

Ecological Oversight in Highway Planning: A Case Study of NH66 and Kerala's Environmentally Sensitive Landscapes

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Abstract

The catastrophic 2018 floods in Kerala claimed over 400 lives and displaced thousands. These floods exposed the critical consequences of unscientific infrastructure development. This development disregarded natural water flow and ecological balance. Despite clear warnings from the Post-Disaster Needs Assessment (PDNA) report and related policy frameworks, construction of the NH66 highway proceeded without integrating eco-sensitive guidelines. The PDNA emphasised the preservation of wetlands and paddy fields as vital flood buffers. The NH66 construction was characterised by rigid embankments, the filling of wetlands, and the blocking of natural drainage channels. This approach has severely disrupted Kerala's fragile hydrology. Sections of NH66, built after the floods, have caused widespread ecological degradation, increased flood risks, soil instability, and water contamination. These impacts have been observed across districts, including Kannur, Alappuzha, and Kozhikode. Fact-finding studies and local community reports reveal a pattern of engineering failures. Poorly designed culverts and embankments worsen flooding and destroy habitats. There has been a clear disregard for risk-informed, integrated water resource management. The state's Paddy Land and Wetland Act has also been sidelined. The resulting infrastructure threatens both ecological sustainability and public safety. This case highlights the urgent need to align Kerala's rebuilding efforts with disaster-resilient and environmentally conscious principles. These principles are envisioned in the "Nava Keralam" campaign and international best practices for risk-informed development and green reconstruction.

Keywords: Post-Disaster Needs Assessment (PDNA) report, eco-sensitive guidelines, unscientific infrastructure development, Risk-informed development, culverts and embankments, disaster-resilient

Introduction

The catastrophic floods that struck Kerala claimed over 400 lives, displaced thousands, and left widespread devastation. In response, the Post-Disaster Needs Assessment (PDNA) Report, prepared jointly by the Kerala government, UN, ADB, World Bank, and EU, issued a strong warning against infrastructure development that blocks natural water flow. It emphasised that wetlands and paddy fields should be preserved and integrated as essential natural buffers, rather than being cleared for construction. The report recommended an Integrated Water Resources Management (IWRM) strategy that adopts eco-sensitive, risk-informed planning for land use and settlements. It called for a people-centred recovery approach built around the principles of "room for the river" and "living with the water," the very foundation of what later became the

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Chief Minister's widely promoted "Nava Keralam" (New Kerala) campaign (Radhakrishnan, 2025). The recovery policy framework for building a Green Kerala, aligned with the Chief Minister's vision of Nava Keralam (New Kerala) and the principle of "build back better and faster," is built on four pillars, one of which emphasizes eco-sensitive and risk-informed approaches to land use and settlements. This pillar advocates for reconstructing buildings using disaster-resilient techniques, ensuring they are located away from vulnerable areas such as floodplains and unstable slopes. In line with the Kerala State Disaster Management Policy, reconstruction efforts must consider local hazards, community capacities, and resilient designs suited to risks like floods, cyclones, earthquakes, and droughts. To support Kerala's goal of becoming a green state, it is crucial to adopt alternative, low-carbon construction technologies that reduce environmental impact across all types of infrastructure projects, including roads. While organizations like Laurie Baker's architectural legacy, Habitat Technology Group, COSTFORD, the People's Movement for Sustainable Architecture, and the government supported Nirmiti primarily focus on sustainable housing, their principles of using local materials, energy efficiency, and ecological sensitivity offer valuable lessons for broader infrastructure development. Applying these types of sustainable construction approaches can help minimize carbon emissions, protect fragile ecosystems, and promote resilience in Kerala's infrastructure projects. Integrating such environmentally conscious methods into road design and construction supports the state's commitment to green development and disaster risk reduction in an ecologically sensitive region. Rebuilding efforts also present a valuable opportunity for skill development and the creation of green jobs. To manage the environmental impacts of increased construction, it is recommended to apply an Integrated Strategic Environmental Assessment, a method successfully used in post-disaster reconstruction in Sri Lanka and Nepal (UNDP, 2018).

Literature Review

The Asian Development Bank (2018) in "Risk-Informed Development: Using disaster risk information for resilience" report emphasises the need to tailor disaster risk information to the specific needs of end users, such as planners and policymakers, to enhance sustainable development and resilience. It highlights the importance of involving these users early in the risk assessment process to ensure relevant and actionable data. The Wellington, New Zealand case exemplifies a successful multi-stakeholder approach where scientific data directly informed urban planning and emergency management. Key lessons include starting with available data, transparently communicating uncertainties, and integrating community knowledge to enrich scientific findings. This study provides valuable insights into co-producing risk information that supports inclusive, effective disaster risk reduction and planning.

BMT (2021) in the study "ALARP: Is the Risk as Low as Reasonably Practicable?" discusses reducing risks to a level as low as reasonably practicable through practical control measures and engineering judgment. The article outlines various approaches for demonstrating ALARP, including risk criteria comparison, cost-benefit analysis, qualitative assessment, and expert judgment. It emphasises the hazard management hierarchy, prioritising inherently safer solutions over engineering and administrative controls. Case studies from chemical and storage facilities illustrate how combining qualitative and quantitative methods effectively supports ALARP demonstrations.

Coffin, A.W., and his colleagues in their study “The Ecology of Rural Roads: Effects, Management, and Research” explore the ecological impacts of expanding rural road networks, highlighting habitat destruction, traffic disturbances, invasive species introduction, pollution, hydrological changes, and increased access leading to ecosystem degradation. They emphasise how road ecology as a discipline quantifies these effects and informs strategies to mitigate negative impacts through better transportation planning and management. The authors propose practical mitigation measures such as road placement to avoid sensitive areas, wildlife crossings, fencing, and traffic controls during critical periods. This work contributes valuable insights into balancing infrastructure development with ecological sustainability in rural landscapes.

GNDR (2022) in the report “Risk-Informed Development Guide: A Practical Approach for Civil Society Organisations and Communities Most at Risk” emphasises a rights-based approach to risk-informed development that centres on respecting and empowering communities most at risk. The guide outlines a three-phase process: Define, Assess and Anticipate, and Act and Manage that prioritises active community engagement and incorporates their perspectives into planning. It highlights key stages such as risk prioritisation, strategic foresight, and collaborative decision-making to enhance resilience and sustainable development outcomes. Furthermore, GNDR stresses the necessity of accountability and continuous learning with communities throughout the development process. This practical framework supports civil society organisations and communities in integrating rights and local knowledge into risk management and development strategies.

Radhakrishnan S (2025), in the essay "NH66 in Kerala: Built Against Water Logic, Designed to Collapse?" argues that the collapse of NH66 in Kerala was not an accident but a consequence of disregarding natural water systems, terrain, and local communities during construction. The highway was built by filling wetlands and blocking natural drainage, which led to flooding and infrastructure failure even under normal rainfall. The author highlights how ignoring ecological and social realities results in both environmental damage and community disruption. This case exemplifies the dangers of imposing infrastructure projects without respecting local environmental and social contexts.

The Hindu Bureau (2025) in "NH Development Destroying Kannur Wetlands, Says Fact-Finding Panel" reports that the National Highway development in Kannur is causing extensive destruction of mangrove-rich wetlands between Pullupikadavu and Kattampally. A fact-finding team under the district environmental coordination committee warns of irreversible ecological damage due to these construction activities. The report highlights that mangrove forests, crucial for fish breeding, ecological balance, and local livelihoods, are being lost without any plans for restoration. This case underscores the environmental risks posed by infrastructure projects that fail to consider the ecological sensitivity of wetland ecosystems.

Walia, K., Aggarwal, R.K., & Bhardwaj, S. K. (2025), in "Environment Impact Assessment of Highway Expansion – A Review analyses the long-term ecological impacts of highway expansion, focusing on land-use changes, habitat fragmentation, and alterations in ecosystem services, with a case study on Highway 6 in Puli Township. They emphasise that road construction causes significant landscape restructuring, affecting habitat connectivity and leading to biodiversity loss, especially in rural and developing regions. The study highlights that indirect effects, such as deforestation and microclimatic changes along forest edges, have profound and far-reaching consequences on both terrestrial and aquatic ecosystems. The

authors conclude that comprehensive assessments of highway impacts on air, soil, water quality, and human health remain insufficient and call for more detailed future studies to address these gaps.

Research Methodology

This study adopts a qualitative research approach based entirely on secondary data sources. Data has been collected from existing research papers, government reports, policy documents, project evaluations, and credible news articles related to road infrastructure development, disaster risk management, and environmental impacts in Kerala. The analysis focuses on synthesising insights from these sources to identify key challenges, risks, and best practices relevant to road construction in extreme environmental conditions. By relying on secondary data, this study leverages established findings and documented case studies, ensuring a comprehensive understanding of the issues without direct fieldwork or primary data collection.

Statement of the Problem

The road infrastructure development of the state, as seen in projects like NH66 (National Highway 66 runs 1,622 km from Kanyakumari to Mumbai, entering Kerala at Talapady and passing through major cities like Kannur, Kozhikode, Kochi, and Thiruvananthapuram before reaching Tamil Nadu), reveals a persistent gap between ecological sensitivity, disaster risk awareness, and engineering practice. The state's fragile environment, with its wetlands, waterways, and flood-prone areas has been compromised due to poorly informed planning and construction. Traditional road design approaches tend to be prescriptive and focus on limited hazard scenarios, often neglecting the complex multihazard risks faced by the region. These oversights have led to increased flood risks, environmental degradation, infrastructure failures, and community resistance.

Given these challenges, there is a critical need for an integrated, risk-informed, and knowledge-based framework that can guide infrastructure development in Kerala's unique and extreme environment. Such a framework should combine scientific risk analysis with local knowledge and adaptive planning to enhance resilience and sustainability. This raises important questions: How can risk-informed, knowledge-based analytical methods be adapted to improve road infrastructure design in Kerala's extreme environmental conditions? What are the key environmental and social risks neglected in current road construction projects like NH66, and how can they be mitigated? And how effective are advanced decision-making tools, such as Bayesian Networks and ALARP principles, in guiding resilient infrastructure development under multi-hazard scenarios?

Lessons in Environmental Governance and Land Use Planning

The places we live in come with risks, especially in regions like Kerala, where fragile ecosystems and limited natural resources make communities vulnerable to environmental hazards. These risks are also affected by people's actions and social, economic, or mental health challenges that make some people more at risk than others. When development does not consider these risks, it can actually make things worse instead of better, creating new problems, making old ones bigger, and undoing progress. To avoid this, development should be planned with the help of the people who are most affected by the risks. It should bring together different groups to work together and make smart decisions. Good planning should try to avoid creating new risks, reduce existing risks by making people and places stronger, and keep learning from experience to make things better over time. Most importantly, if we listen to the people who face the most risk, development can have a much bigger and more positive impact on their

lives, jobs, and communities (GNDR, 2022). To address the vulnerabilities effectively, comprehensive disaster risk assessments must become an integral part of development planning, especially in ecologically sensitive regions like Kerala. However, current practices often fall short, lacking the foresight and resources needed to anticipate and mitigate future risks.

There is a major gap in doing proper disaster risk assessments for both public and private investments over the medium and long term. These assessments should include looking at tradeoffs that might cause risks in the future, but they are often missing. Decisions based on experience, science, and forward-thinking approaches are also not being used enough. Another big issue is the lack of dedicated funding for disaster risk reduction (DRR), especially in budgeting for the Sustainable Development Goals (SDGs). This is a serious challenge for least developed countries (LDCs), landlocked developing countries (LLDCs), and small island developing states (SIDS), where money and resources for reducing disaster risks were already limited even before the COVID-19 pandemic. Although these countries include small amounts for DRR in their national and local budgets, they often lack the right environment to attract private sector investment. As a result, efforts to prevent disasters, reduce risks, and build resilience remain weak in these vulnerable regions. Effective disaster risk reduction requires not only adequate funding and policy support but also the integration of risk awareness into critical infrastructure planning (UNDRR, 2022).

Road infrastructure plays a crucial role in daily life and economic development, yet its functionality is often threatened by disasters such as landslides and floods. These hazards can severely impact travel efficiency and pose significant safety risks to users. Ensuring the safety and resilience of roads must begin at the design stage, where critical decisions such as road alignment and structural type are determined. While traditional prescriptive-based design establishes minimum safety standards, it often fails to address the full range of potential risks, especially in extreme environments (Li et al, 2021).

To overcome these limitations, risk-based design offers a more comprehensive approach by focusing on operational safety and augmenting prescriptive measures. However, current risk-based models often address only single-disaster scenarios, rely on limited real-world data, and overlook rare but high-impact risks. This indicates a need for more integrated, data-driven methods that account for multiple hazards and enable robust decision making under uncertainty (Li et al., 2021)

In this context, Li et al (2021) introduced the Risk-informed Knowledge-based Analytical Method (RKAM) in their study titled "Risk-informed knowledge-based design for road infrastructure in an extreme environment". RKAM is a collaborative method developed to improve the resilience of road infrastructure in hazardous conditions. It integrates two major components:

- An analytical framework that evaluates various disaster risks.
- A synthesis framework based on Bayesian networks, supported by structured knowledge sources.

This hybrid approach enhances decision-making by incorporating diverse data inputs and allowing adaptability to dynamic risk factors.

Bayesian Networks are graphical probabilistic models that combine statistics and graph theory to model uncertainty and causal relationships. Structured as directed acyclic graphs (DAGs), BNs use Bayes' Theorem to calculate conditional probabilities, helping engineers simulate various disaster scenarios and assess the influence of different variables. In construction engineering, BNs are especially valuable when data is scarce. They allow for scenario simulation, probability updating, and risk evaluation. Despite challenges such as being time-consuming to build and heavily reliant on input quality, they provide critical support in infrastructure decision-making (Leśniak & Janowiec, 2020). A notable real-world application of RKAM was carried out in the Tuoba–Qamdo Highway project in China, which passes through a region exposed to numerous natural hazards. The case study revealed that different design alternatives were vulnerable to various types of disaster risks, such as landslides, floods, and seismic activity. Through RKAM, an integral risk map was developed, which provided comprehensive insight into the relative safety of each design alternative, thus enabling more informed and balanced decision-making (Li et al., 2021).

Safety risks can be managed in several ways, such as by following local and international laws, regulatory guidance, codes, and standards, or by using sound engineering judgment. This approach supports strong decision-making by applying scientific and engineering methods. In important safety decisions, engineering judgment should follow the hazard management hierarchy, which focuses on removing or preventing hazards whenever possible. These types of solutions are preferred over other engineering controls and are better than relying on rules or procedures that depend on human action. In an ALARP (As Low as Reasonably Practicable) decision, it is important to show that no other practical steps can be taken to further reduce safety risks. Efforts should focus on the main sources of risk related to a facility or activity (BMT, 2021).

Risk information related to natural hazards and climate change must be tailored to meet the specific needs of end users. While traditionally handled by scientists, this information now plays a crucial role in development decision-making, requiring adaptation in both content and presentation. Different stakeholders, such as national planners, municipal urban developers, insurance providers, and farming communities, have varied requirements in terms of spatial (location, scale, resolution) and temporal (timing, duration) aspects of risk data. To ensure effective use and integration across sectors, it is essential to standardise the scope and format of data. This includes agreeing on consistent geographic boundaries (e.g., administrative units), appropriate hazard data resolution, and using compatible formats for tables and maps (ADB, 2018).

Kerala has a long history of grappling with the consequences of poorly informed infrastructure development, despite being one of the most ecologically sensitive regions in India. The state's dense water networks, fragile wetlands, and history of recurrent floods demand that road construction be guided by localized risk assessments and environmentally responsive planning. Yet, in practice, road projects have often sidelined such critical inputs. The consequences of this disconnect are starkly visible in major initiatives like NH66, where engineering choices have clashed with Kerala's natural systems and disaster memory.

NH66 now stands as a stark monument to institutional forgetting. With its high embankments and rigid uniformity, the highway carves through Kerala's natural drainage systems, fills once thriving paddy fields, and escalates flood risks across entire districts. This isn't mere oversight;

it reflects a systemic disregard for ecological wisdom and flood resilience. While the National Highways Authority of India (NHAI) executed this environmental disruption, it was the Kerala government that enabled it. The once progressive Paddy Land and Wetland Act of 2008 was systematically weakened, even after the state's devastating floods should have underscored its importance. Rather than defending Kerala's fragile hydrology, the Public Works Department (PWD) aligned with development interests, undermining environmental safeguards. In effect, NH66 symbolises not just flawed infrastructure but a deeper failure to remember and act on the state's lived disaster history (Radhakrishnan, 2025).

Even though it is the same project, the way it was built in different parts of Kerala tells very different stories. The challenges and mistakes vary depending on the local environment and how things were managed on the ground. Now, this study explores how these inconsistencies have led to distinct construction failures in multiple locations across Kerala, revealing deeper structural and systemic issues within the project as a whole.

A fact-finding study by the district environmental coordination committee has revealed alarming ecological destruction caused by the construction of NH66 between Pulluppikadavu and Kattampally in Kannur. Large swathes of mangrove-rich wetlands, crucial for biodiversity, fish breeding, flood regulation, and local livelihoods, have been destroyed without any restoration plans in place. The study, led by convener K. Karunakaran and inaugurated by T.P. Padmanabhan of the Society for Environmental Education in Kerala, accuses the National Highways Authority of India (NHAI) of neglecting the loss of tens of thousands of mangrove trees. Particularly concerning is the use of low-grade silt to fill swamps from Pappinissery Island to Muzhappilangad, creating risks of soil instability. Construction-related waterlogging has already contaminated wells in areas like Keezhattoor and Muzhappilangad, with chemical runoff damaging vegetation and posing public health risks (The Hindu, 2025). The report highlights a series of engineering and planning failures: underpasses built lower than road levels, flawed protective structures, and the complete disregard for natural topography, stream flow, and climate realities. Blocked drains and covered channels have worsened flooding, while changes in water flow direction raise the threat of saltwater intrusion into drinking water and agricultural zones. The panel has called for an immediate halt to construction in ecologically fragile areas, advocating for a viaduct-style approach instead of embankments, especially through sensitive zones like the Munderi Kadavu bird sanctuary, a proposed Ramsar site. It also recommends a full water audit, fresh geotechnical studies, and rectification of all structural and ecological anomalies. The preliminary findings document a trail of habitat destruction, pollution, and infrastructure denial, urging authorities to prioritise local needs and environmental safety before resuming any further work (The Hindu, 2025).

From Thrissur's Kole wetlands to Alappuzha's backwaters, and from Kozhikode's canals to Kollam's service roads, NH66 has carved a trail of ecological and infrastructural damage. Communities and environmental experts consistently raised red flags during its construction, pointing to blocked field channels, faulty culverts, unscientific embankments, and inundated service roads. In Karivellur, Kalikkadavu, and Pilathara, early monsoon floods swept through homes—direct consequences of embankments obstructing natural streams. In Cheruvathur, rare laterite mesas, which once acted as natural slope buffers, were razed to supply construction fill. Wetlands and mangroves in Kattampally, Kuttikkol, and Pulluppikadavu were filled in, leading to widespread water contamination and ecosystem collapse. Despite clear documentation and urgent warnings from affected communities, authorities continued to ignore the mounting evidence (John, 2018).

The fragmented, segmented design of NH66 further diluted public resistance, as communities were left with only partial knowledge of the larger project footprint. As a result, impacts were addressed in isolation rather than collectively. While some completed sections are already open to traffic, many are under construction or already showing signs of failure such as cracking, flooding, or erosion. Across Alappuzha, Kollam, Kozhikode, and Kannur, service roads are washing away, water stagnates in canals and paddy fields, and large cracks have appeared. In Pappinisseri Thuruthi, floodplains once vital for drainage are now reduced to stagnant retention ponds, imprisoned behind the concrete walls of NH66 (Radhakrishnan, 2025).

Keezhattur village in Kannur district has emerged as a flashpoint in Kerala's ongoing struggle between development and environmental preservation. The state government, in collaboration with the National Highways Authority of India, plans to construct a four-lane bypass as part of NH66 to ease traffic congestion in Taliparamba. However, the proposed alignment requires the acquisition of 29.11 hectares of land, of which 21.09 hectares are wetlands and paddy fields, critical ecosystems that function as natural water recharge zones for Keezhattur and surrounding villages. Fearing irreversible ecological damage and the loss of their farming livelihoods, residents have mounted strong resistance (John, 2018).

Leading this grassroots movement is a collective of farmers who call themselves Vayalkilikal, meaning "birds in the paddy fields." What began six months ago as a small protest by 60 villagers has since grown into a significant people's movement, drawing attention across the state and putting mounting pressure on the government. For the protesters, this is not just a battle to save their land but a broader fight to protect Kerala's fragile hydrology from being sacrificed in the name of unchecked infrastructure expansion.

Keezhattur was not ready to wait in a queue near a public tap for drinking water in the hot sun," declared the agitating farmers of Vayalkilikal, emphasizing that their protest was rooted in environmental concern, not politics. Their leader, Suresh Keezhattur, drew from personal experience in Equatorial Guinea, where misinformation about groundwater safety had led impoverished communities to depend on bottled water despite abundant natural reserves. He feared a similar fate for Keezhattur if the wetlands were destroyed. The group strongly opposed the plan to fill fertile paddy fields with 2.6 million tons of soil to build a highway embankment, raising urgent questions: Where would this vast quantity of soil come from? How many hills would be razed to extract it? What would happen to rainwater storage, groundwater recharge, and the village's delicate hydrological balance? Keezhattur's wells had long supplied water to the entire Taliparamba municipality, a testament to the area's ecological richness sustained by its paddy fields and marshlands. Yet, according to Suresh, authorities were not even willing to engage in dialogue over these critical concerns (John, 2018).

A 2020 notification issued by the Ministry of Environment, Forest, and Climate Change (MoEFCC), which exempted certain activities, including the extraction of ordinary earth for linear projects like highways, from requiring prior Environmental Clearance (EC). The National Green Tribunal (NGT) noted concerns raised by the applicant, who argued that such blanket exemptions violated key environmental principles, particularly the Supreme Court's 2012 Deepak Kumar judgment, which mandated ECs for mining-related activities. The applicant argued that the exemption lacked safeguards, had no limits on the scale of earth extraction, and undermined the principles of sustainable development and precautionary regulation. In response, the MoEFCC defended the notification, claiming it was issued in the

public interest to assist communities like farmers and potters and had already been upheld by the Supreme Court in a separate case. However, the NGT observed that the Supreme Court's dismissal of the related writ petition did not clarify the merits of the issue, nor did it establish binding legal precedent. The Tribunal held that while exemptions for certain linear projects might be justified in specific cases, they cannot be granted as blanket permissions without proper environmental safeguards, limits on excavation, and mechanisms for impact assessment. It directed the MoEFCC to revisit and revise the notification within three months, ensuring alignment with sustainable development principles as mandated under the NGT Act, 2010 (NGT, 2020). Most funding for environmental conservation in India comes from the government, while private investments are very small. For the year 2024-25, only a tiny portion, about 0.00087% of the national budget, is allocated directly to the Ministry of Environment, Forest, and Climate Change for protecting nature and ecosystems. Other ministries also invest in environmental issues, but mainly for dealing with the effects of environmental damage. Despite this, public funds are limited and face many competing priorities, which means there is not enough money for restoring and maintaining the environment, something essential for people's health and quality of life. Private investors are generally not interested because preserving natural resources often is not economically profitable, highlighting a market failure. While charities and aid groups help support some environmental projects, their efforts alone are not enough (Sitling, 2025).

India's environmental governance faces critical challenges in balancing infrastructure development, such as road construction, with ecological protection. Despite stringent laws like the Environment (Protection) Act, 1986, enforcement weaknesses due to underfunded and understaffed regulatory bodies have allowed projects to proceed with minimal environmental oversight. Relaxation of Environment Impact Assessment (EIA) norms has facilitated road and infrastructure expansions that often encroach upon sensitive ecosystems, leading to habitat loss, wetland degradation, and disruption of natural water systems. Public participation in decision-making is frequently overlooked, marginalising communities affected by such projects. Additionally, inadequate monitoring technology and reliance on manual inspections hamper the timely detection of environmental violations during construction. These factors collectively undermine ecological conservation amid rapid infrastructure growth, highlighting the urgent need for stronger enforcement, transparent assessments, and sustainable construction practices to mitigate environmental damage from road development (Drishti IAS, 2025).

The expansion of National Highway 66 in Kerala has revealed the devastating consequences of unscientific construction practices, ecological disregard, and bureaucratic negligence. In Thaliparamba, Puliparambil Sreedharan's home, though technically outside the acquisition zone, was destabilised due to hill excavation for soil, forcing his family to evacuate without compensation. Similar chaos unfolded in nearby Kuppam and Keezhattur, where indiscriminate soil extraction and faulty embankment construction triggered landslides, road collapses, and destruction of wetlands. Keezhattur, a site of sustained resistance since 2018, has seen its paddy fields and natural hydrology severely compromised despite repeated warnings from local communities. As embankments built over marshy terrain gave way, cracks and collapses emerged across service roads and elevated segments, posing life-threatening risks, as seen in Malappuram, where residents narrowly escaped tragedy during a sudden highway collapse. Despite mounting evidence, the National Highways Authority of India (NHAI) denied engineering faults, attributing the incidents to rain infiltration. Experts, including E. Sreedharan, have since reiterated that raising embankments on soft, flood-prone terrain is fundamentally flawed. Civic groups and engineers alike argue that had the road been built on concrete pillars instead of unstable gabion-filled embankments, these disasters could

have been avoided. The collapse of NH66 infrastructure is not just a technical failure; it is a human and ecological crisis stemming from ignored warnings, compromised methods, and institutional indifference (Shaji, 2025). Road construction and its drainage systems change how water moves across the land, affecting nature and water bodies nearby. Roads are made of surfaces that don't let water soak in, and the drainage systems are designed to push rainwater away quickly.

This prevents water from going into the ground to refill the underground water and helps plants grow. Instead, the water flows fast into streams, which can cause floods. In farming and forest areas, unpaved roads wash loose soil into rivers and lakes, making the water dirty and warmer. This harms fish like trout and salmon that need cold, clean water. When many roads are built in one area, the soil and rocks used to build them can slide into streams, damaging plant and animal life in the water. Roads also break up natural areas and change how water flows, especially near rivers and streams. In flat areas or mountains, roads can block water from spreading across floodplains, which changes normal flooding patterns and affects the land and wildlife. In places like the Everglades in Florida, roads like the Tamiami Trail have blocked water for years, leading to problems with fires, animal movements, and how nutrients are spread. Roads also change the weather around them. Because they are more open and paved, the areas near roads can become hotter, drier, and windier than the land nearby. These changes can harm plants and animals living close to the roads. All these problems show why it's important to plan and build roads in a way that protects nature (Coffin et al, 2021). In rural areas, especially in developing countries, the construction of roads has been closely linked to land cover changes, particularly deforestation. Roads make previously inaccessible forest areas reachable, leading to large-scale clearing of land. One of the most serious consequences of this is habitat fragmentation, which poses long-term threats to biodiversity. The impact of road construction varies depending on the type of road and the region's level of economic development. For example, in the Amazon, road development has been directly associated with climate change, increased deforestation, and forest fragmentation. Based on principles from land use planning, transportation systems, network theory, and ecology, the ecological road network theory helps explain how road systems affect ecosystems. Studies show that road networks can disrupt large landscapes, create isolated habitat patches and reducing ecological connectivity across the region (Walia et al, 2017).

Discussion

Infrastructure development, especially highway construction, has far-reaching consequences that go beyond just building roads. When highways are expanded or newly built without considering the natural landscape and ecosystems, the results can be devastating. Roads often fragment habitats, disrupt animal and plant life, and alter the delicate balance of ecosystems. This fragmentation doesn't just affect the immediate area—it changes entire landscapes and can contribute to deforestation, changes in microclimate, and loss of biodiversity. These impacts are particularly severe in rural and ecologically sensitive areas, where the natural environment plays a critical role in supporting livelihoods and maintaining ecological health. A striking concern is that even after catastrophic floods and infrastructure failures, rebuilding efforts often ignore the very environmental and hydrological realities that caused the damage. For example, the collapse of a highway section in Kerala was not simply a structural failure but the outcome of ignoring how water moves through the land, the monsoon's rhythm, and the ecological memory of the region. The highway was built on wetlands, disrupting natural drainage and flooding homes, yet reconstruction efforts tend to focus on rapid repairs rather

than addressing these root causes. This approach perpetuates vulnerability rather than resilience. Similarly, many highway projects continue to destroy vital ecosystems, like mangrove forests in Kerala, without any comprehensive restoration plans. Funding for these projects is typically directed towards construction and short-term fixes rather than long-term ecological restoration and sustainability. This lack of investment in restoration ignores the crucial role these natural systems play in protecting against floods, supporting biodiversity, and sustaining local communities. As a result, environmental degradation and social disruption persist, undermining the very purpose of infrastructure development. Addressing these challenges requires more than technical fixes; it calls for involving communities directly affected by these developments. Engaging people most at risk, listening to their experiences, and incorporating their knowledge ensures that development respects their rights and aspirations. Risk-informed development frameworks emphasize that those vulnerable to environmental and social risks should be active participants in shaping solutions, which leads to more equitable and effective outcomes. This participatory approach, combined with careful scientific analysis, helps identify priorities and strategies that build resilience rather than exacerbate existing vulnerabilities. At the core of managing risks in infrastructure projects is the principle of making risks “as low as reasonably practicable.” This means using sound engineering judgment, following regulations, and prioritizing safer, more sustainable solutions first before relying on administrative controls. It encourages continuous evaluation and balancing of risks, costs, and benefits to ensure that infrastructure development does not come at an unnecessary cost to people or the environment. In essence, sustainable infrastructure development requires a holistic view that respects natural processes, protects ecosystems, involves local communities, and rigorously manages risks. Without this integrated approach, we risk repeating mistakes that lead to environmental degradation, structural failures, and social injustice. But with careful planning, genuine community engagement, and a focus on long-term ecological restoration, it’s possible to build infrastructure that supports economic growth while preserving the natural and social fabric that sustains us all.

Conclusion

The challenges faced by Road infrastructure projects highlight the urgent necessity for a paradigm shift in design and implementation strategies. The introduction of innovative methods like the Risk-informed Knowledge-based Analytical Method (RKAM) offers a promising way forward, enabling a comprehensive understanding of multi-hazard risks and facilitating safer, more resilient road designs. Incorporating tools such as Bayesian Networks and adhering to principles like ALARP (As Low As Reasonably Practicable) can strengthen decision-making under uncertainty. However, technical solutions must be coupled with strong regulatory frameworks, environmental safeguards, and community engagement to prevent further ecological degradation and infrastructure failures. Moving ahead, Kerala’s vision of a Green and Resilient State demands that all infrastructure development be rooted in ecological wisdom, disaster risk management, and sustainable growth to protect both its people and its environment.

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