
- Provision of temporary transitional shelters equipped with Water, Sanitation, and Hygiene (WASH) facilities to meet the immediate needs of displaced households.
- Restoration of critical infrastructure systems including water supply networks, electrical grids, and communication facilities.
- Relief distribution programs providing food supplies, non-food essential items, medicines, and hygiene kits to affected populations.

4.5.5 Long-term Recovery Measures

Beyond immediate stabilization, a set of long-term measures is required to build durable resilience and prevent recurrence of disaster impacts at the same locations:

- Permanent resettlement of households located in high-risk or geologically unstable zones, with relocation to safer, planned settlements.
- Reconstruction of damaged housing stock using disaster-resilient design standards that incorporate slope stability, material durability, and structural integrity principles.
- Rebuilding of roads, bridges, and retaining walls using advanced engineering techniques that address the specific geotechnical challenges of Nagaland's terrain.
- Livelihood restoration programs encompassing agricultural support, vocational skill training, and economic rehabilitation to help affected communities regain self-sufficiency.

4.5.6 Conclusion

The Landslide Disaster Management Plan for Nagaland, as outlined across the three phases of this report, represents a comprehensive and legally grounded framework for reducing the human, economic, and infrastructural toll of landslide events in one of India's most vulnerable regions. The plan is not conceived as a stand-alone document but as an operational and living framework that evolves with updated hazard data, after-action reviews, and refinements to national policy guidelines.

Phase 1 establishes the foundation through proactive shelter provisioning and policy-aligned funding strategies that prioritize communities along the NH-29 corridor before disaster strikes. Phase 2 builds operational capacity through specialized training programs, multi-layered assessment protocols, and inter-agency partnerships that enable the rapid, coordinated responses that save lives during active events. Phase 3 charts a path from emergency stabilization through to long-term community and institutional rebuilding, anchored by a formal SOP, cross-departmental governance structures, and sequenced recovery investments.

A central thread running through all three phases is the integration of national legislative mandates with ground-level operational realities. The Disaster Management Act 2005 and its 2025 amendment, the NDMP 2019, and the NLRMP 2025 collectively provide both the legal obligations and the programmatic tools to implement this plan. What remains critical is consistent, adequately resourced implementation at the state and district levels, regular audits of shelter and training infrastructure, and genuine community engagement at every stage of the planning cycle.

Ultimately, effective disaster preparedness in Nagaland requires more than infrastructure and funding - it demands a shared culture of resilience, institutional accountability, and continuous learning. This plan is a step toward embedding that culture within the formal governance and operational structures of the state.

5 PHASED IMPLEMENTATION FRAMEWORK FOR NAGALAND (2025–2035)

The implementation framework is organized into four phases over 10 years, aligned with India's 16th Finance Commission cycle and Nagaland's Annual Development Plan periods:

Phase I: Foundation and Emergency Stabilization (2025–2027)

Phase I Objectives

Establish institutional infrastructure, complete hazard mapping, stabilize all critically failing slopes, and deploy community awareness systems across all 12 districts.

Activity	Agency	Timeline	Budget (INR Crore)	Funding Source
LHZ mapping (all 12 districts, 1:10,000)	GSI + NRSC + NSDMA	2025–2026	8–12	NDMA, GSI budget
Critical slope inventory (>1,000 sites)	PWD + NSDMA + District GEs	2025	3–5	State Plan
Emergency stabilization of 50 critical sites	PWD/NHIDCL/BRO	2025–2026	150–200	SDRF + NHIDCL
NSDMA Landslide Risk Management Cell setup	NSDMA + NIT Nagaland	2025	2–4	NDMA + State
CB-LEWS pilot in 3 high-risk districts	NSDMA + UNDP	2025–2026	5–8	UNDP + NDMA
Awareness campaign (all 1,536 villages)	NSDMA + Civil Defence	2026–2027	3–6	NSDMA State Plan
Drainage maintenance: 500 km roads	PWD + NRBDC	2025	20–30	State PWD Plan
PHASE I TOTAL	-	-	191–265 Crore	-

Phase II: Systematic Risk Reduction (2027–2030)

Phase II Objectives

Implement slope stabilization and bioengineering on all high-risk road slopes, expand LEWS to all 12 districts, enforce LHZ-based land-use regulations, and commence watershed restoration.

Activity	Agency	Timeline	Budget (INR Crore)	Funding Source
Slope stabilization: 200 road km (all NHs/SHs)	NHIDCL + PWD + BRO	2027–2030	400–600	NHIDCL + ADB
Bioengineering: 50,000 ha degraded slopes	Forest Dept + MGNREGS	2027–2030	75–125	CAMPA + MGNREGS
Retaining structures: 500 critical sites	PWD + State PWD	2027–2030	200–350	State Plan + World Bank
District LEWS expansion (12 districts)	NSDMA + IMD + ISRO	2027–2029	25–40	NDMA + ISRO-DMS
LHZ integration into TCP/Municipal Acts	Dept of TCP + NIC	2027	1–2	State Budget
Watershed restoration: 10 major watersheds	Forest + Agriculture Dept	2027–2030	50–80	IWMP + CAMPA
UAV LiDAR survey (state-wide)	NRSC + Private contractor	2027–2028	3–5	ISRO + State
PHASE II TOTAL	-	-	754–1,202 Crore	-

Phase III: Consolidation and Technology Integration (2030–2033)

Phase III Objectives

Integrate AI-based prediction systems, complete full state coverage of stabilization works on SHs, implement PES scheme, and achieve 70% reduction in landslide-induced casualties.

Activity	Agency	Timeline	Budget (INR Crore)	Funding Source
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AI landslide prediction model (statewide)	NSDMA + IIT Guwahati + IMD	2030–2031	8–15	DST-SERB + NDMA
InSAR monitoring programme (30 sites)	ISRO-SAC + NSDMA	2030–2032	5–10	ISRO + State
Stabilization: 300 km State Highways	PWD + World Bank	2030–2033	600–900	World Bank DREP
PES Scheme pilot (5 watersheds)	Forest Dept + ICIMOD + GIZ	2030–2031	4–8	GCF + GIZ + State
Biochar pilot on 20 degraded slopes	NIT Nagaland + DST	2030–2032	2–5	DST SERB + BIRAC
Tunnel feasibility for 5 worst NH sections	NHIDCL + MoRT&H	2030	3–5	NHIDCL DPR fund
Community forest legal recognition (200 villages)	Forest Dept + NMA	2030–2032	1–3	MoTEFCC + State
PHASE III TOTAL	-	-	623–946 Crore	-

Phase IV: Sustainability and Mainstreaming (2033–2035)

Phase IV Objectives

Achieve comprehensive LHZ compliance in all planning processes, complete all critical road stabilization, institutionalize long-term monitoring, and position Nagaland as a Northeast India model state for landslide risk management.

Activity	Agency	Timeline	Budget (INR Crore)	Funding Source
Annual slope maintenance programme (institutionalized)	PWD + NSDMA	Ongoing	50–80/yr	State PWD + SDRF
LEWS full operation and maintenance	NSDMA + IMD	Ongoing	15–25/yr	NDMA + State
Watershed PES scheme: 20 watersheds	Forest Dept	2033–2035	15–25	REDD+ + GCF
LRMC capacity building (10-year)	NSDMA + NIT + IIT G	Ongoing	3–5/yr	State + NDMA

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NATM Tunnel construction (2 priority sections)	NHIDCL	2033–2035	800–1,500	NHIDCL + MoRT&H
State Landslide Database (public portal)	NIC + NSDMA + GSI	2033	2–4	NIC + State IT Dept
Research partnership (NIT Nagaland + Int'l)	NIT Nagaland	Ongoing	2–4/yr	DST + SERB + ICIMOD
PHASE IV TOTAL	-	-	887–1,643 Crore	-

5.1 Total Investment Summary

Phase	Period	Total Investment (INR Crore)	Priority Level
Phase I: Foundation	2025–2027	191–265	Critical — Must begin immediately
Phase II: Systematic Risk Reduction	2027–2030	754–1,202	High — Core implementation
Phase III: Technology Integration	2030–2033	623–946	High — Consolidation
Phase IV: Sustainability	2033–2035	887–1,643	Medium — Long-term
GRAND TOTAL (10-year)	2025–2035	INR 2,455–4,056 Crore	~INR 245–406 Crore/year

5.2 Institutional Setup

A dedicated Nagaland Landslide Risk Management Authority (NLRMA) or Landslide Risk Management Cell (LRMC) under NSDMA should be established with:

- Director (Geotechnical Engineer, minimum 15 years experience): Overall technical coordination.
- GIS and Remote Sensing Specialist: Hazard mapping, monitoring, database management.
- Bioengineering Specialist: Vegetation stabilization programs.
- Community Liaison Officer: CBDRR, VDB coordination, awareness programs.
- Finance and Procurement Officer: DPR preparation, tender management, fund utilization.
- Data Management Officer: LEWS data, landslide database, reporting.

6. MONITORING AND EVALUATION FRAMEWORK

Indicator	Baseline (2025)	Target (2030)	Target (2035)	Measurement Method
Annual landslide fatalities	30–40/year	< 15/year	< 5/year	SDMA death register
% critical slopes stabilized	< 5%	40%	90%	PWD slope inventory
% villages with LEWS	< 1%	50%	100%	NSDMA records
Forest cover in LHZ-H zones	Declining	Stabilized	+10%	ISFR biennial report
% urban plans with LHZ compliance	0%	50%	100%	TCP Act compliance audit
Annual economic loss (INR Crore)	200–500	100–200	< 50	NSDMA damage report
% roads with drainage maintained	< 20%	60%	95%	PWD inspection records
Community observer network coverage	0 villages	500 villages	1,200 villages	NSDMA CB-LEWS register

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