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Climate-Induced Loss and Damage at 2°C: Economic Risk and Inequality in India

Sanjay Kumar Srivastava

sanjay.sri2025@gmail.com

National Institute of Advanced Studies https://orcid.org/0009-0005-9613-4867

Research Article

Keywords: Loss and Damage, Climate Economics, Disaster Risk, Climate Resilience, Food Security, Development Inequality, Climate Adaptation

Posted Date: May 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9736683/v1

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Additional Declarations: The authors declare no competing interests.

Abstract

Climate change is increasingly reshaping the economic landscape of disaster risk, particularly in developing economies where climate exposure intersects with structural poverty and inequality. As global temperatures approach 2°C above pre-industrial levels, a growing share of climate impacts may exceed the limits of feasible adaptation, emerging as Loss and Damage (L&D). This paper examines the potential economic implications of climate-induced Loss and Damage in India using insights from disaster risk modelling and empirical disaster loss datasets. Scenario-based estimates suggest that climate-related disaster losses could rise to approximately 1.5–2 percent of GDP annually under a 2°C warming pathway, with 20–30 percent representing residual Loss and Damage beyond adaptation limits. These losses are unlikely to be distributed evenly across society and may disproportionately affect vulnerable regions where climate exposure intersects with poverty and agricultural dependence. Using the case of Bihar, the study illustrates how climate risks may reinforce structural inequalities and food security challenges. The paper concludes by outlining policy pathways for minimizing Loss and Damage through climate-resilient agriculture, adaptive social protection, and anticipatory climate risk management.

Highlights

- 2°C warming represents a structural threshold in India's climate risk economy.
- Disaster losses could reach 1.5–2% of GDP annually under warming scenarios.
- 20–30% of these losses may constitute irreversible climate-induced Loss and Damage.
- Vulnerable regions such as Bihar face disproportionate climate inequality risks.
- AI-enabled climate intelligence can strengthen anticipatory disaster governance.

1 Introduction

Climate change is increasingly reshaping the economic foundations of disaster risk. For much of the past three decades, climate policy frameworks have been built around two primary strategies: mitigation, aimed at reducing greenhouse gas emissions, and adaptation, focused on reducing vulnerability to climate impacts. While these strategies remain indispensable, the accelerating pace of climate change is revealing important limits to this framework (IPCC 2023).

Scientific assessments indicate that global temperatures are likely to approach 2°C above pre-industrial levels during the twenty-first century under several emissions scenarios (IPCC 2023; Stern 2007). At this level of warming, climate hazards are projected to intensify significantly. Extreme rainfall events are becoming more frequent, heatwaves are lengthening in duration, and tropical cyclones are showing signs of increasing intensity in several regions (IPCC 2023; UNDRR 2022).

At the same time, expanding infrastructure and rapid urbanisation are increasing the value of assets exposed to climate hazards. As a result, economic losses from disasters have been rising steadily

worldwide (Hallegatte et al. 2017; UNDRR 2022). In this context, the concept of Loss and Damage (L&D) has gained growing attention in both climate policy and economic research. Loss and Damage refers to the residual impacts of climate change that occur despite mitigation and adaptation efforts (UNFCCC 2022). These impacts include irreversible losses to livelihoods, infrastructure, ecosystems, and cultural systems.

For India, the implications are particularly significant. The country's geographic diversity exposes it to multiple climate hazards, ranging from Himalayan floods to coastal cyclones and extreme heat across the Indo-Gangetic plains (World Bank 2022; UNDRR 2022, Dhara et al 2026). At the same time, large segments of the population remain economically vulnerable, limiting their capacity to absorb climate shocks (Hallegatte et al. 2017).

This paper argues that 2°C warming represents a structural break in India's climate risk economy, marking a transition from manageable adaptation challenges to systemic development risks. This study contributes to the emerging literature on the economics of climate-induced Loss and Damage in three ways. First, it develops a scenario-based estimate of potential climate-related disaster losses for India under a 2°C warming pathway using insights from infrastructure risk modelling frameworks. Second, it links climate-induced economic losses to structural inequality by examining how disaster impacts disproportionately affect vulnerable regions such as Bihar. Third, the paper discusses policy pathways for addressing Loss and Damage through adaptive social protection, climate-resilient agricultural systems, and emerging climate intelligence technologies. By integrating economic risk modelling with development inequality analysis, the study aims to advance understanding of how climate-induced losses may reshape development trajectories in emerging economies.

2 The Emerging Economics of Loss and Damage

The concept of Loss and Damage has become increasingly central in global climate governance. It gained institutional recognition through the Warsaw International Mechanism for Loss and Damage and was further strengthened by the establishment of a Loss and Damage Fund under the UNFCCC (UNFCCC 2022).

From an economic perspective, Loss and Damage represents the residual risk that remains after mitigation and adaptation measures have been implemented (Pindyck 2013; Nordhaus 2019). These impacts arise when climate hazards exceed infrastructure design thresholds, ecosystems cross irreversible tipping points, or vulnerable communities lack sufficient adaptive capacity (Adger et al. 2003).

One of the significant research indicates that global disaster losses now exceed US$700 billion annually, reflecting both hazard intensification and growing economic exposure (UNDRR 2022). Infrastructure disruptions can significantly amplify these losses because modern economies depend heavily on interconnected infrastructure systems such as power, transportation, and water supply (Hallegatte et al. 2018).

For rapidly developing economies such as India, where infrastructure expansion is occurring at an unprecedented scale, the economic stakes associated with climate resilience are particularly high (World Bank 2022).

4 Estimating Climate-Induced Loss and Damage at 2°C: Analytical Framework

Assessing the economic implications of climate-induced Loss and Damage requires an analytical framework that connects climate hazards with economic exposure and social vulnerability. This study adopts a scenario-based approach grounded in disaster risk modelling principles widely used in catastrophe risk analysis (Hallegatte et al. 2017; UNDRR 2022).

At the center of this framework is the concept of Average Annual Loss (AAL), which represents the expected economic loss from disasters in any given year. AAL is commonly used in probabilistic risk assessments because it integrates the likelihood of hazard events with the magnitude of their economic consequences (Hallegatte et al. 2017). In simplified terms, Average Annual Loss can be expressed as the sum of potential losses associated with different hazard events weighted by their probability of occurrence.

Empirical evidence suggests that climate-related disasters currently generate losses equivalent to roughly 0.8–1 percent of India's GDP each year (EM-DAT 2024; Munich Re 2024). These losses arise primarily from floods, cyclones, droughts, and extreme heat events (UNDRR 2022). However, climate projections indicate that the intensity and frequency of several of these hazards are likely to increase as global temperatures approach 2°C warming (IPCC 2023).

To explore the potential implications of this warming threshold, the study considers a scenario in which climate-related disaster losses increase by approximately 30–50 percent, consistent with estimates from global disaster risk modelling studies (Hallegatte et al. 2017; UNDRR 2022). Under such conditions, India's climate-related Average Annual Loss could increase to approximately 1.5–2 percent of GDP annually.

Not all of these losses would necessarily represent Loss and Damage in the strict sense. Investments in resilience—such as improved infrastructure design, early warning systems, and climate-resilient agricultural practices—can reduce the economic impact of disasters (Hallegatte et al. 2018). Nevertheless, a portion of these losses is likely to occur beyond feasible adaptation limits. Following emerging climate economics literature, this study assumes that approximately 20–30 percent of disaster losses under a 2°C scenario may represent residual climate-induced Loss and Damage(UNFCCC 2022; Pindyck 2013).

This analytical framework provides a basis for exploring how climate-induced losses may interact with socioeconomic vulnerability to generate unequal outcomes across regions and communities.

To estimate the economic implications of climate-induced Loss and Damage, this study adopts a simplified disaster-risk formulation commonly used in probabilistic risk modelling (Hallegatte et al. 2017; UNDRR 2022).

Equation 1: Expected Disaster Loss

The expected annual economic loss from disasters is expressed as:

$$AAL = \sum_{i=1}^{n} P_i \times L_i$$

Where:

- AAL = Average Annual Loss
- P_i = probability of hazard event i
- L_i = economic loss associated with event i

Average Annual Loss represents the long-term expected economic loss from disasters in any given year and is widely used in catastrophe risk modelling.

Empirical estimates suggest that India's current climate-related disaster losses correspond to approximately 0.8–1% of GDP annually (EM-DAT 2024; Munich Re 2024).

Equation 2: Climate-Induced Loss and Damage

As warming approaches 2°C, a share of disaster losses may occur beyond feasible adaptation limits. The residual Loss and Damage component can be expressed as:

$$LD = \alpha \times AAL$$

Where:

- LD = climate-induced Loss and Damage
- α = proportion of losses exceeding adaptation capacity

Based on emerging climate economics literature, this study assumes:

$$\alpha = 0.2 - 0.3$$

This implies that 20–30% of disaster losses could represent residual climate-induced Loss and Damage.

Equation 3: Inequality Amplification Function

The distributional impact of climate losses can be conceptualized as:

$$I = f(LD, V, C)$$

Where:

- I = inequality impact
- LD = climate-induced Loss and Damage
- V = vulnerability (poverty, infrastructure deficit)
- C = adaptive capacity

In regions where vulnerability is high and adaptive capacity is limited, the inequality effects of climate losses are magnified.

The analysis draws on multiple data sources commonly used in disaster risk research. Historical disaster loss trends are derived from the EM-DAT International Disaster Database and the Munich Re NatCatSERVICE database. Development indicators are based on the NITI Aayog SDG Index and the Multidimensional Poverty Index. These datasets provide consistent information on disaster frequency, economic losses, and socioeconomic vulnerability, allowing for scenario-based estimation of potential climate-induced Loss and Damage under a 2°C warming pathway.

The analytical framework provides a basis for exploring the potential magnitude of climate-induced Loss and Damage under a 2°C warming scenario. While precise estimates depend on detailed catastrophe risk modelling, scenario-based calculations can provide useful insights into the scale of potential economic impacts.

Empirical disaster datasets indicate that climate-related disasters currently generate economic losses equivalent to approximately 0.8–1 percent of India's GDP annually (EM-DAT 2024; Munich Re 2024). These losses are primarily associated with floods, cyclones, droughts, and extreme heat events.

Climate projections suggest that warming toward 2°C is likely to intensify several of these hazards. Observational evidence already indicates increasing frequency of extreme rainfall events in parts of India, as well as longer and more severe heatwaves across the Indo-Gangetic plains. At the same time, rapid infrastructure expansion and urbanization are increasing the value of assets exposed to climate hazards.

Drawing on global disaster risk modelling literature (Hallegatte et al. 2017; UNDRR 2022, Dhara et al 2026), this study assumes that climate-related disaster losses could increase by approximately 30–50 percent under a 2°C warming scenario.

Under this assumption, India's climate-related Average Annual Loss (AAL) could rise to approximately 1.5–2 percent of GDP annually.

However, not all of these losses would necessarily constitute Loss and Damage in the strict sense. Adaptation investments—such as flood protection infrastructure, climate-resilient agriculture, and early

warning systems—can reduce a portion of disaster losses. Nevertheless, a share of these impacts is likely to occur beyond feasible adaptation limits.

Following the analytical framework introduced earlier, this study assumes that 20–30 percent of total disaster losses under a 2°C scenario could represent residual Loss and Damage.

Table 2
Scenario-Based Estimate of Climate-Induced Loss and Damage in India

Scenario	Average Annual Loss (% GDP)	Residual Loss & Damage (% GDP)	Estimated Economic Impact
Current climate	0.8–1.0	–	Baseline disaster losses
2°C warming	1.5–2.0	0.3–0.6	Residual climate Loss & Damage

Source

Author estimates based on EM-DAT (2024), Munich Re (2024), Hallegatte et al. (2017), UNDRR (2022).

These estimates suggest that **climate-induced Loss and Damage could reach approximately 0.3–0.6 percent of India's GDP annually under a 2°C warming scenario**.

In absolute terms, this could translate into tens of billions of dollars in economic losses each year, depending on future GDP growth trajectories.

Importantly, these losses are unlikely to be evenly distributed across regions or population groups. Instead, they are likely to fall disproportionately on vulnerable communities with limited adaptive capacity.

Regions characterized by high disaster exposure, persistent poverty, and climate-sensitive livelihoods are particularly vulnerable to such impacts. In India, this includes flood-prone regions of eastern and northeastern states, drought-prone areas of central India, and cyclone-exposed coastal regions.

5 Sectoral dimension of the Loss and Damage

Agriculture is likely to bear a disproportionate share of climate-induced Loss and Damage, particularly in developing economies where livelihoods remain closely tied to climate-sensitive natural resources. In India, agriculture continues to support a large share of the rural population and plays a central role in food security, employment, and rural incomes. However, the sector is highly exposed to climate variability and extreme weather events, including floods, droughts, heatwaves, and shifting monsoon patterns. Evidence suggests that climate shocks can lead to significant crop losses, reduced farm incomes, and disruptions to rural food systems (IPCC 2023; Hallegatte et al. 2017). As warming approaches 2°C, the frequency and intensity of such hazards are expected to increase, implying that a

substantial share of climate-induced Loss and Damage may occur within the agricultural sector. These impacts are particularly pronounced in agrarian states such as Bihar, where a large proportion of the population depends on smallholder agriculture and where climate variability already poses persistent risks to crop production and rural livelihoods (NITI Aayog 2023; World Bank 2022).

India's progress toward the NITI Aayog Sustainable Development Goals has improved steadily over the past decade, yet significant disparities remain across sectors and states. According to the latest **SDG India Index**, India's overall score has risen to around 71, reflecting notable advances in areas such as poverty reduction, clean energy, and basic health services. However, **SDG 2: Zero Hunger** continues to be among the weakest performing goals nationally. Persistent challenges in nutritional outcomes, agricultural productivity, and rural livelihoods mean that progress toward eliminating hunger and ensuring food security remains uneven across the country. These challenges are particularly important in the context of climate change, as agriculture remains highly sensitive to climatic variability and extreme weather events, which can directly affect crop yields, farm incomes, and food availability.

The situation is even more pronounced in states such as **Bihar**, which consistently ranks near the bottom of the SDG Index across several development indicators. Bihar's performance on **SDG 2** is among the lowest in India, reflecting the structural vulnerability of its agrarian economy. A large share of the state's population depends on agriculture and allied activities for livelihoods, and smallholder farming dominates the rural economy. The agrifood system therefore serves as the backbone of household income, employment, and food security. However, this dependence also increases exposure to climate risks, particularly recurrent flooding and erratic monsoon patterns that frequently disrupt agricultural production. As climate hazards intensify in a warming world, these pressures may deepen existing food security challenges and reinforce the cycle of vulnerability in agrarian regions such as Bihar, where climate risk, poverty, and livelihood dependence on agriculture converge.

The conceptual pathway illustrated in Fig. 1 provides the broader analytical framework for understanding how climate warming translates into economic losses and ultimately contributes to structural inequality. As global temperatures approach **2°C**, intensifying climate hazards such as extreme rainfall, floods, heatwaves, and cyclones are expected to increase disaster risk and elevate **Average Annual Loss (AAL)** at the national level (IPCC 2023; UNDRR 2022). A portion of these losses may occur beyond the limits of feasible adaptation, emerging as **climate-induced Loss and Damage**. Importantly, these losses are rarely distributed evenly across societies. Instead, they tend to concentrate in regions where climate exposure intersects with high poverty levels, limited infrastructure resilience, and strong dependence on climate-sensitive livelihoods (Hallegatte et al. 2017).

Figure 2 translates this national-level risk pathway into a localized development context by examining the case of **Bihar**. The Bihar climate risk–poverty nexus model illustrates how recurrent flood hazards interact with structural development challenges, including multidimensional poverty, agricultural dependence, and limited adaptive capacity. In such settings, climate shocks can trigger cascading effects—crop losses, income instability, and food insecurity—that reinforce existing socioeconomic

inequalities. Taken together, Figs. 1 and 2 demonstrate how the macro-level dynamics of climate risk escalation can translate into localized cycles of vulnerability, particularly in agrarian regions where climate exposure and development deficits converge.

Reducing Loss and Damage therefore requires placing climate-resilient agriculture at the center of adaptation and development strategies. Strengthening agricultural resilience involves a combination of technological, institutional, and policy interventions, including climate-resilient crop varieties, improved irrigation systems, diversified cropping patterns, and enhanced climate advisory services. Investments in early warning systems, weather-based crop insurance, and digital climate information platforms can also help farmers anticipate and respond to climate risks more effectively. Such measures are critical not only for protecting farm incomes but also for safeguarding national food security and advancing progress toward SDG 2 (Zero Hunger). In this sense, building resilience in agrifood systems represents one of the most effective pathways for minimizing climate-induced Loss and Damage while sustaining rural livelihoods in a warming climate (Hallegatte et al. 2017; OECD 2022).

The case of **Bihar** illustrates how climate risks can intersect with structural development challenges. Frequent flooding along Himalayan river systems regularly damages agricultural land and rural infrastructure, while high poverty levels limit households' ability to recover from disaster losses.

Consequently, climate-induced Loss and Damage may reinforce existing development inequalities by concentrating economic impacts in already vulnerable regions.

These findings underscore the importance of integrating climate risk considerations into economic planning and development strategies. Without proactive resilience investments, climate-induced Loss and Damage could significantly slow progress toward poverty reduction and sustainable development.

6 Addressing Climate Risk and Inequality

Reducing climate-induced **Loss and Damage** requires a deliberate shift from reactive disaster response toward long-term resilience building in sectors that are most exposed to climate risks. In India, this challenge is particularly evident in **agriculture and agrifood systems**, which remain central to rural livelihoods, food security, and employment. A large share of the population continues to depend on climate-sensitive agricultural production, making the sector highly vulnerable to floods, droughts, heatwaves, and shifts in monsoon rainfall patterns. As climate hazards intensify in a warming world, strengthening the resilience of agricultural systems becomes one of the most effective ways to avert and minimize potential Loss and Damage. Measures such as climate-resilient crop varieties, improved irrigation infrastructure, diversified cropping systems, and climate-informed farm advisory services can help farmers better cope with climate variability and reduce crop losses (IPCC 2023; Hallegatte et al. 2017). Equally important are institutional mechanisms—including early warning systems, weather-indexed crop insurance, and anticipatory social protection programs—that enable farmers to absorb shocks before they translate into long-term economic losses. By protecting agricultural productivity and

stabilizing rural incomes, such interventions contribute directly to advancing **SDG 2 (Zero Hunger)** while reducing the vulnerability of agrarian communities to climate risks.

At the same time, effectively addressing Loss and Damage requires confronting the **structural inequalities that shape climate vulnerability**. Poor and marginalized households often face disproportionate impacts from disasters because they have limited access to financial resources, resilient infrastructure, and risk information. Policies designed to address Loss and Damage must therefore integrate climate resilience with inclusive development strategies. Expanding adaptive social protection programs, strengthening rural credit systems, and improving access to climate information services can help vulnerable households recover more quickly from climate shocks (World Bank 2022; OECD 2022). Investments in resilient rural infrastructure—such as flood-resistant roads, irrigation networks, and climate-resilient storage and market facilities—can further reduce the cascading economic impacts of disasters on agrarian communities. These efforts are increasingly reflected in global climate policy discussions under the **Paris Agreement**, where Loss and Damage has emerged as a central pillar of international cooperation. Mechanisms such as the **Warsaw International Mechanism for Loss and Damage** and the evolving Loss and Damage funding arrangements seek to support countries in both minimizing unavoidable climate impacts and addressing their consequences (UNFCCC 2022; Mechler et al. 2019). For countries such as India, integrating these global policy frameworks with national strategies for climate-resilient agriculture and inclusive development will be essential for reducing climate-induced losses while safeguarding food security and rural livelihoods.

7 Policy Pathways for Minimizing Climate-Induced Loss and Damage

Minimizing climate-induced **Loss and Damage (L&D)** requires moving beyond traditional disaster response toward a proactive approach that integrates resilience into development planning. In India, this effort must focus particularly on sectors and communities where climate exposure intersects with livelihood vulnerability. Three mutually reinforcing policy pathways—**climate-resilient agriculture, adaptive social protection, and anticipatory climate risk management**—offer important opportunities to reduce potential losses while supporting inclusive and sustainable development.

Climate-Resilient Agriculture

Strengthening climate resilience within agricultural systems represents one of the most effective strategies for minimizing Loss and Damage. Agriculture remains the primary source of livelihood for a large share of India's rural population, and the sector is highly sensitive to climate variability. Floods, droughts, and heat stress can significantly reduce crop yields and destabilize rural incomes (IPCC 2023; Hallegatte et al. 2017). Investments in climate-resilient crop varieties, improved irrigation infrastructure, diversified cropping patterns, and sustainable soil management can enhance the capacity of farmers to withstand climatic shocks. Expanding climate advisory services and digital agriculture platforms can further support farmers by providing timely weather information and risk guidance. These interventions are particularly important in states such as Bihar, where agrarian livelihoods dominate and climate risks

frequently disrupt agricultural production. Strengthening resilience in agrifood systems not only reduces disaster-related crop losses but also contributes directly to progress toward **SDG 2 (Zero Hunger)** and broader rural development goals.

Adaptive Social Protection

Climate risks also highlight the need for stronger **adaptive social protection systems** capable of supporting vulnerable populations before, during, and after climate shocks. Traditional disaster relief mechanisms often focus on post-event recovery, which can be slow and insufficient to prevent long-term livelihood losses. Adaptive social protection integrates climate risk considerations into existing social safety nets, enabling governments to provide timely financial support when hazards occur (Hallegatte et al. 2017; World Bank 2022). Instruments such as employment guarantee programs, targeted cash transfers, and weather-indexed crop insurance can help households maintain income stability during climate shocks. By protecting household consumption and enabling quicker recovery, these mechanisms reduce the likelihood that temporary climate shocks evolve into long-term poverty traps.

Anticipatory Climate Risk Management

A third pathway involves strengthening **anticipatory climate risk management** through improved climate intelligence and early warning systems. Advances in Earth observation technologies, climate modelling, and artificial intelligence now enable governments to anticipate hazards and their potential socioeconomic impacts with increasing accuracy. Impact-based forecasting systems can translate weather forecasts into actionable risk information for sectors such as agriculture, infrastructure, and public health (OECD 2022). When combined with early action protocols—such as pre-positioning relief supplies, protecting critical infrastructure, or providing advance financial support to vulnerable households—these systems can significantly reduce disaster losses before hazards occur. Such anticipatory approaches are increasingly recognized as essential components of modern disaster risk governance (UNDRR 2022).

Integrating Pathways to Reduce Inequality

Together, these policy pathways help interrupt the **climate risk → disaster loss → inequality** pathway described in this study. Climate-resilient agriculture reduces exposure to climate shocks, adaptive social protection strengthens household recovery capacity, and anticipatory risk management lowers disaster losses before they materialize. When implemented in an integrated manner, these strategies can significantly minimize climate-induced Loss and Damage while supporting more equitable and resilient development outcomes.

Linking National Policy Pathways with Global Loss and Damage Governance

Efforts to avert, minimize, and address climate-induced Loss and Damage in countries such as India are increasingly connected to evolving international climate governance frameworks. Under the **Paris Agreement**, Loss and Damage has emerged as a distinct pillar of climate policy alongside mitigation and

adaptation. Institutional mechanisms such as the **Warsaw International Mechanism for Loss and Damage** and the recently operationalized **Loss and Damage funding arrangements** seek to support countries in addressing unavoidable climate impacts. For developing economies with large vulnerable populations and climate-sensitive livelihoods, access to such international financial and technical support will be increasingly important. In the Indian context, aligning national strategies—such as climate-resilient agriculture, adaptive social protection, and anticipatory risk management—with global Loss and Damage frameworks can help mobilize additional resources while strengthening domestic resilience systems. Ultimately, reducing climate-induced Loss and Damage will require coordinated action across local, national, and international levels, ensuring that climate resilience investments simultaneously safeguard food security, protect vulnerable communities, and support more inclusive development pathways in a warming world (Mechler et al. 2019; UNFCCC 2022; IPCC 2023).

As global temperatures approach **2°C above pre-industrial levels**, climate change is likely to reshape the economics of disaster risk in ways that extend beyond traditional adaptation strategies. This study suggests that rising climate hazards may significantly increase **Average Annual Loss (AAL)** from disasters in India, with a growing share emerging as residual **Loss and Damage** when adaptation limits are exceeded. These impacts are unlikely to be distributed evenly; instead, they may disproportionately affect vulnerable regions where climate exposure intersects with poverty and agricultural dependence. The case of Bihar illustrates how climate shocks can reinforce existing development inequalities and threaten food security. Addressing these risks requires an integrated policy approach that strengthens **climate-resilient agriculture, adaptive social protection systems, and anticipatory climate risk management**. Such strategies can help minimize climate-induced losses while supporting more equitable and resilient development pathways in a warming world.

Box: Climate Risk and Inequality

Climate hazards do not affect societies uniformly. Their impacts are shaped by socioeconomic conditions such as income distribution, infrastructure access, and institutional capacity.

In India, climate vulnerability is closely linked with patterns of poverty and regional inequality. Poor households often live in hazard-prone environments such as floodplains or drought-prone agricultural regions. Moreover, these households frequently lack financial instruments that could cushion disaster losses.

Repeated exposure to disasters can therefore produce cycles of vulnerability. Households that lose assets during disasters may struggle to rebuild their livelihoods, particularly if they lack access to credit or insurance.

Over time, these dynamics can reinforce structural inequality and slow progress toward poverty reduction.

Bihar: Climate Risk and Poverty Nexus

The state of Bihar illustrates the interaction between climate exposure and socioeconomic vulnerability. Situated in the downstream floodplains of several Himalayan rivers, Bihar experiences frequent seasonal flooding. Rivers such as the Kosi and Gandak regularly overflow during the monsoon season, affecting millions of people each year.

At the same time, Bihar remains one of India's poorest states. Development indicators related to nutrition, education, and infrastructure remain significantly below national averages. The convergence of high disaster exposure and persistent poverty creates a powerful vulnerability trap.

Flood events repeatedly damage crops, livestock, and rural infrastructure. Even when large-scale disasters are avoided, repeated seasonal losses gradually erode household resilience.

8 Loss and Damage and Food Security

Climate-induced Loss and Damage has important implications for food security. Agriculture remains highly sensitive to climate variability, particularly in regions dependent on monsoon rainfall.

Rising temperatures, erratic rainfall patterns, and increased flood frequency may disrupt crop yields across several agricultural zones. In states such as Bihar, where smallholder farming dominates rural livelihoods, these risks are particularly significant.

Yield declines for staple crops could translate directly into income loss and food insecurity for vulnerable households.

9 Artificial Intelligence and Climate Intelligence

Technological innovation offers new opportunities for managing climate risk. Artificial intelligence systems can integrate satellite observations, climate models, and socioeconomic data to produce high-resolution climate intelligence.

Such systems enable impact-based forecasting, allowing governments and communities to anticipate not only hazards but also their potential economic consequences.

Applications include flood forecasting, agricultural advisories, and infrastructure risk mapping. India's expanding investments in artificial intelligence and Earth observation systems provide a strong foundation for developing national climate intelligence platforms.

As global temperatures approach 2°C warming, climate-induced Loss and Damage is likely to become an increasingly important dimension of economic risk. For India, these impacts may not only increase disaster losses but also reshape patterns of inequality by concentrating economic shocks in already vulnerable regions. Integrating climate risk considerations into development planning, strengthening adaptive social protection systems, and leveraging emerging technologies for climate intelligence will

therefore be critical for safeguarding development gains. Addressing Loss and Damage is ultimately not only a climate policy challenge but also a central component of equitable and resilient development.

10 Conclusion

As global temperatures approach 2°C warming, the economic consequences of climate risk are likely to become increasingly significant. For India, this threshold represents more than a symbolic climate target. It marks a structural transition in which climate hazards increasingly exceed the limits of adaptation.

The analytical framework presented in this study suggests that as Average Annual Loss increases with climate warming (Eq. 1), a growing share of these impacts may manifest as residual Loss and Damage beyond adaptation limits (Eq. 2). In regions characterized by high vulnerability and limited adaptive capacity, such losses may translate into disproportionate inequality effects (Eq. 3).

This study suggests that climate-related disaster losses could rise substantially under a 2°C warming scenario, with a significant portion representing irreversible Loss and Damage. These impacts are likely to fall disproportionately on vulnerable populations, particularly in regions where disaster exposure intersects with poverty and food insecurity.

Addressing Loss and Damage therefore requires integrating climate resilience into economic planning, strengthening social protection systems, and leveraging emerging technologies to improve anticipatory governance.

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Figures

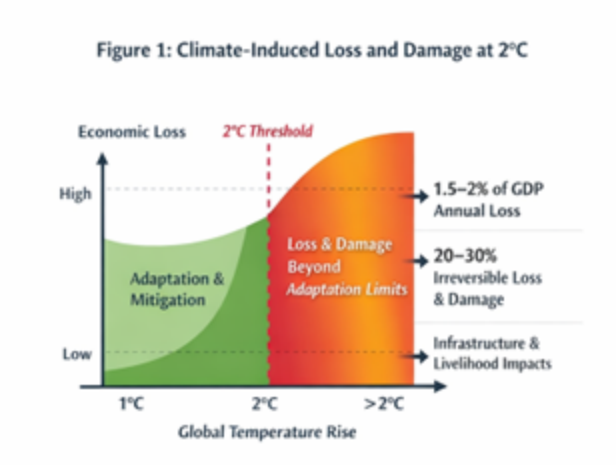


Figure 1

Climate-Induced Loss and Damage at 2°C

Caption:

Conceptual relationship between global warming and economic losses. As warming approaches 2°C, disaster losses increase due to intensifying hazards and rising economic exposure. A portion of these losses may exceed feasible adaptation limits and manifest as climate-induced Loss and Damage (Equation 2). The figure illustrates the escalation of Average Annual Loss (Equation 1) and the emergence of residual losses beyond adaptation.

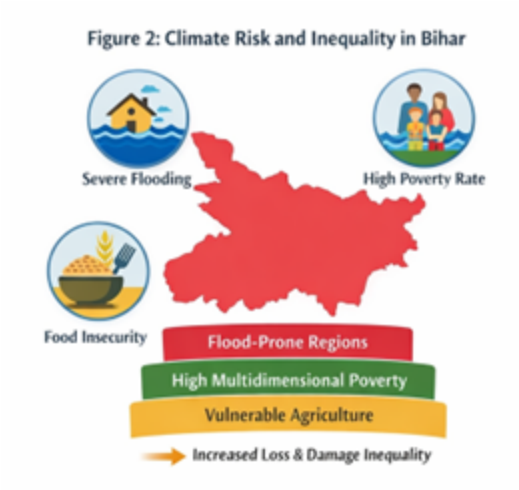


Figure 2

Climate Risk and Inequality Nexus in Bihar

Caption:

Conceptual model illustrating how climate hazards interact with socioeconomic vulnerability to generate disproportionate impacts. High flood exposure, multidimensional poverty, and agricultural dependence amplify climate-induced Loss and Damage and contribute to rising inequality (Equation 3).

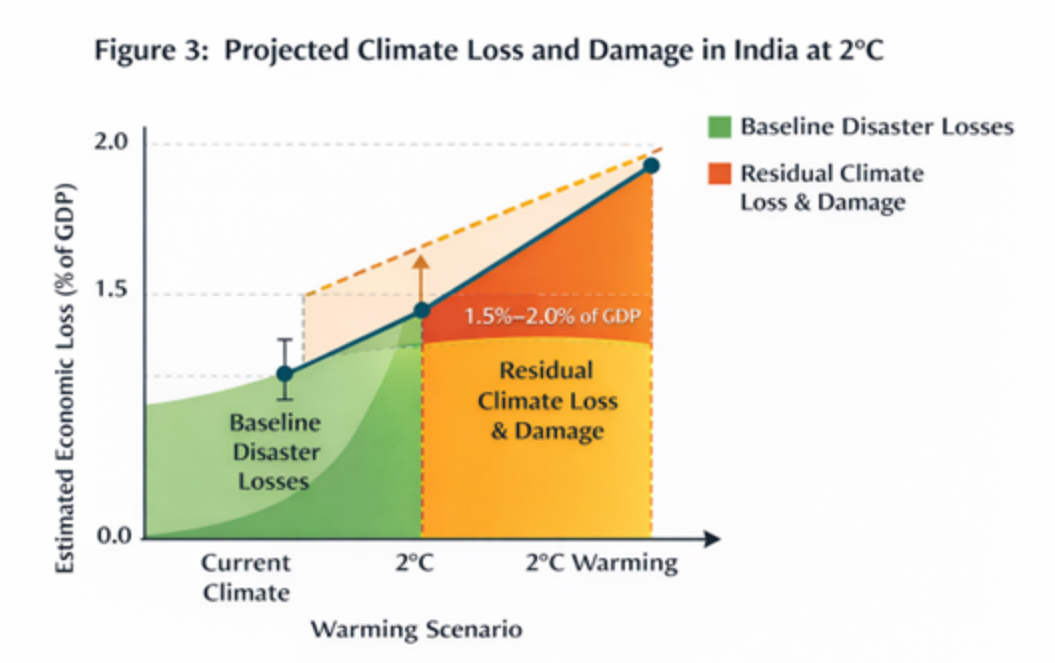


Figure 3

"Projected Climate Loss and Damage in India at 2°C" — a simple **GDP loss curve graph** derived from Table 2.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- GA.png