

Towards Resilient Public Finance

**Sub-National Assessment of Fiscal Risks
in Critical Infrastructure Sectors
in Tamil Nadu**



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Foreword



Amit Prothi

Director General
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Tamil Nadu, situated on the Indian Peninsula, is highly vulnerable to a range of natural hazards. The State is prone to multiple hazards and frequently experiences more disasters than other states. The state has experienced a range of natural hazards, including floods, cyclonic storms, and drought. The frequency and intensity of these climate-induced hazards have been increasing, placing significant strain on critical infrastructure and public finances. Each major disaster not only damages vital infrastructure and disrupts essential services but also hampers socio-economic progress and redirects limited resources from long-term development and growth priorities. The resulting fiscal pressures limit the state's ability to respond swiftly, recover sustainably, and invest in future resilience. Therefore, strengthening financial preparedness against these compounding risks is essential for safeguarding Tamil Nadu's development trajectory.

As part of the Coalition for Disaster Resilient Infrastructure's (CDRI) efforts to mainstream resilience in infrastructure systems, this model disaster risk finance study assesses the fiscal risks posed by disasters across key infrastructure sectors in Tamil Nadu. The study is among the first of its kind at the state level in India to systematically connect disaster-related infrastructure impacts to fiscal outcomes. It offers practical recommendations to enhance disaster risk financing strategies, strengthen institutional capacities, and manage contingent liabilities more effectively in the infrastructure domain.

This assessment aims to establish a benchmark for sub-national disaster risk financing by providing a methodology to evaluate the economic and fiscal implications of disasters, review existing financing instruments, and highlight the importance of forward-looking, risk-informed public investment and budgetary practices. We believe this report will be a valuable resource for policymakers, financial planners, and development partners working towards strengthening fiscal resilience in Tamil Nadu.

We are grateful to our consultant, the Asian Disaster Preparedness Center (ADPC), and the Government of Tamil Nadu for their leadership and constructive involvement throughout this process. As Tamil Nadu continues to pursue resilient and sustainable development, it is crucial that disaster risk finance becomes a core element of public financial decision-making. This report marks a significant step in that direction.

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Executive Summary

Climate-induced disasters such as floods, cyclones, droughts, and other hazards have serious implications for human lives, infrastructure, and fiscal stability. These events not only disrupt lives but also negatively impact economies, reducing output, causing job losses, and damaging property that may take years to repair. On average, such disasters increase the fiscal deficit by 0.8 percent and 0.9 percent of gross domestic product (GDP) in lower-middle-income and low-income countries, respectively. Disasters can significantly impair infrastructure and human development while increasing fiscal risks. They also have a detrimental impact on government revenue, affecting tax collection and disrupting economic activity across sectors.

Tamil Nadu is among the more disaster-prone states in India due to its long coastline, monsoonal patterns, and complex geography. The state experiences frequent cyclones, urban floods, droughts, and landslides. Major disasters such as the 2004 Indian Ocean Tsunami, the 2015 Chennai Floods, and Cyclones Thane (2011), Gaja (2018), and Vardah (2016) have caused significant loss of life and property while inflicting severe fiscal stress on the state government. Despite advancements in early warning systems and emergency preparedness, the recurring nature of disasters continues to pose significant challenges to Tamil Nadu's economic and fiscal resilience.

This report assesses the financial vulnerabilities and potential economic impacts of disasters on critical infrastructure in Tamil Nadu. By analyzing historical disaster data, fiscal impact analysis, economic modelling, and probabilistic risk assessment, this study presents a comprehensive overview of the fiscal risks posed by natural hazards to the state's power and road infrastructure.

The analysis finds that Tamil Nadu's current disaster risk financing mechanisms need to be strengthened to better meet post-disaster financing requirements. The average share of the State Disaster Response Fund (SDRF) in covering damages from major disasters between 2014 and 2021 was notably limited, reflecting the state's growing reliance on additional allocations from the National Disaster Response Fund (NDRF), increased borrowings, and Central Government grants. Reconstruction costs often far exceed available funds, leading to delays in recovery and diversion of resources from development programmes.

Beyond loss of life and infrastructure, disasters in Tamil Nadu have caused significant disruptions in agricultural output, industrial production, and urban services. These disruptions have resulted in reduced tax and non-tax revenues and placed additional strain on the state's expenditure obligations. The total economic loss from major disasters over the last decade amounts to several billion rupees, representing a substantial share of the state's Gross State Domestic Product (GSDP) and hindering its ability to achieve projected growth rates.





Economic modelling was conducted to estimate the indirect and network effects of disasters using state-level data. A fixed-effects panel regression model was applied, linking fiscal variables such as total expenditure, internal debt, and social services spending to a disaster intensity index based on human fatalities, people affected, and economic damage. The model suggests that a severe disaster, comparable in intensity to the 2004 tsunami or the 2015 floods, would lead to a significant increase in the state's total expenditure and internal debt issuance, along with a notable rise in relief and social sector spending. While Central Government grants increase following disasters, they do not fully offset the state's financial burden.

If a disaster of the scale of the 2004 tsunami were to occur again, the model estimates an increase of INR 166,573 lakh in total expenditure, including INR 20,555 lakh in additional social services spending and INR 9,448 lakh in relief payments. Internal debt issuance would increase by INR 29,162 lakh. For a disaster similar to the 2015 floods, total expenditure is estimated to increase by INR 16,741 lakh, which will lead to a corresponding increase in internal debt and a moderate rise in central grants. The fiscal impact is most pronounced in the year immediately following the disaster. Although localized long-term economic impacts likely persist for households and businesses, these effects do not appear to be significantly evident at the state level. Improved data collection at the district and sub-district levels is needed to assess these impacts more accurately.

Flood modelling results are well-aligned with historical impact data from Tamil Nadu. The estimated 1-in-50-year flood loss is approximately \$620 million¹, comparable to the damage incurred during the 2015 floods. Cyclone risk projections from high-resolution climate models indicate that future storms may intensify under high-emission scenarios, further increasing fiscal risks. Although sector-level financial data are limited, available estimates indicate that power and road infrastructure account for most of the damage in large-scale events.

The analysis concludes that the SDRF is inadequate to meet future disaster-related expenditure needs. It is often insufficient even to cover basic infrastructure recovery, let alone broader reconstruction or resilience-building efforts. The state will continue to require financial assistance from the NDRF and other sources, including debt financing, to cover the annual shortfall in disaster response funding. This growing dependency threatens Tamil Nadu's fiscal stability, especially amid increasingly frequent and severe climate events.

Based on the findings, Tamil Nadu must strengthen its financial preparedness and explore sustainable risk financing strategies. Recommendations include integrating risk-informed planning into public finance, enhancing the resilience of critical infrastructure, and exploring insurance or market-based risk-transfer mechanisms to manage disaster-related fiscal shocks effectively. Tamil Nadu's ability to recover quickly and maintain economic growth will depend on building a robust, well-financed, and forward-looking disaster risk management framework.

¹ All figures in \$ refer to US dollars unless otherwise specified.

Tamil Nadu Leading the Way

Tamil Nadu, through a unified approach for climate governance under the Tamil Nadu Green Climate Company (TNGCC), has been a beacon for other states on how to structure a robust institutional framework for the state's sustainability strategies and climate policy actions.

And the outcomes of this institutional framework are evident in its significant public investment to address climate-related changes. The significance of this institutional framework and its impact was highlighted in the International Monetary Fund's Climate-Public Investment Management Assessment (C-PIMA). This was only the second sub-national PIMA to be completed in the world, and the first in India.

As the focal institution, TNGCC oversees the implementation of Tamil Nadu's four flagship environmental missions: (a) Tamil Nadu Climate Change Mission (TNCCM); (b) Green Tamil Nadu Mission (GTM); (c) Tamil Nadu Wetlands Mission (TNWM); (d) Tamil Nadu Coastal Restoration Mission (TNCRM).

This institutional structure has allowed the state to weave in climate policies and investment in the state's plans, budgets and infrastructure development, scale up adoption of renewable technologies and develop low-carbon pathways for energy-intensive sectors. This is supported by developing strong research capabilities, community-led capacity development, and data-driven climate governance that enable the government to make effective decisions to strengthen resilience, safeguard natural resources, reduce vulnerabilities, and support inclusive and climate-responsive development.

While Tamil Nadu is a highly industrialized state with per capita income exceeding the national average, its long coastline and a tropical monsoon climate bring in climate risks that make its infrastructure vulnerable.

The state, through its climate-responsive institutions and policies, has enabled not only public investment but also supported the private sector to make significant investments in both adaptation and mitigation – wind and solar energy and in technologies that lead to improved energy efficiency. It has also set up a comprehensive disaster risk management strategy and crafted financial frameworks like Tamil Nadu Green Climate Fund (TNGCF) and TN-SHORE for mangrove conservation and Green Infrastructure Funding to achieve net zero before 2070.



Chapter 1

Introduction



Introduction

Tamil Nadu, located on the southeastern coast of India, is highly vulnerable to various natural hazards due to its diverse geographical, climatic, and ecological characteristics. The state regularly encounters disasters such as cyclones, floods, droughts, tsunamis, and landslides. These events not only result in significant loss of life and property but also disrupt essential services and pose considerable fiscal risks. Given the growing frequency and intensity of extreme weather events linked to climate change, Tamil Nadu is facing increasing challenges in maintaining economic and fiscal stability.

Disasters directly affect public infrastructure and socio-economic systems, which, in turn, influence the state's budgetary allocations, debt patterns, and revenue sources. Addressing these challenges requires integrating risk-informed approaches into public financial management and infrastructure planning. Strengthening fiscal resilience through improved risk assessment, budgeting, and investment prioritization is essential to safeguard development outcomes and ensure timely disaster response and recovery.



This report presents a comprehensive fiscal risk assessment (FRA) for Tamil Nadu, focusing on critical infrastructure sectors, including power and transport. It evaluates both historical and modelled impacts of disasters on state finances and infrastructure assets. The objective of the report is to estimate the magnitude of fiscal risks posed by disasters, assess existing disaster risk financing mechanisms, and identify potential funding gaps.

Through empirical analysis and economic modelling, the FRA aims to support policymakers in understanding the fiscal implications of disasters, improve the design of financial instruments, and enhance institutional mechanisms for risk management. This assessment is intended to inform decision-making processes in Tamil Nadu by highlighting the fiscal vulnerabilities and resilience-building opportunities across key infrastructure sectors.

Fiscal Risk Assessment Framework

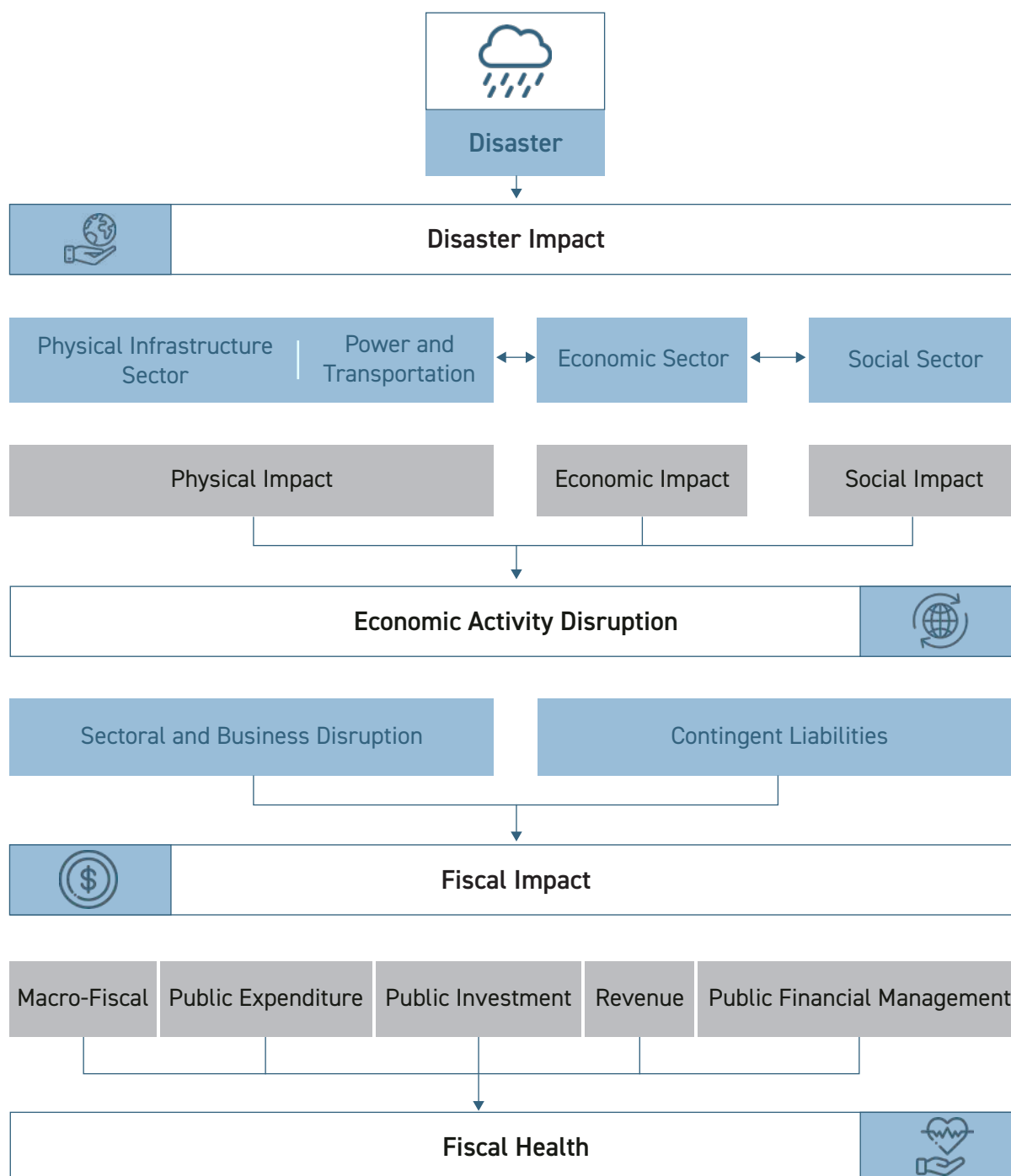
The International Monetary Fund (IMF) defines fiscal risk as the economic factors that may cause actual fiscal outcomes to differ from projected or expected fiscal outcomes. The Organisation for Economic Co-operation and Development (OECD) describes fiscal risks as changes in the expected fiscal outcomes outlined in an economy's annual budget or forecasting documents. These fiscal risks can arise from macroeconomic shocks or from contingent liabilities triggered by uncertain events. It is essential for governments to comprehend these risks and prepare for them by performing FRAs to allocate resources effectively in the event of a disaster.

Fiscal risks can emerge from various sources, including macroeconomic shocks, financial sector crises, legal issues, sub-national government liabilities, and challenges associated with state-owned enterprises (SOEs). Disasters pose a significant fiscal risk, costing an average of 1.5 percent of gross domestic product (GDP) and up to 6 percent in extreme cases. Public-private partnerships (PPPs) can create fiscal risks if the government is required to make payments to private partners, even when the expected benefits are not realized. Liabilities of private non-financial companies can arise from corporate bailouts or when the government assumes their debt obligations. According to a study by Bova et al. (2016), disasters imposed the second-highest fiscal costs, averaging 1.6 percent of GDP, following financial sector shocks, which accounted for 9.7 percent. Effectively managing fiscal risk and ensuring the government's ability to respond effectively during a crisis depends on recognizing and controlling these risks.

Disasters have significant fiscal implications for governments. The Inter-American Development Bank (IDB) has categorized fiscal impact channels into macro-fiscal, revenue-related, public expenditure, public investment, and public financial management aspects (IDB 2016). Understanding these channels is essential for policymakers to effectively manage the fiscal consequences of disasters.

Figure 1.1 presents the structured framework used in this report. The framework illustrates the cascading effects of disasters on economic and fiscal stability, beginning with the disaster's impact on physical infrastructure, economic sectors, and social sectors. These disruptions affect economic activity, including sectoral and business-level disruptions, thereby creating contingent liabilities for the government. As economic activity declines, various fiscal consequences emerge and are categorized as fiscal impacts. These effects influence macro-fiscal stability, public expenditure, public investment, revenue generation, and public financial management. Ultimately, these cumulative fiscal pressures determine the government's overall fiscal health.

Figure 1.1: Framework for Assessing Fiscal Risk Arising from Disasters



Source: ADPC



Chapter 2

Financial Risk Assessment based on Historical Data

Financial Risk Assessment based on Historical Data

Climate-induced disasters, such as floods, cyclones, and other hazards, can have a severe impact on human lives, economies, and fiscal accounts. These disasters can result in loss of life, displacement of people, and damage to infrastructure, which, in turn, reduce economic output and increase demand for emergency services, reconstruction efforts, and social welfare programmes. On average, climate-induced extreme weather events increase the fiscal deficit by 0.8 percent of GDP in lower-middle-income countries and by 0.9 percent for low-income countries. From a fiscal perspective, the frequency and intensity of climate-related disasters heighten the risk of negative fiscal shock, as they strain public fiscal accounts. This strain can lead to budget deficits and debt accumulation, resulting in a weaker fiscal stance due to negative effects on revenue and expenditure channels, increased public debt, postponed investment projects, and cyclical fiscal policy.



Disasters can also significantly affect government revenues, particularly by reducing economic activity. This usually results in reduced tax and non-tax revenues due to lower tax collections, disruptions in international trade, and decreased labour hours. However, there may also be a post-disaster recovery boost that stimulates economic activity, resulting in a short-term increase in foreign aid or tax revenue. In addition to immediate changes in revenue and spending, disasters can also affect the government's assets and obligations. For example, damage to public infrastructure raises the cost of repair or replacement. Yet many governments do not maintain complete balance sheets that account for non-financial assets, making it more challenging to evaluate the fiscal impacts of disasters.

Between 1994 and 2013, disasters caused an estimated \$2.6 trillion in economic losses globally, which was equivalent to 4 percent of the world's GDP in 2015.² On average, across a sample of events between 1990 and 2014, the financial impact of disasters on a country's economy was 1.6 percent of its GDP. In some cases, the costs were significantly higher, with the most significant disasters resulting in losses of up to 6 percent of GDP.³ A study by the IMF identified a maximum fiscal cost of 6 percent of GDP associated with these events. Numerous studies have shown a negative correlation between disasters and economic growth, indicating that these events can lower GDP in both the short and long term. To ensure that governments are adequately prepared for worst-case scenarios and do not undervalue the financial implications of such disasters, it is essential to improve future damage predictions and conduct better studies on low-frequency, high-impact disasters.

Figure 2.1: Fiscal Impact Channels of Disasters



Source: ADPC

As governments borrow money to fund recovery efforts, public debt levels may increase. Disasters can lead to production losses, disrupt global trade, and reduce tax revenues due to lost labour hours and decreased business earnings, which significantly impact overall revenue. It is crucial for state governments to promptly set aside funds for emergency response and recovery as they frequently split the expenses of disasters with local governments, necessitating further assistance. Public financial management faces challenges in guaranteeing the effective use of disaster funds and maintaining transparency. Furthermore, public investment is constrained because funds that could be used for future projects are redirected to rebuild damaged infrastructure.

Overview of Impact of Disasters in Tamil Nadu

Due to its geo-climatic, geological, and physical characteristics, Tamil Nadu is susceptible to multi-hazards and experiences disasters more frequently than other states (NIDM Tamil Nadu). The state has faced various natural hazards, including floods, cyclones, droughts, tsunamis, landslides, and earthquakes. Among these, it is mainly affected by floods, cyclonic storms, and drought risk. Of the 32 districts in the state, nearly all are vulnerable to disasters caused by at least one type of hazard or another (TNSDMA). Communities living along the southern coast of India face threats from tsunamis, cyclones, and floods, while residents in the plains and hilly regions of the state are at risk from landslides, earthquakes, and floods.

Tamil Nadu experienced a range of severe disasters from 2004 to 2021, including tsunamis, cyclones, and floods, which affected multiple districts. The 2004 Indian Ocean Tsunami was among the most catastrophic events, affecting 13 districts and 230 villages. It resulted in 7,995 deaths, with over 1.06 million people affected and 52,622 houses damaged. Cyclones have also been a recurring hazard in the region. Cyclone Gaja in 2016 affected eight districts, displacing 560,000 people and damaging 220,000 homes. Cyclone Ockhi in 2017 claimed 203 lives, while Cyclone Nisha in 2008 and Cyclone Thane in 2011 together resulted in 250 fatalities. The 2015 Chennai floods were particularly devastating, affecting six districts and nearly 4 million people, including 1.8 million who were displaced. These floods caused damage to more than 116,000 houses.

Despite improvements in early warning and evacuation systems, some events have still resulted in significant loss of life and property. Cyclone Nivar in 2020 led to the evacuation of more than 100,000 people, while Cyclone Nilam (2012) and Cyclone Vardah (2016) also contributed to the toll. Additionally, floods in 2019 and 2021 affected various parts of the state, resulting in multiple fatalities. These recurring disasters have placed considerable strain on Tamil Nadu's disaster management and fiscal resources. Consequently, the government has consistently had to allocate substantial funds for relief operations, housing reconstruction, and the rehabilitation of affected communities and infrastructure.

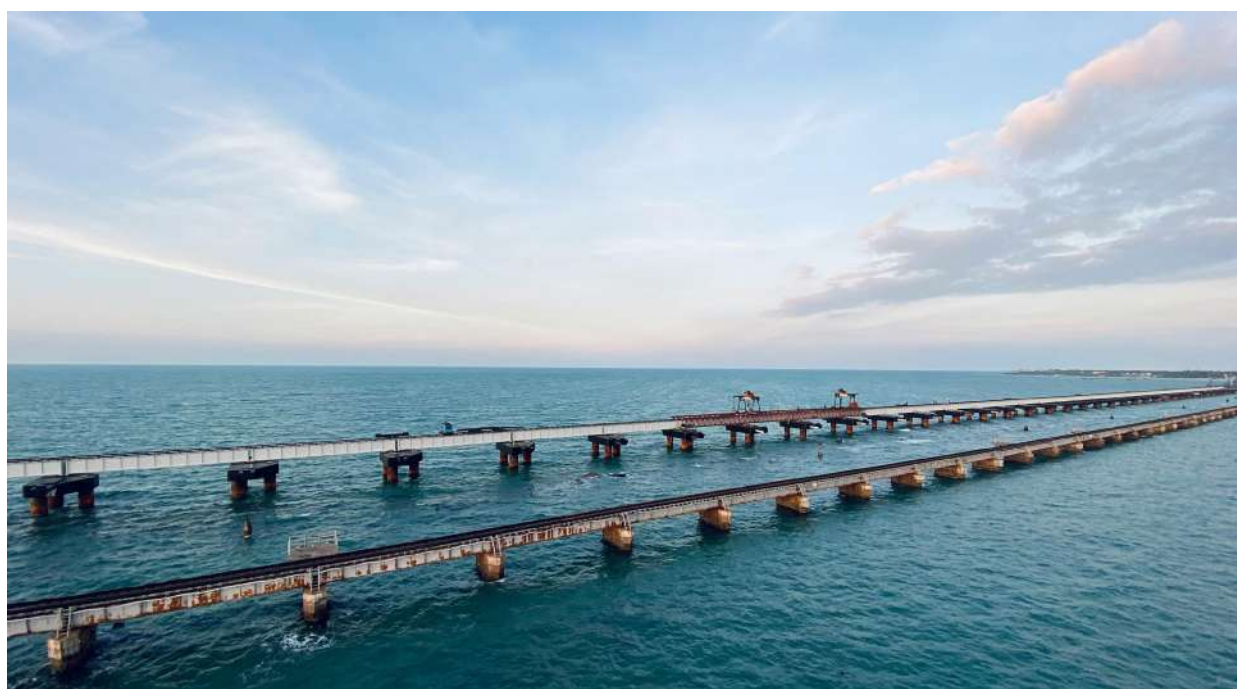
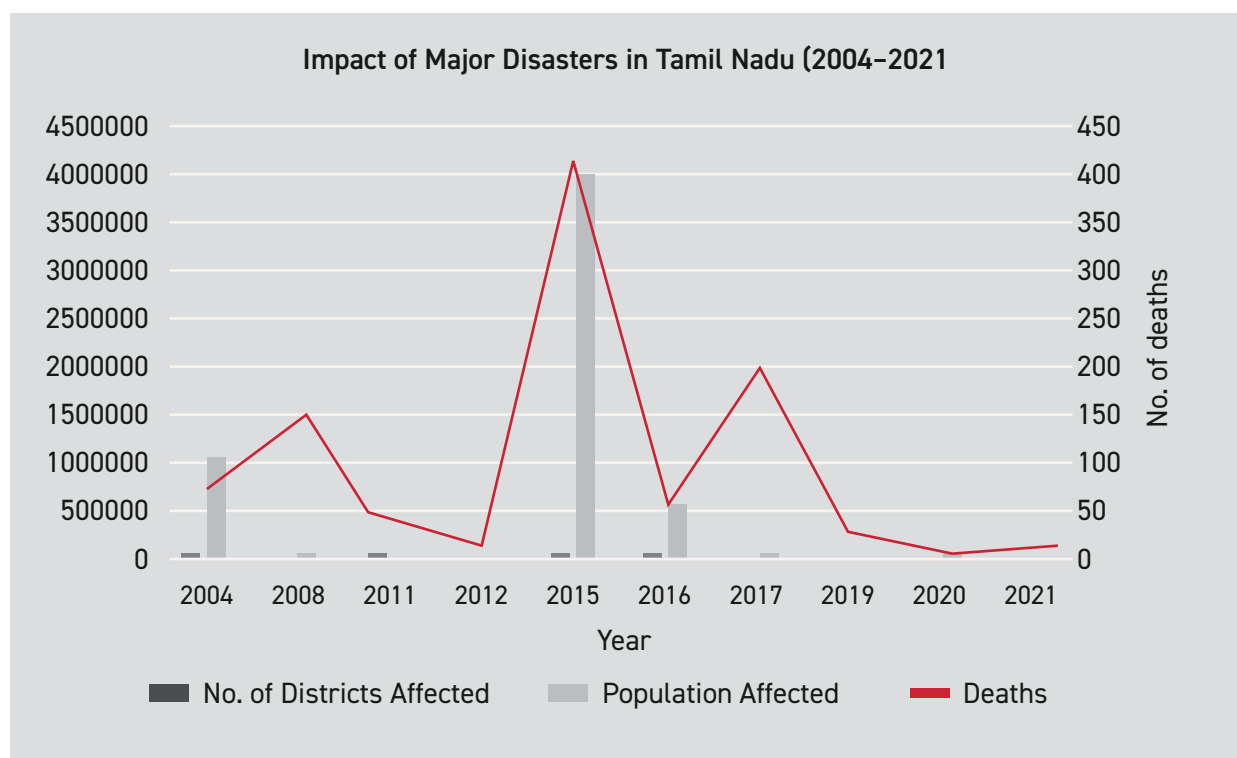


Figure 2.2: Impact of Disasters in Tamil Nadu



Source: Compiled by ADPC from Government of Tamil Nadu reports

Figure 2.2 illustrates the recurrent and severe impact of disasters in Tamil Nadu. The sharp increase in the population affected and the death tolls, particularly in 2004 and 2015, highlight the state's vulnerability to extreme weather events. These events underscore the fiscal risks associated with disasters, especially in densely populated urban areas and coastal zones where critical infrastructure is concentrated.

Floods and cyclones are among the most recurrent and damaging natural hazards in Tamil Nadu. Located along the southeastern coast of India, the state is highly vulnerable to tropical cyclones due to its proximity to the Bay of Bengal, particularly during the northeast monsoon season (October–December). Coastal districts such as Nagapattinam, Cuddalore, Chennai, and Ramanathapuram have repeatedly faced destructive cyclonic storms, including Gaja (2018), Vardah (2016), Thane (2011), and Nivar (2020). These events bring intense rainfall, high wind speeds, and storm surges, resulting in widespread damage to homes, power infrastructure, agriculture, and transportation networks.

Floods, both riverine and urban, are a persistent hazard that are often exacerbated by cyclones and poorly managed drainage systems. A significant example is the 2015 Chennai floods, when prolonged monsoon rainfall submerged large parts of the city, disrupted essential services, and displaced nearly 2 million people. Flood-prone rivers such as the Adyar, Cooum, and Tamirabarani, along with rapid urbanization and encroachments on natural water bodies, increase flood risk in major cities and low-lying districts across the state.

Although Tamil Nadu is not classified as a high-risk seismic zone, certain areas, such as Coimbatore and the Nilgiris, are categorized under Seismic Zone III. This designation indicates a moderate earthquake vulnerability. Additionally, although earthquakes are historically infrequent in this region, landslides can pose serious localized threats, particularly in hilly districts such as the Nilgiris during heavy rainfall. These landslides can obstruct roads and endanger rural communities.

The economic impact of recurring disasters is substantial. Damage to public infrastructure and disruptions to economic activity compel the state to make large, often unplanned financial outlays for relief and reconstruction. These expenditures are frequently financed through increased borrowing and the diversion of development funds, thereby increasing public debt and constraining long-term investment planning. The state's dependence on disaster-related contingent liabilities — expenditures that become necessary when a disaster strikes — can lead to fiscal outcomes that significantly diverge from budgeted expectations, especially when no pre-allocated financial reserves are available. This scenario underscores the urgent need for proactive disaster risk financing strategies and the stronger integration of risk management into fiscal policy (OECD, 2012; Mahul et al., 2014).

Impact of Disasters on Power Infrastructure

Tamil Nadu's power infrastructure has sustained frequent damage from cyclones, floods, and tsunamis, with serious implications for public services and economic stability. High wind speeds, flooding, and storm surges caused by these disasters have repeatedly disrupted electricity supply by damaging substations, transformers, poles, and transmission lines. These effects not only result in prolonged blackouts but also significantly increase the costs of recovery and infrastructure restoration.

The 2004 Indian Ocean Tsunami was one of the most devastating events in history, resulting in extensive damage to electrical installations with an estimated loss of INR 16.93 crore (approximately \$3.6 million). Following that, Cyclone Thane (2011) damaged over 45,460 electrical posts, 4,500 transformers, and 12,100 km of electrical lines. Cyclone Gaja (2018) caused widespread infrastructure damage, affecting 331,772 electric poles, 1,655 distribution transformers, and 31,824 km of conductors. The severe flooding in Chennai in 2015 damaged 500 km of low-voltage lines. Furthermore, Cyclone Vardah (2016) disrupted power services, damaging 37 electric poles and causing widespread outages across Northern Tamil Nadu.

Collectively, these events have demonstrated the vulnerability of Tamil Nadu's power sector to hydrometeorological disasters. The high frequency and extent of infrastructure damage necessitate increased investment in resilient energy systems and disaster risk financing.

Impact of Disasters on Roads and Bridges

Tamil Nadu's road and bridge infrastructure, which is vital for transportation, trade, and emergency response, has been significantly impacted by major disasters. This has led to economic disruption and the isolation of impacted communities. Multiple departments, including highways and rural development, are responsible for constructing and maintaining this network, which comprises state and district roads, urban and rural roads, and critical bridge systems.

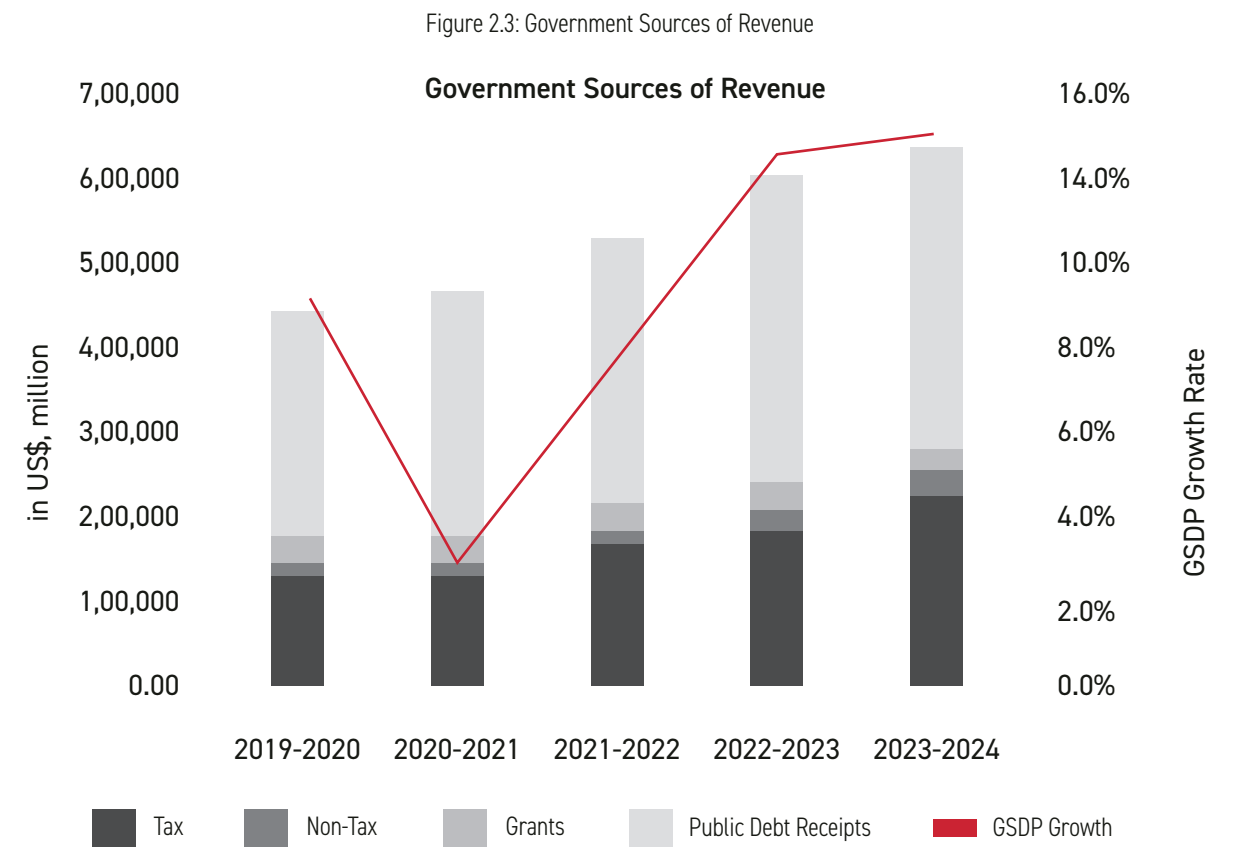
The 2004 Tsunami caused damage totalling INR 380.64 crore (approximately \$83 million) to roads and bridges, particularly in coastal districts like Nagapattinam. In 2011, Cyclone Thane led to severe disruptions, damaging 1,458 km of roads and obstructing major routes due to uprooted trees and waterlogging. Cyclone Gaja, which occurred in 2018, resulted in damage to 284 culverts across the affected districts. The 2015 Chennai floods devastated urban infrastructure, submerging roads and paralyzing transportation in the capital region. Additionally, Cyclone Vardah in 2016 affected nearly 200 roads due to massive tree falls and debris, temporarily cutting off access to several regions and halting airport operations.

These events emphasize the critical need for climate-resilient road infrastructure and robust maintenance systems to endure future disasters in Tamil Nadu.

Fiscal Impact

The Government of Tamil Nadu plays a crucial role in financing disaster relief and recovery efforts. The state frequently experiences high-impact events such as cyclones, floods, and tsunamis, which place significant strain on its fiscal capacity. Each major disaster results in substantial unplanned expenditures for emergency response, infrastructure rehabilitation, and livelihood support. These costs often require reallocating resources from long-term development programmes, thereby adversely affecting the implementation of welfare schemes and capital investments.

The sources of revenue for the Tamil Nadu government are summarized in Figure 2.3.



Source: Compiled by ADPC from the Government of Tamil Nadu reports

Tax revenues increased gradually from approximately \$130,000 million to nearly \$200,000 million. In contrast, non-tax revenues have remained low, and the proportion of grants has decreased over time. This increase in grant dependence, coupled with increased debt, underscores the state's fiscal vulnerability and its limited capacity to finance disaster recovery on its own.

The GSDP growth rate declined sharply to approximately 3 percent in 2020–21 due to the pandemic and concurrent disasters. However, it rebounded robustly, reaching nearly 15 percent by 2023–24. Despite this economic recovery, the structural fiscal stress caused by recurring climate shocks remains unaddressed. Tamil Nadu's increasing debt burden underscores the need to develop a disaster resilient fiscal framework.

Table 2.1: Summary of Revenue 2019-24 (In \$ millions)

Description	2019-2020	2020-2021	2021-2022	2022-2023	2023-2024	Change	Change(%)
Tax Revenue	17755.97	17832.47	21149.07	22982.38	25589.66	7833.69	44.1%
Goods and Services Tax	6084.16	6169.54	7332.43	7478.63	7768.38	1684.22	27.7%
Taxes on Income & Expenditure	2129.05	2071.98	2878.89	2693.49	3077.82	948.78	44.6%
Taxes on Property, Capital & Other Transactions	1475.47	1618.13	1919.74	2331.03	2137.12	661.64	44.8%
Taxes on Commodities & Services other than Goods and Services Tax	8067.29	7972.82	9020.66	6695.22	3106.97	-4960.32	-61.5%
Non-Tax Revenue	1709.60	1417.87	1598.27	2075.12	3040.76	1331.16	77.9%
Grants-in-Aid & Contributions	3685.44	4431.96	4623.71	4589.57	45803.70	42118.26	1142.8%
Public Debt	35430.37	41906.03	43605.02	43875.53	45803.70	10373.33	29.3%

Source: Compiled by ADPC from the Government of Tamil Nadu reports

The combined effect of rising expenditures and changing revenue dynamics is putting fiscal pressure on Tamil Nadu's financial stability. Key trends include the following:



Spike in Grants Dependency:

Tamil Nadu saw an exponential rise in grants-in-aid and contributions, from \$3,685.44 million in 2019–2020 to \$45,803.70 million in 2023–2024. This represents a surge of over 1,142.8 percent. This trend indicates an increased reliance on central or external support to finance post-disaster activities, particularly given the widening gap between recovery costs and state-resources (including SDRF).



Diversion of Developmental Funds:

With non-tax revenue increasing by only 77.9 percent, the burden of funding immediate relief and long-term reconstruction has strained the allocation for developmental sectors, delaying essential infrastructure and welfare projects.







Chapter 3

Institutional Frameworks and Provisions for Financing Post-Disaster Losses

Institutional Frameworks and Provisions for Financing Post-Disaster Losses

This chapter reviews the different disaster risk financing (DRF) plans and policies of the national and state governments. It focuses on funding mechanisms for post-disaster response and recovery measures to provide a clear understanding of the current DRF environment. This includes an overview of the specific mechanisms and processes in place, the hazards and assets or activities covered by the existing national framework, and the available funding amounts. Additionally, it offers detailed insights into the current budgetary provisions and government funding sources. A historical record of disaster-related expenditure from different government and non-government sources is also included in this section.

Institutional Framework for Disaster Risk Management

India has a well-established framework for Disaster Risk Management (DRM) that operates at the national, state, and district levels. At the national level, the Disaster Management Act of 2005 provides the legal framework for disaster preparedness, mitigation, and response. The National Disaster Management Authority (NDMA), led by the Prime Minister, is responsible for formulating policies and guidelines related to disaster management. The Ministry of Home Affairs (MHA) oversees disaster response, while sector-specific ministries are responsible for managing hazards such as cyclones, floods, and earthquakes.



The Tamil Nadu State Disaster Management Authority (TNSDMA) serves as the apex body responsible for creating policies, plans, and guidelines for disaster management in the state. It coordinates disaster preparedness, response, recovery, and mitigation efforts across Tamil Nadu. At the district level, the District Disaster Management Authority (DDMA) plays a key role in coordinating disaster management activities and implementing the policies and plans developed by the TNSDMA. The DDMA conducts risk assessments, prepares disaster management plans, and oversees disaster response and recovery efforts within its jurisdiction. Various government departments, including those responsible for agriculture, health, transportation, and education, incorporate disaster risk reduction strategies into their sectoral plans and operations. These departments collaborate closely with the TNSDMA and DDMA to ensure a coordinated response during disasters. Additionally, the Tamil Nadu State Disaster Response Force (SDRF) is a dedicated force trained and equipped to conduct search-and-rescue operations during disasters.

Disaster Risk Financing Mechanism in India

In India, the responsibility for DRF is divided between the states and the Union government. States are primarily responsible for responding to disasters, which includes conducting rescue operations, evacuating residents, providing relief, and assisting affected individuals. The Union government offers financial and technical assistance as needed. Generally, state governments bear the majority of disaster-related costs. In the event of a major disaster, the Union government provides additional funding to support and replenish the state's disaster relief fund.

The Disaster Management Act 2005 has significantly transformed the approach to disaster management in India. This act facilitates financial assistance through the SDRF and the National Disaster Response Fund (NDRF) for disasters officially declared. These funds were established under Sections 46 and 48 (1) of the Disaster Management Act, 2005. The current disaster risk finance mechanism is guided by the recommendations of the 15th Finance Commission (FC-XV) for the period 2020-25. The FC-XV proposed the creation of two major funds: the State Disaster Risk Management Fund (SDRMF) and the National Disaster Risk Management Fund (NDRMF).

Historical Perspective of Disaster Risk Financing in India

The Disaster Relief Fund in India is established based on the Finance Commission's (FC) recommendations. The second Finance Commission (FC-II), which operated from 1957 to 1962, introduced the 'margin money scheme' to allocate specific amounts from the states for relief measures. The sixth Finance Commission (FC-VI), active from 1974 to 1979, was the first to formally address the financing of relief expenditures in its terms of reference, a focus that subsequent Commissions have also maintained. However, it was not until the eighth Finance Commission (FC-VIII), which operated from 1984 to 1989, that any changes were made to the system established by FC-II. For several years, the same approach continued without modification. The ninth Finance Commission (FC-IX), covering the period from 1989 to 1995, recognized the inadequacies of the margin money scheme in financing relief expenditures. Instead, it recommended a new approach that involved providing substantial funds directly to states. This approach would enable states to manage emergency situations independently, without relying on central teams, state memoranda, or the margin money system. As a solution, the commission suggested creating a Calamity Relief Fund (CRF) for each state.

The tenth Finance Commission (FC-X), from 1995 to 2000, proposed specific operational procedures for the CRF. Additionally, it recommended the establishment of a National Fund for Calamity Relief (NFCR) to assist any state affected by a rare and severe disaster. In line with the existing system of the Calamity Relief Fund, the eleventh Finance Commission (FC-XI) covering the period from 2000 to 2005, continued with the existing system of the Calamity Relief Fund. It also reviewed the functioning of the National Fund for Calamity

Relief. It found that the fund's entire corpus had been exhausted within three years and that it failed to provide sufficient resources to address the needs arising from extremely severe calamities. As a solution, FC-XI recommended establishing a National Calamity Contingency Fund (NCCF) with an initial corpus of INR 500 crore. This fund is intended to be replenished through the imposition of a special surcharge on central taxes.



Disaster Funding Mechanisms in Tamil Nadu



Post-disaster financing sources are crucial for states to recover and rebuild after a disaster strikes. When a disaster occurs, states often rely on a combination of financial sources to fund recovery and reconstruction efforts. The primary sources of DRF in the state are the SDRMF and the NDRMF. The SDRMF comprises two main funds: the SDRF and the State Disaster Mitigation Fund (SDMF). The SDRF is allocated 80 percent of the total SDRMF, while the SDMF receives the remaining 20 percent. Within the SDRF allocation of 80 percent, the distribution is further divided into three sub-allocations: response and relief (40%), recovery and reconstruction (30%), and preparedness and capacity-building (10%). Likewise, the NDRMF consists of two components: The National Disaster Response Fund (NDRF) and the National Disaster Mitigation Fund (NDMF). Similar to the SDRF, the NDRF has sub-allocation into response and relief (40%), recovery and reconstruction (30%), and preparedness and capacity building (10%).



Emergency credit from international financial institutions, such as the World Bank and Asian Development Bank (ADB), provides loans and grants to enable countries to respond promptly, recover effectively, and rebuild more resilient communities. Beyond providing immediate relief, emergency credit also supports long-term recovery efforts, including reconstruction, restoration of essential services, and rehabilitation of affected communities.



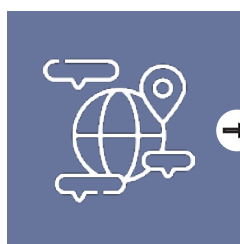
Private sector finance, through both corporate social responsibility (CSR) and non-CSR funds, has emerged as a significant player in disaster relief and recovery efforts. In addition to providing financial support, the private sector also contributes innovation, expertise, and efficiency to disaster relief and recovery efforts.



The Prime Minister's Relief Fund in India, a charitable trust, was established to provide immediate financial assistance to affected communities by natural catastrophes, accidents, and other calamities to cover medical expenses, rehabilitation, and education. The fund is managed by the Prime Minister's Office (PMO) and is exclusively utilized for rehabilitation efforts during crises.

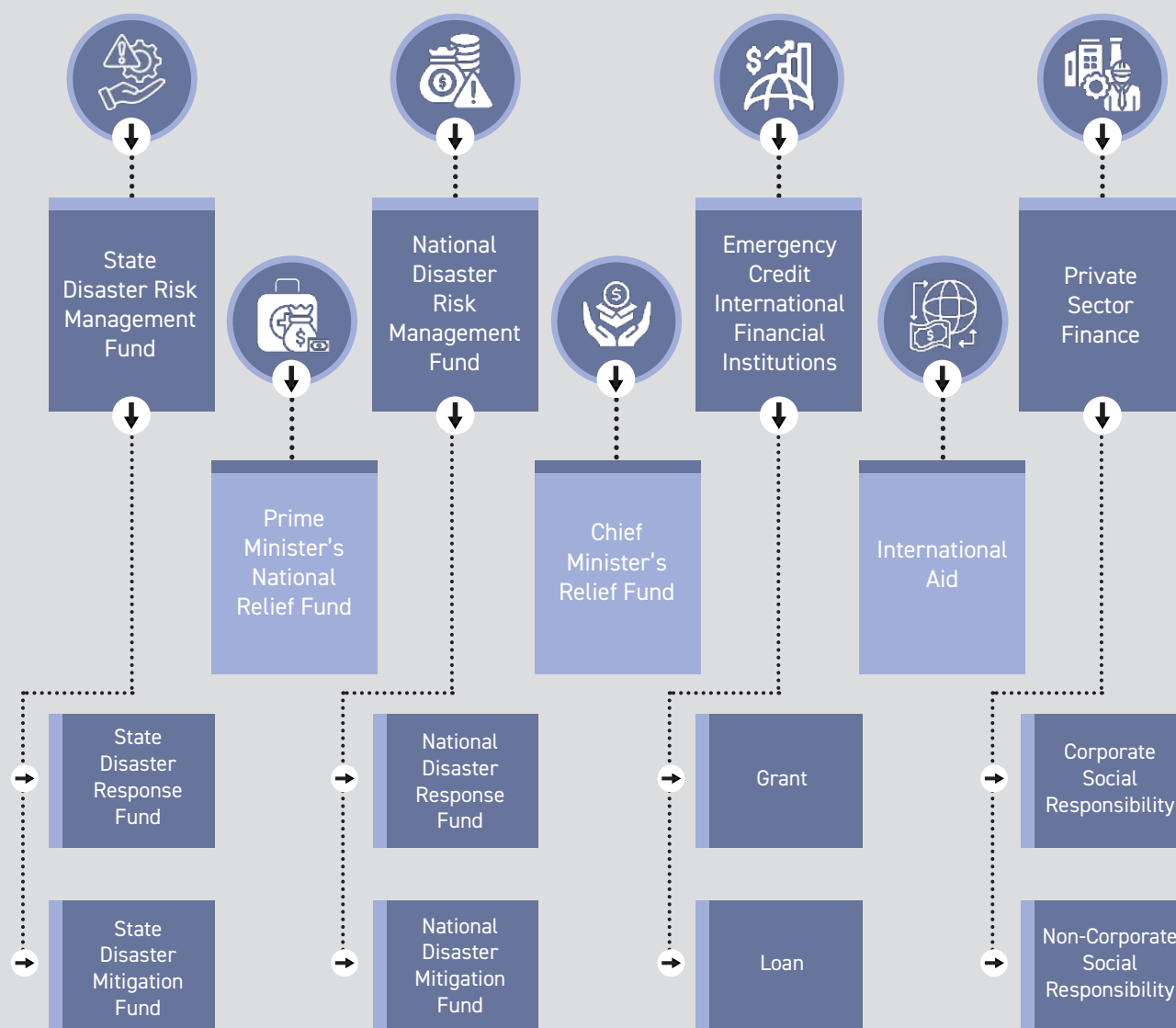


The Chief Minister's Relief Fund aims to provide immediate assistance to the people of Tamil Nadu in times of distress. This fund is supported by budgetary allocations from the Government of Tamil Nadu and by voluntary donations from the general public and social responsibility organizations.



International assistance for disaster relief in Tamil Nadu, like in any other Indian state, typically involves cooperation and support from foreign governments, international organizations, and non-governmental organizations (NGOs).

Figure 3.1: Sources of Disaster Risk Financing



Source: ADPC

NDRF Allocation Mechanism

The NDRF offers financial support for severe disasters in addition to the provisions of the SDRF. When a severe disaster strikes and the funds available in the state's SDRF are insufficient, the state government can request additional assistance from the NDRF by submitting a memorandum.

This memorandum is reviewed to evaluate the estimated funding needs based on the items and expenditure guidelines established for both the SDRF and the NDRF. After a preliminary examination, if it is determined that the SDRF has sufficient funds to provide relief in accordance with regulations, the states will be notified. However, if further assistance is necessary, an Inter-Ministerial Central Team will be dispatched to the affected area for an on-site evaluation.

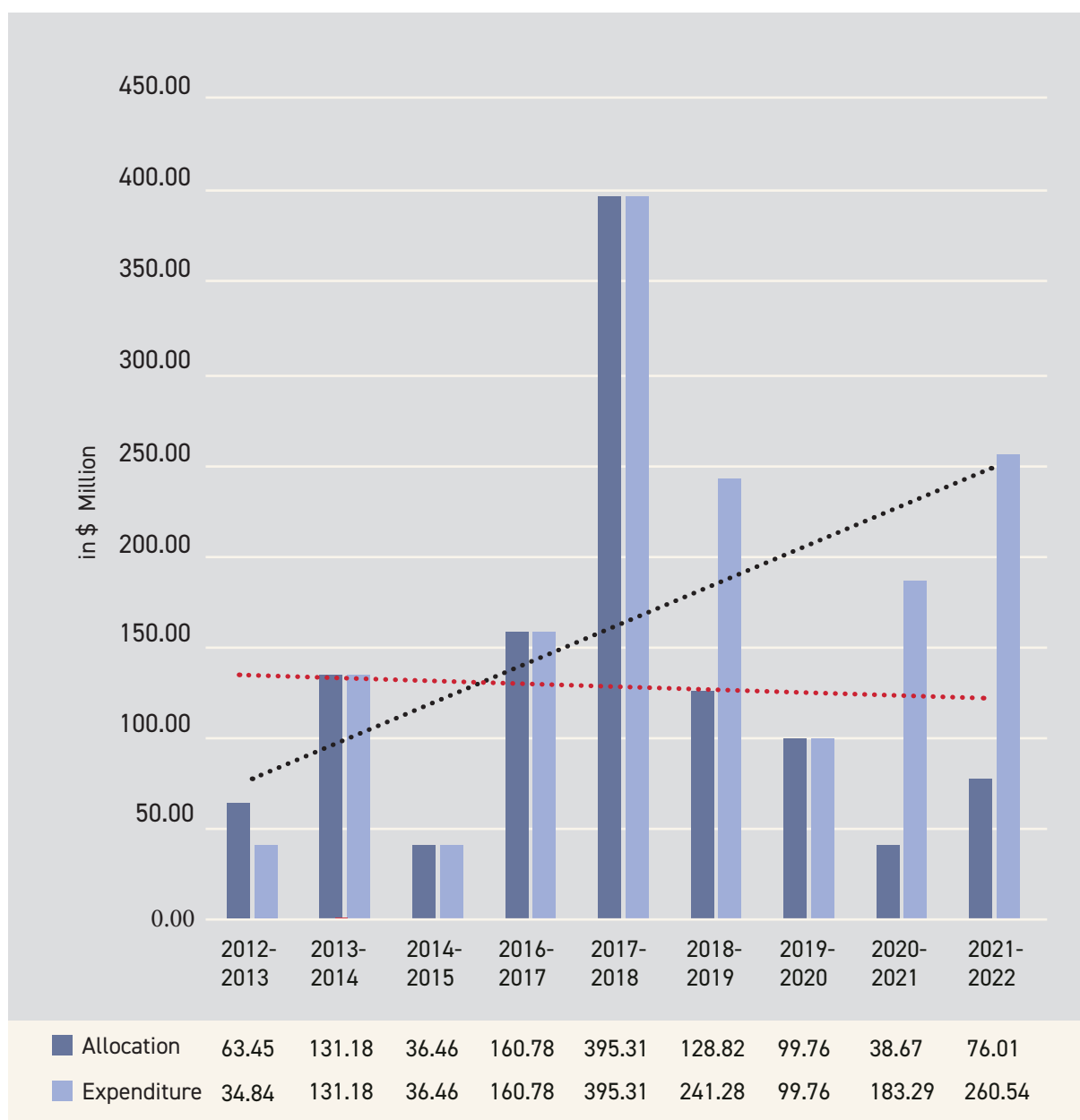
The National Executive Committee then reviews the report from the Central team through a sub-committee. This sub-committee assesses relief expenses eligible for funding under both the NDRF and the SDRF. Finally, the high-level committee considers the sub-committee's recommendations and determines the amount of immediate aid to be allocated from the NDRF.

Trend Analysis of Disaster Risk Financing in Tamil Nadu

This section presents the trend analysis of allocations and expenditures from primary disaster financing sources in Tamil Nadu, namely the SDRF, NDRF, and Prime Minister's National Relief Fund (PMNRF). The SDRMF consists of both the SDRF and the SDMF, with 80 percent of the SDRMF allocated to SDRF and the remaining 20 percent to SDMF. Within the SDRF, allocations are further divided across response and relief (40%), recovery and reconstruction (30%), and preparedness and capacity building (10%). While SDRF and SDMF funds are non-transferable, there is some flexibility to reallocate funds among SDRF sub-windows. In instances where SDRF proves insufficient to respond to major calamities, Tamil Nadu has sought additional financial assistance from the NDRF.



Figure 3.2: Annual Allocation and Expenditure from SDRF and NDRF in Tamil Nadu



Source: Compiled by ADPC from the Government of Tamil Nadu reports

Figure 3.2 showcases the comparative allocation and utilization of SDRF and NDRF funds in Tamil Nadu from 2012 to 2022. The expenditure often exceeds the allocation, reflecting not only an underestimation of disaster impacts but also highlighting funding gaps that can destabilize post-disaster recovery.

Figure 3.3: Annual Allocation and Expenditure from Prime Minister's National Relief Fund in Tamil Nadu (2012-13 to 2021-22)



Source: Compiled by ADPC from the Government of Tamil Nadu reports

Figure 3.3 illustrates the status of fund allocation and expenditure from the Prime Minister's National Relief Fund from the 2021-22 fiscal year. This fund aims to alleviate the suffering of affected individuals and help them regain stability in their lives. It is entirely funded by public contributions and receives no government budgetary assistance. The highest allocation and utilization of the fund occurred during the 2015-16 fiscal year, following the Chennai floods and Cyclonic Storm Vardah.



Chapter 4

Economic Modelling



Economic Modelling

Estimating the indirect effects of hazards has traditionally been challenging, and, as a result, has received less attention in the research literature. While the

direct effects, such as immediate asset damage, loss of life, and the costs associated with delivering aid, are highly visible, the indirect effects can be more systemic and less noticeable. This section provides a sector-specific estimation of the indirect impacts of disasters, focusing on how losses in one sector can affect related sectors. The assessment quantifies these indirect effects of disasters in terms of loss of income and value-added or overall economic output. Economic modelling techniques are designed to assess the economic activities reliant on specific infrastructure segments and to measure the costs associated with their loss. This analysis includes the interruption of economic activity due to the loss of essential infrastructure and the decreased productivity that results from dependence on less efficient alternatives.

The indirect impact of disasters was modelled using a panel regression model, which compared government fiscal variables against a derived measure of disaster intensity (Noy 2016a). This analysis employed a fixed effects panel model that included both state and time variables. Such panel models are routinely used in the economic analysis of complex, real-world issues that cannot be adequately represented by cross-sectional or time-series data alone (Balaji 2013). A fixed effects model with both state and time variables incorporates cross-sectional data, representing each state's intrinsic characteristics that do not vary over time (state-invariant aspects), as well as time series data, which comprise variables that change over time but remain constant across states (time-invariant aspects). By including data from both before and after the disaster event across affected and unaffected states, this panel model can effectively quantify the fiscal implications of the events.

Equation 1: Panel Model Equation

$$Y_{it} = \alpha_i + \sum_{j=1}^p \Phi_j Y_{i,t-j} + X_{it}\beta + \varepsilon_{it}$$

Y	is the modelled fiscal variable
α	is the fixed effects for the states
p	is time lag variable
Φ	is the number of lags included in the model
X	is the disaster intensity variable
ε	is the error term

All modelling was performed using the R statistical language, specifically utilizing the R-plm package. This package includes a suite of functions for analyzing panel data. Additionally, it provides methods for hypothesis testing, including tests for both individual and time effects (Croissant and Millo 2008).

Economic Panel Model and Data

States included in the Economic Panel Model

In this study, each Indian state is treated as a cross-sectional unit in an econometric panel model. By including data from before and after the disaster, across affected and unaffected states, the panel model quantifies the disaster's fiscal implications on each state's government finances. However, historical data are not available for all Indian states, as some were created more recently through the division of existing states. Moreover, the formation of new states often leads to significant changes in the fiscal variables of the states from which they were carved out. To address these issues, newly formed states were merged with their original states to ensure a complete historical record and to eliminate any noticeable decline in GDP associated with state creation. Furthermore, states with small populations were excluded from the analysis. A cut-off population of 5 million, based on the 2011 Indian Census, was used to determine which states to exclude. As a result, 14 states were excluded because their populations fell below this threshold. The final list of included states is presented in Table 4.1.

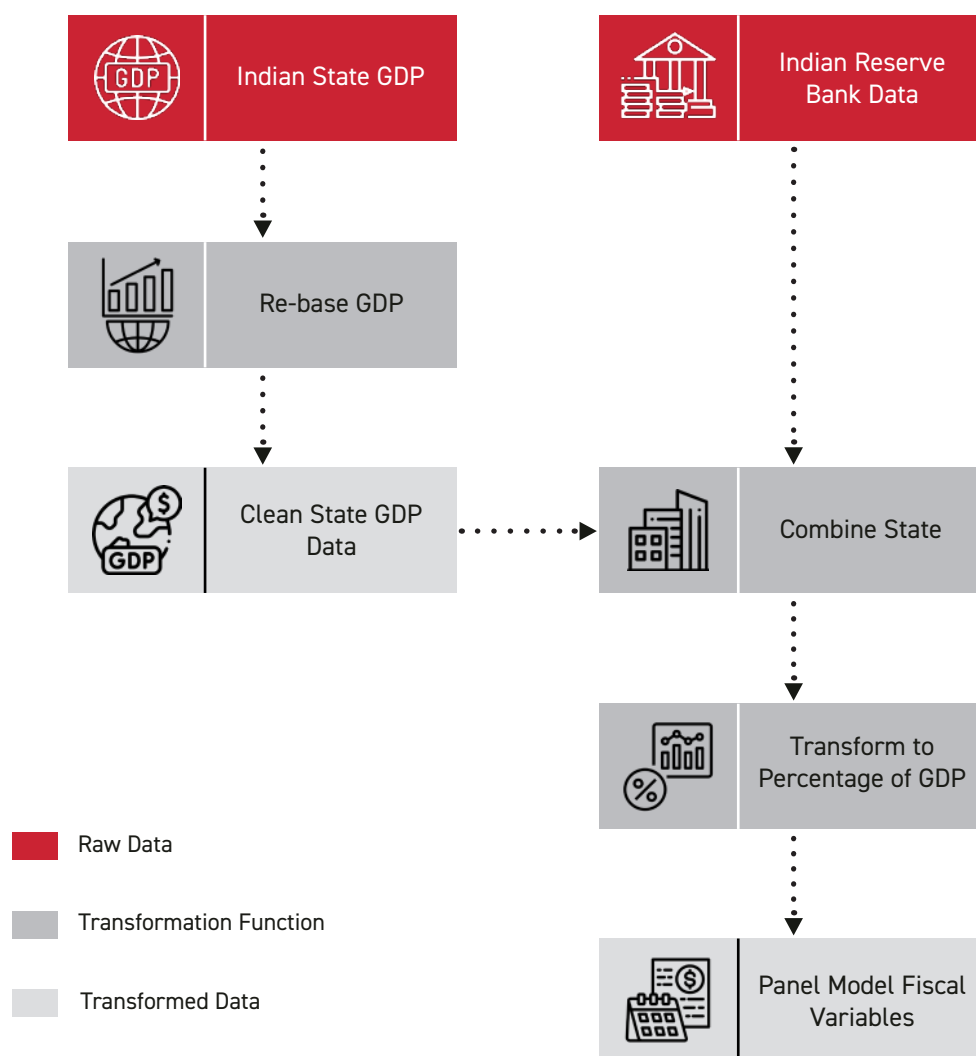
Table 4.1: Included Indian States



Fiscal Variables

All fiscal variables were examined on a state level and expressed as a percentage of GDP. This approach enables better comparability of fiscal variables across states and minimizes the impact of variations in state size. The study utilized data from 1995 to 2019; the period from 2020 to the present was excluded due to the significant effects of the Coronavirus pandemic on the global economy. The fiscal data underwent a thorough review, cleaning, and transformation process. Figure 4.1 provides a broad overview of this process, and the steps taken for each variable are outlined in the sections below.

Figure 4.1: Data Cleaning and Transformation Process for the Fiscal



The GDP data presented in this study have been re-based to a consistent reference year of 2011. This approach provides a consistent measure for cross-temporal comparison while accounting for inflation and other economic factors. All historical fiscal data for each Indian state, sourced from the Reserve revenue. Non-tax revenue includes the states' own non-tax revenue and intergovernmental transfers, which typically consist of grants from the Central Government.

Table 4.2: Fiscal Variables from RBI

	Power sector • Economic services expenditure • Non-tax revenue • Taxes and duties on electricity	• Power project disbursements
	Transport sector • Economic services expenditure • Road transport sector non-tax revenue	
	Other revenue variables • State's non-tax revenue • Grants from the Centre • Total non-tax revenue	• Total tax revenue • Total revenue
	Expenditure variables • Relief on account of natural calamities – developmental expenditure • Social services – developmental expenditure • Total expenditure	
	Capital receipts & disbursement • Internal debt (receipt) • Total capital disbursements	
	Other variables • State GDP • Consumer price index (state and national)	

Figures 4.1 and 4.2 show how each disaggregated variable flows through to a state's aggregated fiscal variables.

Figure 4.2: Expenditure Variables Flow Diagram

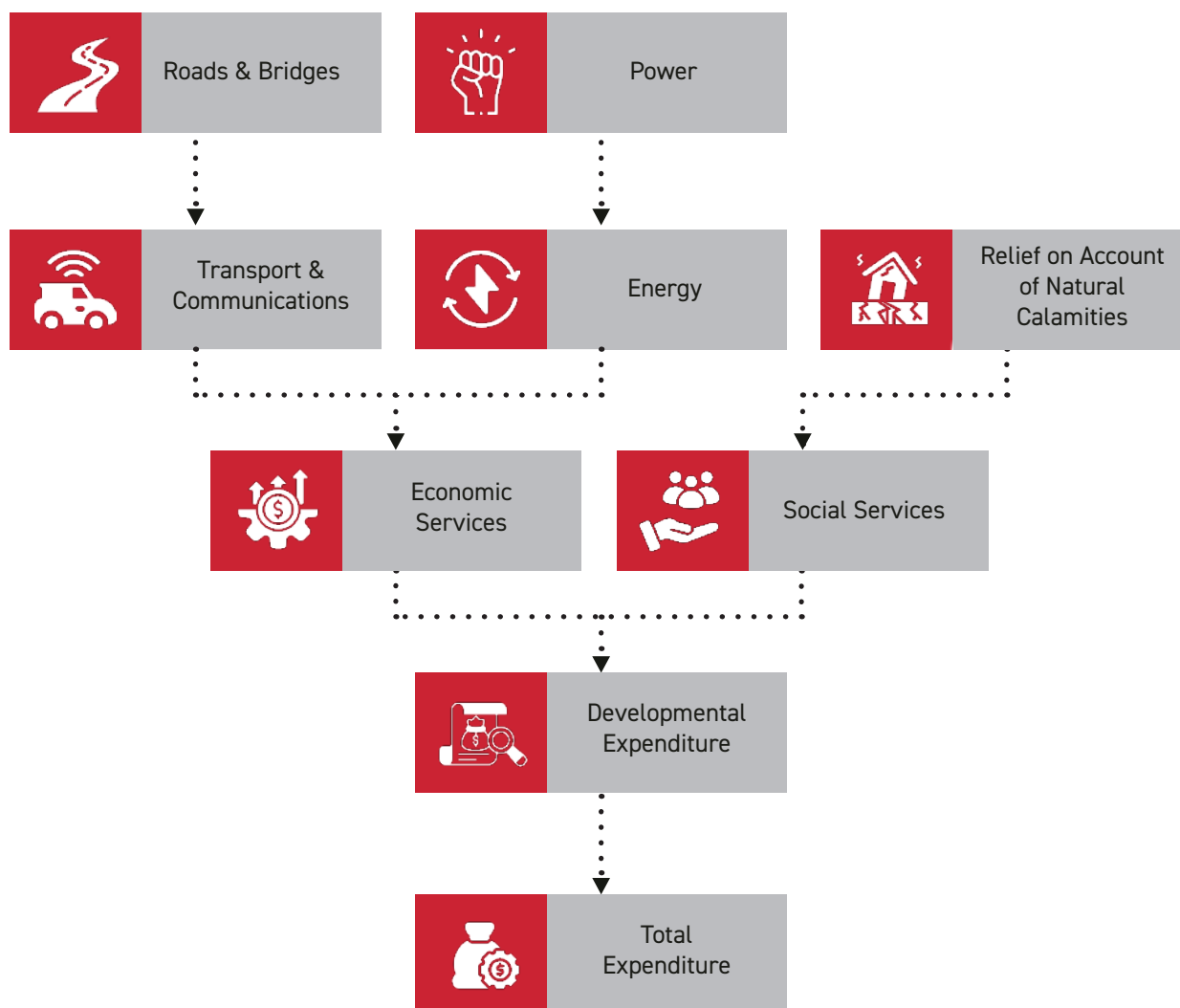
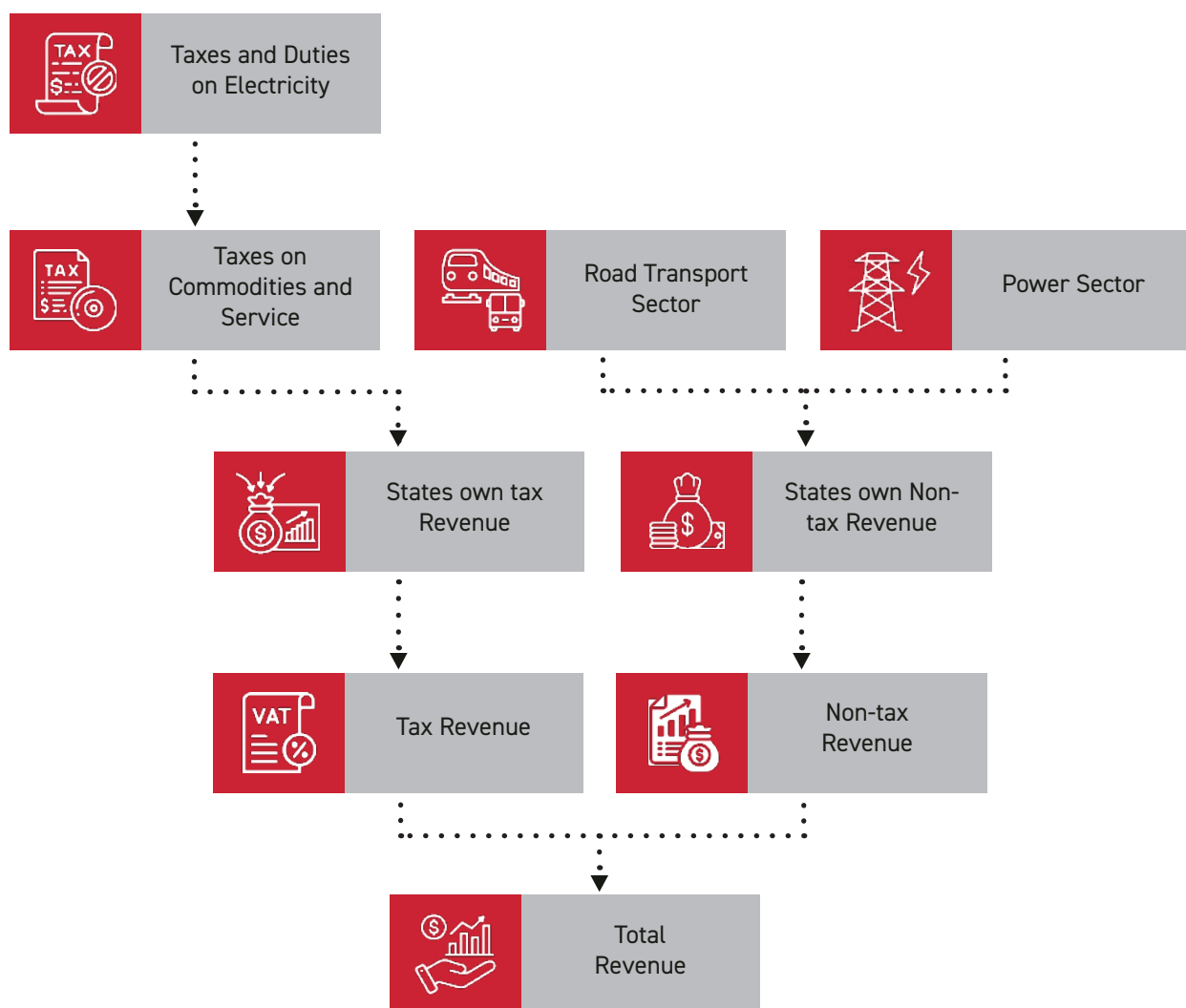


Figure 4.3: Revenue Variables Flow Diagram



Because a panel model requires stationary data, the fiscal variables were tested for stationarity. Non-stationary data refers to a time series whose statistical properties, such as mean, variance, and autocorrelation, change over time. This characteristic can pose significant challenges for econometric modelling (Brockwell and Davis 2002). The analysis showed that the fiscal variables were non-stationary. As a result, all fiscal variables were first-differenced, thereby transforming the dataset into a stationary time series.

Disaster Intensity Variable

The data on disaster events for this study were obtained from two primary sources: the EM-DAT International Disaster Database (EM-DAT n.d.) and the Indian Central Water Commission (CWC) (Central Water Commission n.d.). The time period for the disaster data aligns with the fiscal data, covering the period from 1995 to 2019. Both datasets provide several statistics that were used in the study:



To obtain state-level data on disaster impacts, each disaster was assigned to the state in which the affected districts or areas were located. For cyclone-related losses, these losses were specifically allocated to coastal states. If a cyclone affected multiple coastal states, the state with the highest impact was identified by examining the cyclone's path and the corresponding Wikipedia page for that cyclone. The losses were then allocated to this state.

For flood data, we used data from the CWC. This dataset provides annual flood-damage totals for each state, compiled from 1953 to 2020.

Life Years Lost Calculation

The disaster intensity variable in our panel model is based on the 'Life Years Lost' (LYL) measure. The total monetary damage from a disaster is linked to both the severity of the disaster and the income and asset values of the affected population, which makes it challenging to compare damage across regions and countries. By incorporating data on fatalities and affected individuals, the LYL provides a more standardized measure of disaster severity. As an index, LYL allows for better comparison across various types of disasters and regions. Noy (2016a) adapted the equation for disaster intensity and presented the following equation, which was used to calculate the LYL.

Equation 2: Life Years Lost Equation

$$LifeYearsLost = M \cdot (A^{expect} - A^{median}) + e^{TN_{EMDAT}} + \frac{(1 - c)Y}{GDP_{pc}}$$



The first component of the LYL calculation is the fatality component. The World Health Organization's (WHO) Disability Adjusted Life Years (DALY) of 92 years was used for A^{expec} , while the median age for each state was used as per the 2011 census. M is derived from the number of fatalities from a given disaster. This helps measure the productive capacity lost for each individual who dies in a disaster.

Equation 3: Mortality Component of LYL Equation

$$M \cdot (A^{\text{expec}} - A^{\text{median}})$$

The next component relates to the cost function associated with the affected population, as illustrated in Equation 4. e represents the welfare reduction function, for which a value of 0.054 was employed, consistent with Noy (2016a) and the WHO's index. The variable T denotes the time it takes for an affected person to return to normalcy or for the impact of the disaster to subside, while the N^{EMDAT} term refers to the number of affected individuals, as reported in the EM_DAT database.

Equation 4: Cost Function Associated with the Population Affected

$$eTN^{\text{EMDAT}}$$

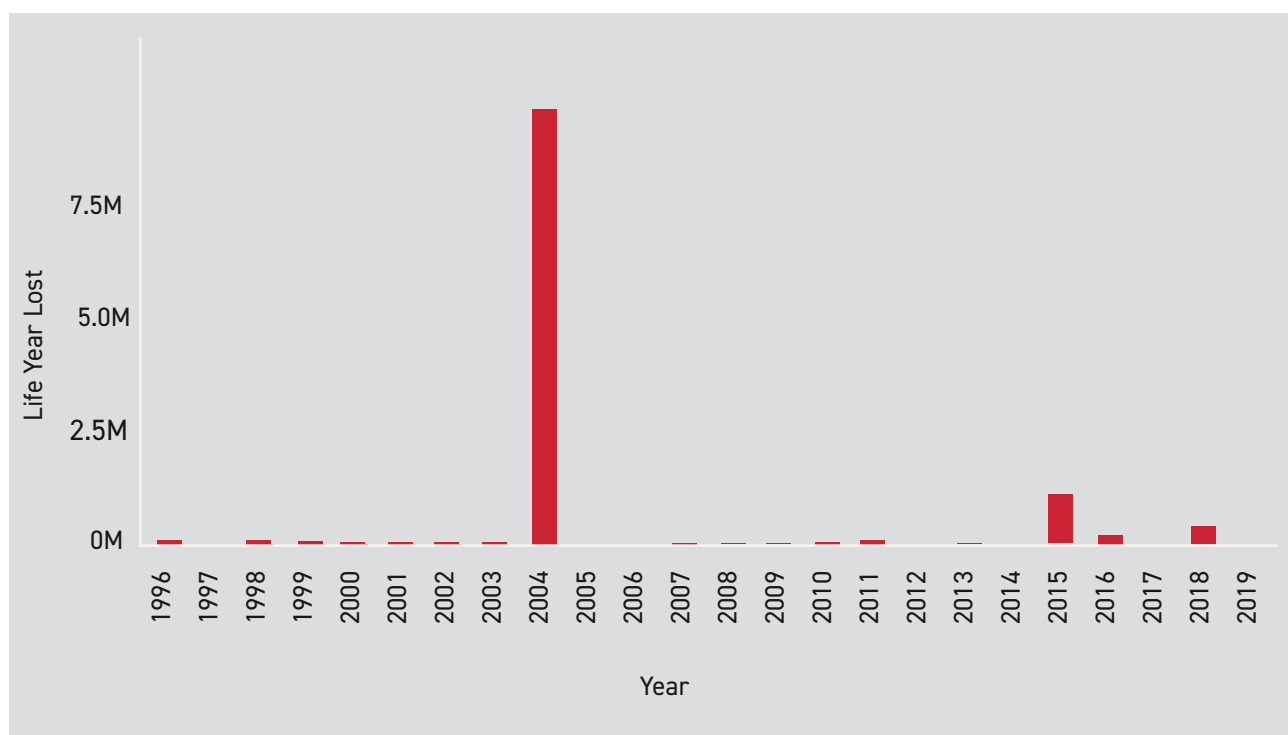
The final component of the LYL model is related to the financial losses associated with the disaster. The variable e denotes the discount factor, with the benchmark specification of the index utilizing a discount rate of 75 percent. This rate is consistent with the findings of Noy (2016a) and is employed in this study. Additionally, the variable Y represents the financial losses incurred due to the disaster, while GDP_{pc} signifies the GDP per capita for the state.

Equation 5: Equation Associated with The LYL due to Damages to Physical Capital and Infrastructure

$$\frac{(1 - c)Y}{GDP_{pc}}$$

Figure 4.4 shows the LYL value per year for Tamil Nadu from 1996 to 2019. The highest values correspond to events with the highest severity in terms of fatalities, affected population, and total monetary damage. The severity of disasters varies substantially from year to year, with an average LYL of 67,724 and 1 standard deviation of 187,784. The most severe events during this period were the 2004 Indian Ocean tsunami, which had a 9.3 million LYL, and the floods in 2015 (0.9 million LYL).

Figure 4.4: Tamil Nadu Life Years Lost per Year

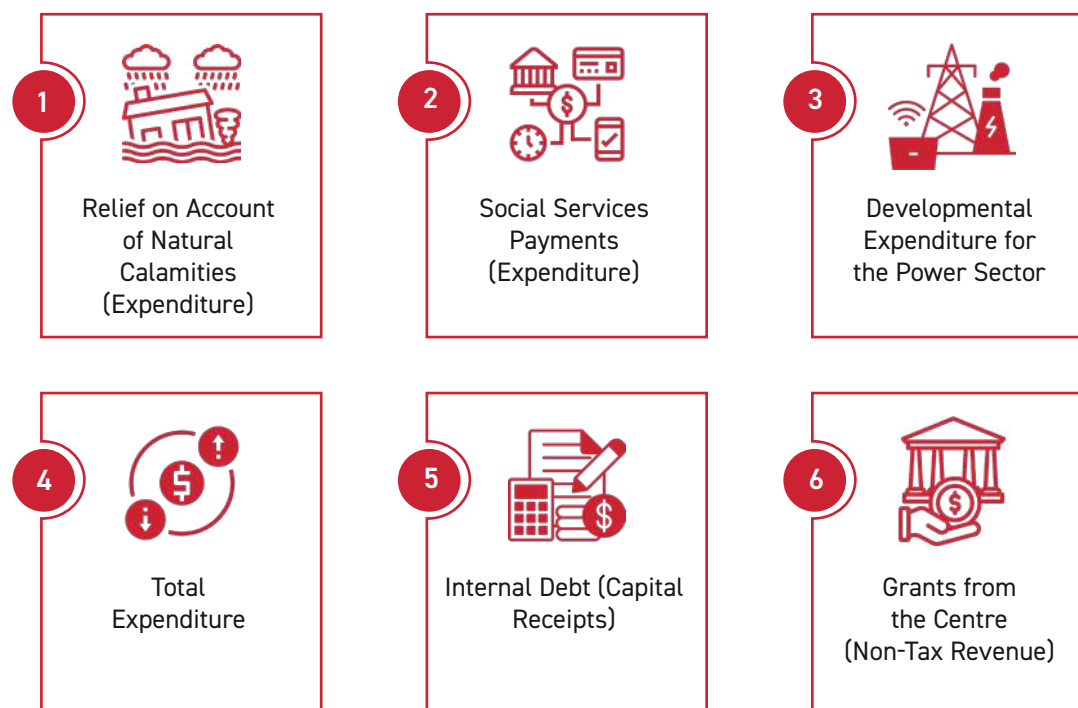


The LYL values in Figure 4.4 reflect the human and economic severity of disasters. These peaks support the modelling approach and its role in forecasting fiscal risk, which is a core objective of the study.



Economic Modelling Results

The economic modelling revealed a significant increase in expenditure and a rise in debt issuance following a disaster. Additionally, revenue from central grants increased markedly following such events. The analysis identified that six of the modelled fiscal variables were significantly affected by disasters. The specific fiscal variables impacted by these events included:



The other fiscal variables included in the analysis did not exhibit a significant effect of the LYL disaster variable (at the 5% level). Table 4.3 shows the coefficients for LYL for each of the fiscal variables that were identified as statistically significant in the panel model.

Table 4.3: Coefficients and Significance (P-Value) for each Fiscal Variable where there was a Significant Effect

Fiscal variable	LYL coefficient	P-value	Standard error
Relief on Account of Natural Calamities	2.182155e-09	1.181e-08	3.7437e-10
Social Services Payments	3.480725e-09	5.245e-06	7.5343e-10
Developmental Expenditure on Power Sector	2.5703e-09	0.03808	1.2351e-09
Total Expenditure	8.873447e-09	1.576e-05	2.0289e-09
Internal Debt Issuance	4.769941e-09	0.0052	1.6974e-09
Grants from the Centre	3.18e-09	0.0026	1.0481e-09

Average Modelled Fiscal Impact

The tables below illustrate the modelled impacts for two scenarios: an average-intensity disaster and a disaster one standard deviation above average intensity. The results are presented both as a percentage of the monetary value of the fiscal variables and in US dollars (\$). Percentage values can help estimate future impacts in US dollars when fiscal variables are projected. Additionally, a 95 percent confidence interval is included for each modelled output.

The modelling indicated that total expenditure, disaster relief expenditure, and social service expenditure all increase significantly following a disaster. Additionally, there was also a significant increase in Tamil Nadu's internal debt receipts, suggesting that the government may issue new debt to cover the increased spending required. The analysis showed that states' own non-tax revenue did not change significantly, whereas the Central Government increased significantly following a disaster. This finding implies that the Central Government of India consistently supports the Tamil Nadu government in the aftermath of a disaster; however, this funding is substantially lower than our modelled increase in spending on relief and social services. This observation aligns with the Panwar & Sen 2020 paper. There was also a slight increase in developmental spending on the power sector. However, the increase was small, and the confidence interval is wide; therefore, this result should be interpreted with caution.

The coefficients displayed in Table 4.3 represents the change in each fiscal variable for each LYL. However, the impacts of a disaster can yield a wide range of LYL values. For example, the yearly average (mean) LYL for historical disasters in Tamil Nadu is 68,000. Based on this average, Table 4.4 shows the corresponding percent changes for each fiscal variable following a disaster of average intensity.

Table 4.4: Percentage Change in Tamil Nadu Fiscal Variables Following an Average Intensity Disaster

Fiscal variable	Average change following a disaster (% of fiscal variable)	95% confidence interval
Relief on Account of Natural Calamities	0.02%	± 0.006%
Social Services Payments	0.03%	± 0.011%
Developmental Expenditure on Power Sector	0.02%	± 0.019%
Total Expenditure	0.07%	± 0.031%
Internal Debt Issuance	0.04%	± 0.026%
Grants from the Centre	0.02%	± 0.016%

These values represent changes in fiscal variables that can help us understand their impact in US dollars. Table 4.5 shows these figures in US dollars based on the 2022 values of the modelled fiscal variables. As these fiscal variables change over time, percentage changes can help gauge how the overall impact evolves with changes in fiscal variables. Following an average disaster, total expenditures are expected to increase by \$12.1 million, partially offset by Central Government grants amounting to \$0.6 million. Additionally, spending on social services is expected to increase by \$1.5 million, while internal debt issuance is projected to increase by \$2.1 million.

Table 4.5: Monetary Change in Fiscal Variables (\$) in Tamil Nadu from an Average Intensity Disaster

Fiscal variable	Average change following a disaster (\$)	95% confidence interval
Relief on Account of Natural Calamities	6,852	± 2,304
Social Services Payments	1,490,808	± 632,484
Developmental Expenditure on Power Sector	222,852	± 209,892
Total Expenditure	12,080,952	± 5,414,088
Internal Debt Issuance	2,115,036	± 1,475,184
Grants from the Centre	623,244	± 402,588



Table 4.6: Percentage Change in Tamil Nadu Fiscal Variables in a Year which Suffers a Disaster One Standard Deviation Above the Average Severity

Fiscal variable	Change for a disaster 1 std deviation above the average (%)	95% confidence interval
Relief on Account of Natural Calamities	0.06%	± 0.021%
Social Services Payments	0.10%	± 0.043%
Developmental Expenditure on Power Sector	0.07%	± 0.071%
Total Expenditure	0.26%	± 0.116%
Internal Debt Issuance	0.14%	± 0.097%
Grants from the Centre	0.09%	± 0.060%

While these figures represent changes in fiscal variables for an average severity event in Tamil Nadu, the impacts of disasters can vary widely. The LYL data exhibit a significant range, including several extreme events with very high LYL values. To gain a clearer understanding of the range of impacts, Table 4.6 shows the percent change in fiscal variables for a disaster with a severity level one standard deviation above the average severity for Tamil Nadu. This corresponds to a LYL of approximately 256,000.

Table 4.7 presents the changes in US dollars for each fiscal variable following a disaster that has an intensity one standard deviation above the average, based on the 2022 value of each fiscal variable. Following an average disaster event, total expenditure in the subsequent fiscal year is expected to increase by \$45.6 million. This increase is partially offset by Central Government grants amounting to \$2.4 million. Additionally, spending on social services is projected to increase by \$5.6 million, while internal debt issuance is expected to rise by \$8.0 million.

Table 4.8 through to Table 4.11 show the modelled impacts for two of the most severe events that have occurred in Tamil Nadu. These events are the 2004 Indian Ocean Tsunami and the 2015 Tamil Nadu Floods. The results are expressed in both percentage change of the fiscal variable and the corresponding monetary value in USD based on the value of the fiscal variables in 2022. A 95 percent confidence interval is also provided.

The LYL values for both events were much higher than average: 9.3 million LYL for the Indian Ocean Tsunami and 0.9 million for the 2015 Floods. These values were used to calculate the potential effect on fiscal variables if an event of the same severity were to strike Tamil Nadu in 2022.

The projected increase in total expenditure if an event as severe as the 2004 Indian Ocean Tsunami were to occur today was \$1.7 billion including \$205.6 million increased spending on social services and \$0.9 million spending on relief payments. Tamil Nadu's internal debt issuance would increase by \$291.6 million. Central government grants would increase by \$85.9 million.

The projected increase in total expenditure if an event as severe as 2015 Tamil Nadu Floods were to occur today was \$167.4 million including \$20.7 million increased spending on social services and \$0.1 million increase spending on relief payments. Tamil Nadu's internal debt issuance would increase by \$29.3 million. Central government grants would increase by \$8.6 million.

Table 4.7: Monetary Change in Fiscal Variables (\$) in Tamil Nadu from a Disaster 1 Standard Deviation in Intensity Above Average

Fiscal variable	Change for a disaster 1 std deviation above the average (\$)	95% confidence interval
Relief on Account of Natural Calamities	25,848	± 8,688
Social Services Payments	5,624,484	± 2,386,224
Developmental Expenditure on Power Sector	840,792	± 791,892
Total Expenditure	45,578,760	± 20,426,172
Internal Debt Issuance	7,979,580	± 5,565,540
Grants from the Centre	2,351,376	± 1,518,888



Table 4.8: Percentage Change in Tamil Nadu Fiscal Variables if an Event Equivalent to the Indian Ocean Tsunami Occurred in 2022

Fiscal variable	Change in fiscal variable (%)	95% confidence interval
Relief on Account of Natural Calamities	2.3%	± 0.782%
Social Services Payments	3.7%	± 1.574%
Developmental Expenditure on Power Sector	2.7%	± 2.581%
Total Expenditure	9.5%	± 4.239%
Internal Debt Issuance	5.1%	± 3.546%
Grants from the Centre	3.4%	± 2.190%

Table 4.9: Monetary Change in Fiscal Variables (\$) in Tamil Nadu If an Event Equivalent to the Indian Ocean Tsunami Occurred in 2022

Fiscal variable	Change in fiscal variable (%)	95% confidence interval
Relief on Account of Natural Calamities	944,796	± 317,688
Social Services Payments	205,554,300	± 87,207,900
Developmental Expenditure on Power Sector	30,727,908	± 28,940,592
Total Expenditure	1,665,737,052	± 746,501,700
Internal Debt Issuance	291,624,312	± 203,400,012
Grants from the Centre	85,934,160	± 55,509,876

Table 4.10: Percentage Change in Tamil Nadu fiscal variables if an Event Equivalent to the 2015 Tamil Nadu Floods Occurred in 2022

Fiscal variable	Change in fiscal variable (%)	95% confidence interval
Relief on Account of Natural Calamities	0.23%	± 0.08%
Social Services Payments	0.37%	± 0.16%
Developmental Expenditure on Power Sector	0.28%	± 0.26%
Total Expenditure	0.95%	± 0.43%
Internal Debt Issuance	0.51%	± 0.36%
Grants from the Centre	0.34%	± 0.22%

Table 4.11: Monetary Change in Fiscal Variables (\$) in Tamil Nadu if an Event Equivalent to the 2015 Tamil Nadu Floods Occurred in 2022

Fiscal variable	Change in fiscal variable (%)	95% confidence interval
Relief on Account of Natural Calamities	94,956	± 31,932
Social Services Payments	20,658,504	± 8,764,524
Developmental Expenditure on Power Sector	3,088,200	± 2,908,572
Total Expenditure	167,408,940	± 75,024,480
Internal Debt Issuance	29,308,656	± 20,441,988
Grants from the Centre	8,636,508	± 5,578,824



Chapter 5

Probabilistic Assessment of Future Fiscal Risks through Catastrophe Modelling



Probabilistic Assessment of Future Fiscal Risks through Catastrophe Modelling

Fiscal Risk Assessment (FRA) is the evaluation of potential consequences of hazardous events that could impact elements under the state's responsibility. This assessment helps identify the losses that the public sector must manage using financial protection instruments, which provide liquidity and ensure the fiscal sustainability of the territory. When assessing the government's ability to address risks in sectors it oversees, a risk assessment offers insights into the financial demands placed on the state. These demands must be met by well-defined risk-retention or risk-transfer instruments, tailored to the actual levels of risk involved.

Disaster risk is inherently uncertain due to the unpredictable nature of hazard occurrences and the causes of losses. The uncertainty is compounded by the unknowns related to future climate conditions and the limitations of representing reality accurately. Therefore, the model's outputs should be viewed as a reasonable approximation of the issue. They serve to communicate the potential financial consequences that the government may face. It is important to remember that these consequences are variable and cannot be known with absolute precision.



Hazard Models

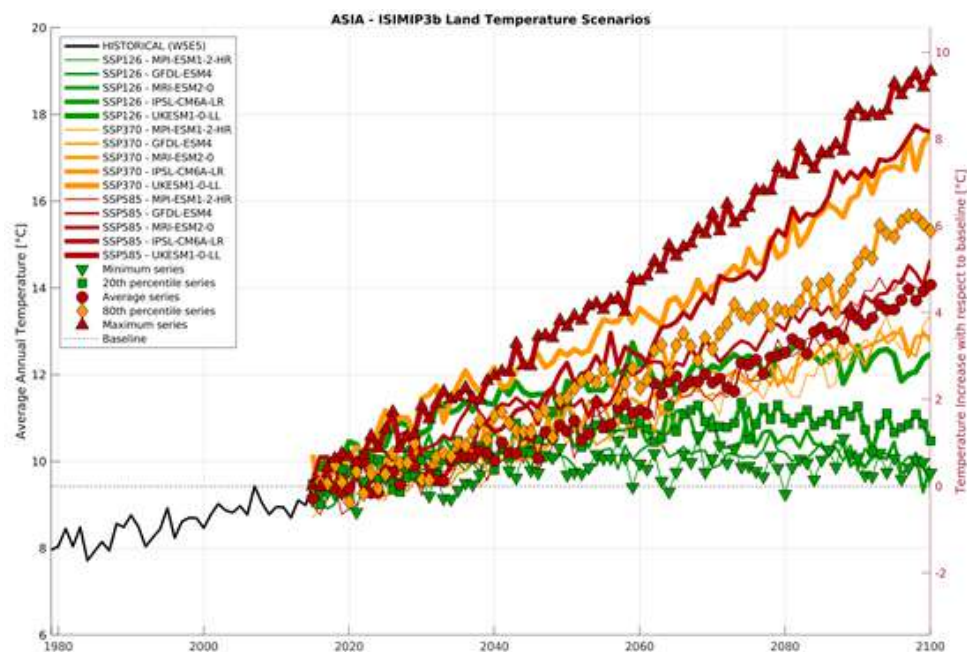
For the FRA of Tamil Nadu, four hazards have been identified: earthquakes, tropical cyclones, floods, and landslides. These natural hazards are represented as a collection of events. Each event denotes a single occurrence of the hazard (i.e., one tropical cyclone) that produces a specific intensity at the location of the infrastructure elements and has a specified probability of occurrence. The complete set of events (i.e., all the simulated tropical cyclones) comprehensively illustrates the possible occurrences of each hazard. In the following sections, we will describe the various hazard models used in this assignment.

Climate Models

Model for Flood and Landslide Hazards

The climate models considered for this assignment are identical to those defined in the development of the Global Infrastructure Risk Model & Resilience Index (GIRI) of CDRI (Cardona et. al. 2023). Multiple projections from global circulation models included in CMIP6² were verified, focusing on anthropogenic forcing expressed through a combination of scenarios from the SSP (shared socio-economic pathways) and RCP (representative concentration pathways), as defined by the IPCC (AR6). Figure 5.1 shows the spatial average of various future projections of surface temperature over Asia for the period up to 2100. This data is obtained from the ISIMIP3b (ISIMIP n.d.) database and is compared to the average historical series obtained from the W5E5 (ISIMIP n.d.) dataset.

Figure 5.1: Average of Future Climate Projections Obtained from CMIP6 Global Circulation Models



Cardona et al. (2023) identified the 20th and 80th percentiles of climate variation as representative projections for the lower and upper bounds. These percentiles align with projections from the IPSL-CM6A-LR model developed by the Institut Pierre-Simon Laplace, specifically under the lower-bound scenario (SSP1-RCP2.6) and the upper-bound scenario (SSP5-RCP8.5).

Hydrometeorological phenomena are modelled using meteorological variables such as precipitation and temperature from a historical period known as the base climate. This period corresponds to 1980-2010, representing a recent 30-year norm for climate data. Climate projections are used to modify the base climate using the Delta method, which adjusts meteorological factors to align with the 30-year average of the projected climate. From this adjusted data, hydrometeorological hazards can be recalculated.

² In the context of climate modelling, high resolution refers to a spatial grid of 50 km in pixel size.

Model for Tropical Cyclone Hazard

Therefore, not all climate models included in CMIP6 are suitable for modelling cyclone hazards. Only a select few have sufficient spatial resolution to project future cyclone tracks. These models are part of the PRIMAVERA High-Resolution³ Project within CMIP6. For this assignment, we will use four high-resolution models: CMCC-CM2-VHR4,⁴ CNRM-CM6-1-HR,⁵ EC-Earth3P-HR,⁶ and HadGEM3-GC31-HM.⁷ These models focus solely on the emissions scenario SSP5-RCP8.5, meaning that the projections for tropical cyclones are based on a single trajectory rather than on the two bounds of climate variation, as is the case for the other hydrometeorological hazards.

Flood Hazard Model

For flood hazard modelling, the global flood hazard model developed by Alfieri et al. (2023) was used. The model defines inflows to different sections of the tributary basin upstream of various points along the main rivers and streams. It hydraulically manages flows within the channels, incorporating inflows from the sub-basins that comprise the main channel basin. This approach enables coverage of all rivers in the country at an intermediate resolution, thereby facilitating the determination of flood areas and depths resulting from overflow.

Flood discharge magnitude is estimated using statistical analysis methods based on data from the hydrological region. In this case, the method employed was regional frequency analysis. This proposed methodology analyzes statistical data from a homogeneous region identified using the Index Flood Method (IFM) to estimate flood frequency at the site with the highest possible confidence, including quantiles with very low frequencies. Once discharge quantiles are obtained, they are used as input data for a simplified hydraulic flood model. The model generates hydraulic cross-sections in which the flood stage is computed from the flow value by solving the Manning equation. These stages are then interpolated based on the local relative morphology, and modifications are included to account for longitudinal hydraulic connectivity between sections, especially in large flood plains. Figure 5.2 presents the uniform flood hazard map for India at a 100-year return period. This spatial analysis places Tamil Nadu's exposure within a broader national context, thereby supporting targeted mitigation strategies for flood-prone infrastructure.



³ In the context of climate modelling, high resolution refers to a spatial grid of 50 km in pixel size.

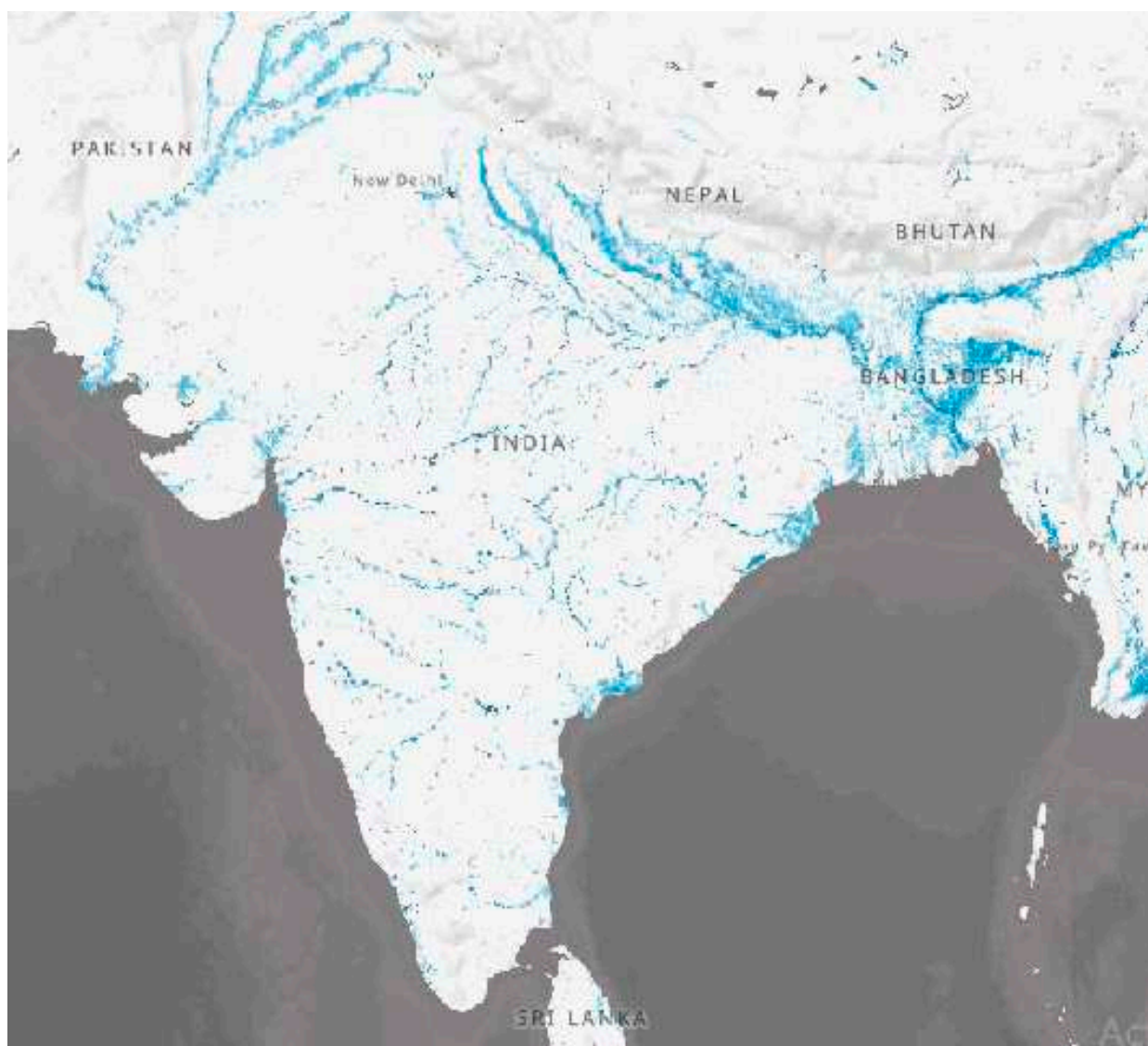
⁴ Centro Euro-Mediterraneo sui Cambiamenti Climatici

⁵ Centre National de Recherches Météorologiques. Meteo France.

⁶ Earth Consortium

⁷ Hadley Centre Global Environment Model

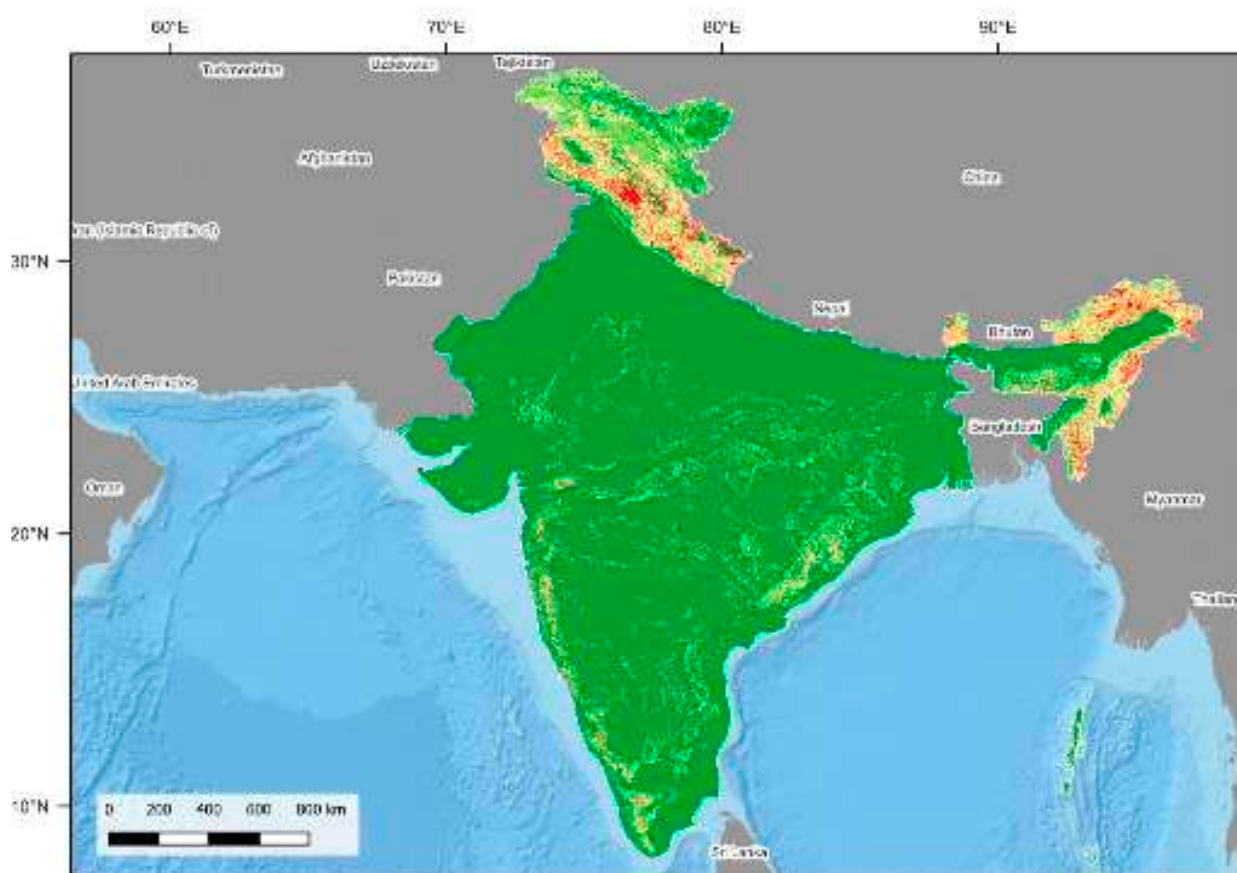
Figure 5.2: Flood Hazard Map for 100 Years Return Period for Present Climate Conditions in India



Landslide Hazard Model

The model for global susceptibility to landslides was developed by Nadim et al. (2023) (see Figure 5.3). Susceptibility is assessed heuristically based on factors such as slope, lithology, vegetation cover, and soil moisture. Each of these characteristics is assigned to a susceptibility factor (an integer number between 0 and 5) and weighted according to the expected influence on the landslide susceptibility. The final result is the weighted sum of these characteristics for each mountainous location within the studied area. Local modifiers, such as population density or road density, are included to account for anthropogenic influences on landslide occurrence. The susceptibility is mapped at a spatial resolution of 30 m and represented as an integer value between 0 and 5. Further details on the model are provided in Nadim et al. (2023).

Figure 5.3: Landslide Susceptibility of India



Source: : Nadim et al. (2023)

Landslide hazard depends not only on susceptibility, but also on triggering factors, which are external forces that increase local instability and initiate a landslide. In this assignment, we focus on two main triggers: excessive rainfall and seismic acceleration. The rainfall trigger is derived directly from climate modelling, while the earthquake trigger is simulated using the seismic hazard model. However, it is important to establish landslide thresholds to determine the corresponding triggering intensity. For this assignment, we will use the thresholds proposed by Nadim et al. (2023), which are detailed in Tables 5.1 and 5.2.



Table 5.1: Rainfall Threshold for Landslide Hazard (from Nadim et al., 2023)

Range of P_n ⁸	Susceptibility				
	Susc. 1	Susc. 2	Susc. 3	Susc. 4	Susc. 5
$P_n < 0.3$	0%	0%	0%	0%	0%
$0.3 \leq P_n < 2.0$	0%	1%	2%	3%	5%
$2.0 \leq P_n < 3.7$	0%	2%	3%	5%	10%
$3.7 \leq P_n < 5.0$	0%	3%	5%	10%	15%
$P_n > 5.0$	0%	5%	10%	15%	20%

Table 5.2: Seismic Acceleration Threshold for Landslide Hazard (from Nadim et al., 2023)

Range of PGA ⁹	Susceptibility				
	Susc. 1	Susc. 2	Susc. 3	Susc. 4	Susc. 5
$0.05 \leq \text{PGA} < 0.15$	0%	0%	0%	0.1%	0.5%
$0.15 \leq \text{PGA} < 0.25$	0%	0%	0.1%	0.5%	1%
$0.25 \leq \text{PGA} < 0.35$	0%	0.1%	0.5%	1%	5%
$0.35 \leq \text{PGA} < 0.45$	0%	0.5%	1%	5%	10%
$\text{PGA} \geq 0.45$	0%	1%	5%	10%	40%

The model estimates the probability of a landslide based on susceptibility and thresholds, considering the simulated triggering factors such as rainfall or seismic acceleration. It is important to note that landslides are events characterized by a very high level of local energy. As a result, the vulnerability of any exposed element is fully saturated, leading to a total loss. Consequently, vulnerability functions are not developed for this phenomenon.

Tropical Cyclones Hazard Model

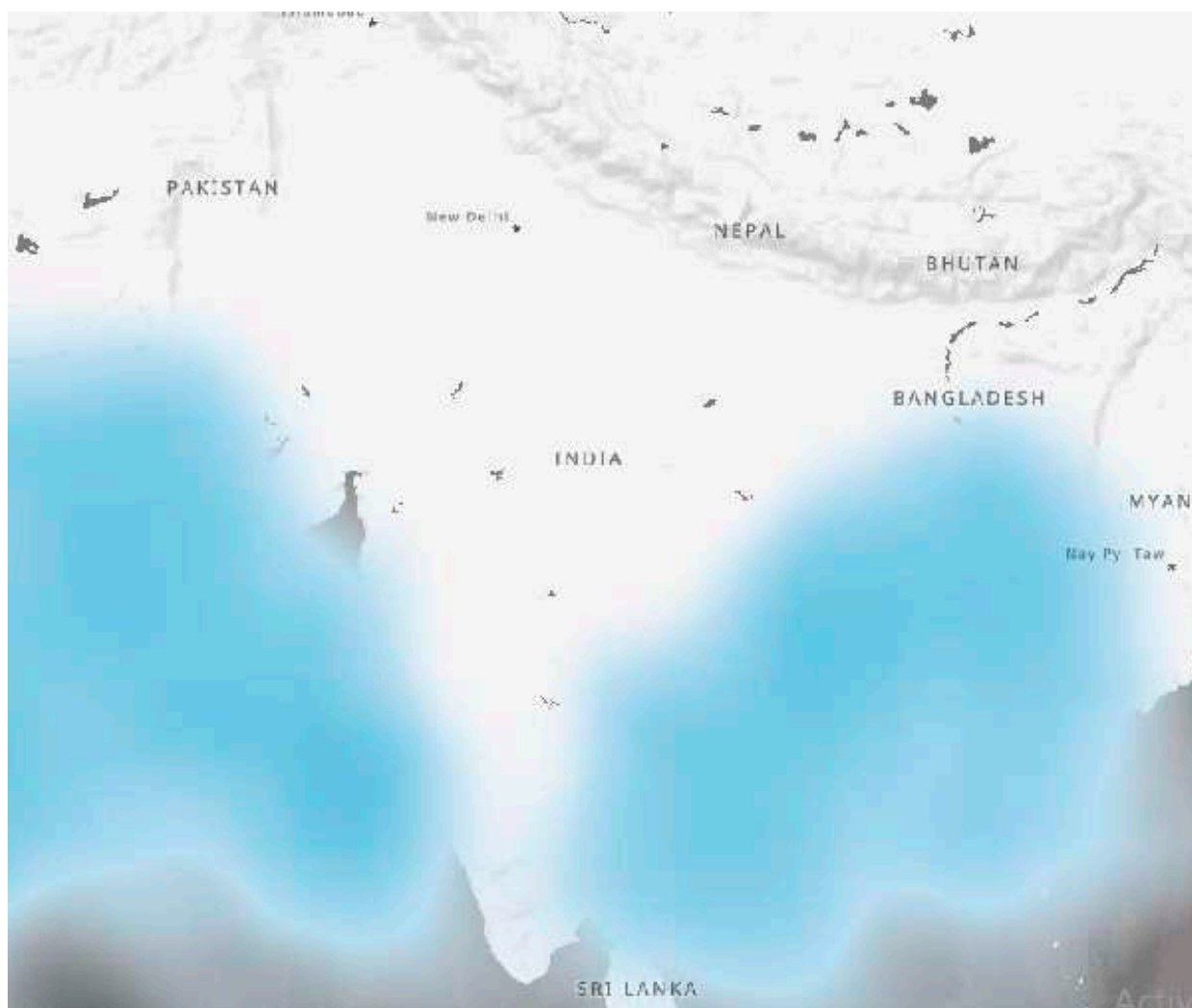
For this assignment, we updated the tropical cyclone hazard information, incorporating the latest cyclone trajectories up to 2024. We used the same calculation method as Cardona et al. (2023) for CDRI's GIRI and Cardona et al. (2014) for the UN Global Assessment Report on Disaster Risk Reduction

⁸ P_n is the 24-hour normalized rainfall, expressed in mm.

⁹ PGA is the peak ground acceleration expressed as a fraction of g ($g = 9.81 \text{ m/s}^2$).

(GAR). This method is implemented in the CAPRA ROBOT software module TCHM (Bernal 2018). For detailed information on the methodology, refer to Cardona et al. (2014). In this project, we assessed the hazards associated with both strong winds and storm surge, using an updated catalogue that includes 155 historical tropical cyclones from the North Indian Ocean basin. We calculated the completeness periods to quantify the frequency of occurrence of these historical cyclones. For each historical track, a set of associated 'children' tracks was obtained using a bi-dimensional Wiener process. The strong winds speed and storm surge flooding were calculated for each cyclone child track, and these results were used to compute the probability moments of wind speed and coastal flooding for each historical track. The findings for strong winds are presented as the geographical distribution of peak wind speeds, specifically 3-second gusts. In contrast, the results for storm surge are illustrated by the distribution of maximum surge run-up and its corresponding flooding along the shorelines. This analysis was repeated for all historical and future cyclone tracks. The hazard assessment produced a set of probabilistic wind fields and storm-surge flood scenarios. Figure 5.4 shows the map of the 500-year return period of strong winds for India.

Figure 5.4: Cyclone Wind Hazard for India: 500-year Return Period, intensity II Wind Velocity in km/h

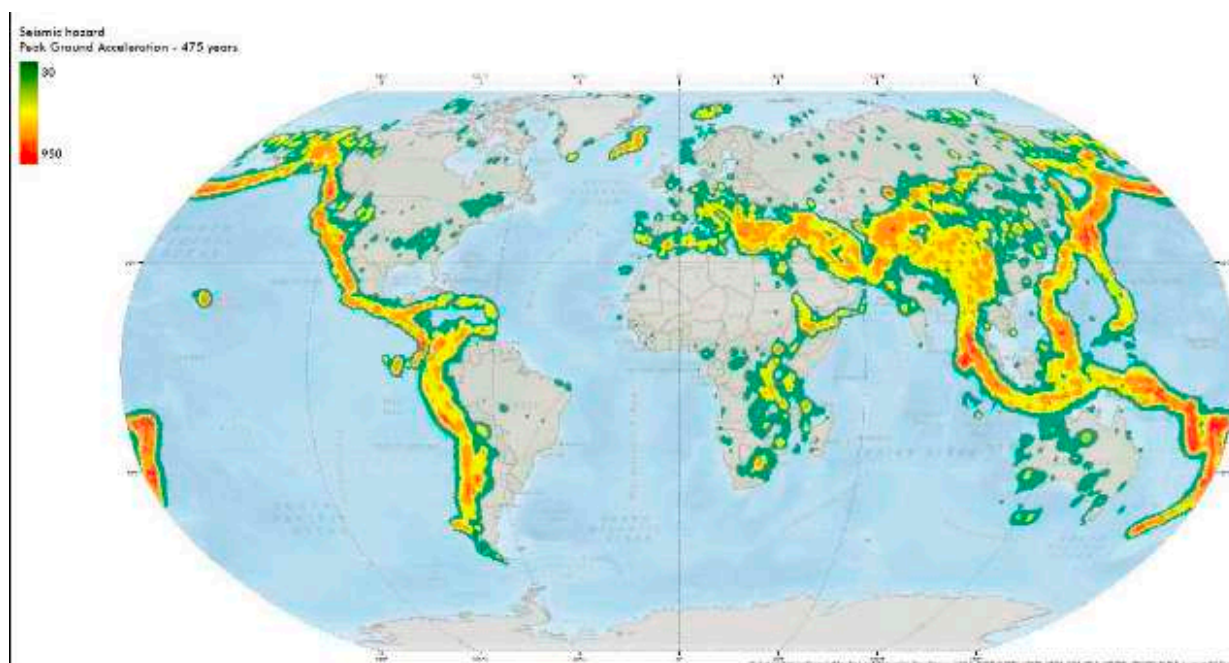


Seismic Hazard Model

Seismic hazard is independent of climate factors and, therefore, is considered a stationary phenomenon. For the FRA of Tamil Nadu, the global seismic-hazard model developed by Cardona et al. (2014) was employed. The spatial resolution of this model is appropriate for this assignment. This section presents a general overview of the model.

The seismic hazard at the bedrock level is determined using historical data from seismic catalogues. By analyzing the magnitude and location of each earthquake's hypocentre, the intensity of the events is calculated by a set of stochastic scenarios that are mutually exclusive and collectively exhaustive. Each scenario is associated with a probability distribution across a geographical area. This process accounts for the attenuation of seismic energy with distance from the epicentre of each event. As a result, we can construct a curve that shows the probability of exceeding specified acceleration thresholds at specific locations where exposed assets may be located. Since this curve can be generated for each point within the calculation grid, it is possible to calculate the seismic hazard maps for various spectral ordinates and return periods. This means we can tailor the maps to reflect the dynamic structural response from the exposed structures. This input is fundamental to conducting a probabilistic risk assessment of the inventory of exposed elements in countries that face seismic hazards. An in-depth description of the seismic hazard model can be found in Cardona et. al. (2014). Figure 5.5 shows an example of a seismic hazard map calculated for a 475-year return period of peak ground acceleration at bedrock level (i.e., $V_{s30} = 1,100$ m/s) (Note: V_{s30} is the shear wave velocity of the top 30 meters below the surface. It is a parameter commonly used to account for the subsurface materials' stiffness.)

Figure 5.5: Seismic Hazard Map for Peak Ground Acceleration and 475-Year Return Period



Exposure Model

The database of exposed elements is defined as the collection of physical components that constitute an infrastructure system. For each element, three minimum properties are established: its geographic location, its physical value or replacement cost, and a constructive or archetypal class that allows its vulnerability to be related. It is common for some, or even all, of the three fundamental characteristics to be absent from the country's existing information. As a result, estimates are necessary to approximate the inventory of exposed elements. In this assignment, the focus on exposure is limited to the energy and roads sectors in Tamil Nadu.

Energy Sector

In this assignment, the energy sector encompasses the existing infrastructure for the generation, transmission, and distribution of electricity within the territory. Oil and gas infrastructure, although some authors consider it part of the energy sector, is not included.

The energy sector is therefore sub-divided into three subsectors: generation, transmission, and distribution. Each subsector requires an independent exposure model that accounts for its unique characteristics. For example, in the generation subsector, power plants vary widely in the types of energy they convert, plant capacity, and the components that comprise the facility. On the other hand, transmission lines, although diverse as well, are far more constrained in terms of the number of typologies to be considered. This complexity makes the energy sector one of the most challenging areas to engage for risk assessment modelling.

According to data from WRI¹⁰ and OSM¹¹, there are more than 26,000 MW of installed generation capacity, distributed among eight different types of energy conversion, as shown in Table 5.3. In terms of transmission, Tamil Nadu has more than 41,000 km of transmission lines. Table 5.4 provides a breakdown of the total length of transmission lines categorized by operational voltage.



¹⁰ World Resources Institute

¹¹ Open Street Map

Table 5.3: Installed Capacity of the Generation Sector in Tamil Nadu

Source energy	Capacity [MW]	[-]
Bioenergy (biomass, waste, etc.)	80	0.3%
Coal	12,862	48.2%
Gas	1,058	4.0%
Hydro	541	2.0%
Oil (petroleum derivatives)	1,085	4.1%
Other	1,800	6.8%
Solar (photovoltaic)	8,727	32.7%
Wind	504	1.9%
Total general	26,657	

Table 5.4: Transmission Lines Voltages and Lengths in Tamil Nadu

Voltage (kV)	Length	[-]
<110	608	1.5%
110 - <220	14,961	36.1%
220 o >220	25,878	62.4%
Total	41,446	

The procedure for defining the replacement cost of energy-sector components is the one proposed by Cardona et al. (2023) and used to value exposed elements in the GIRI model of CDRI.

Generation

The replacement-cost approximation for the exposed elements in the generation subsector is based on information from the Global Power Plant Database (WRI) and the Power Plant Database (OSM). It is worth noting that no official information was received during the execution of this assignment. The procedure for estimating the cost of generation infrastructure is outlined below.

First, the raw data are cleaned by removing records that lack information on the energy source or generation capacity. Then, the data on the energy source is reclassified into one of the basic categories presented in Table 5.5. Next, the capacity of each plant is verified using the existing information. If there is no data on a plant's capacity, it is randomly assigned based on a probability distribution of the capacities from a similar type of energy source (see Cardona et al. 2023 for further details). Finally, the replacement cost is calculated using the cost indicators used by Cardona et al. (2023) and defined by IRENA (IRENA 2023), multiplied by the plant capacity.

Table 5.5: Basic Energy Source Classes and Unitary Costs

Energy source	Cost indicator (\$/kW)
Bioenergy (biomass, waste, etc.)	2,353
Battery (storage)	758
Coal	875
Gas	1,116
Geothermal	3,991
Hydro	2,135
Nuclear	3,782
Oil (petroleum derivatives)	795
Solar (photovoltaic)	857
Wave and tidal	7,038
Wind	1,325
Other	1,134

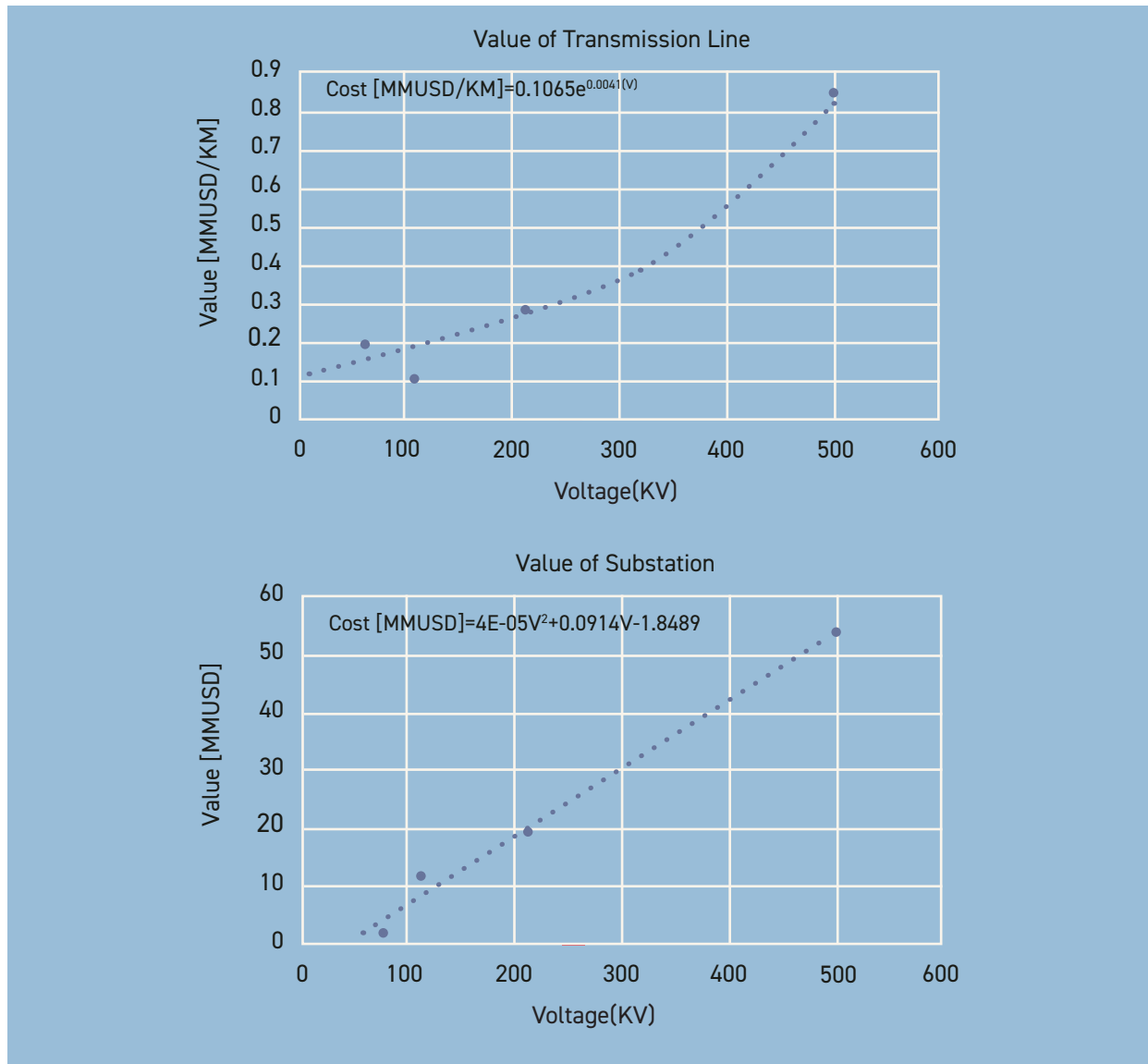
Transmission

For the transmission subsector, the raw data is sourced from the Power Lines Database and Power Substations Database, both provided by OSM. No official information was received during the execution of this assignment. The procedure for estimating the cost of transmission infrastructure is described next.

For transmission lines, the length of each element is first determined using the raw spatial data. Long elements are then trimmed into segments of 150 m or less. Then, the line voltage is used to determine the cost indicator, following the price function proposed by Cardona et al. (2023), as shown in Figure 5.6 (left). Finally, the overall cost of each segment is computed by multiplying the corresponding cost indicator by the segment length. For substations, the initial step is to debug the raw data by removing

substation elements that are not part of the transmission or distribution networks. Finally, the cost is evaluated based on the working substation voltage using the pricing function proposed by Cardona et al. (2023) and is presented in Figure 5.6 (right).

Figure 5.6: Pricing Function Based on Transmission Line Voltage (Left) and Based on Voltage at Substation (Right)



Distribution

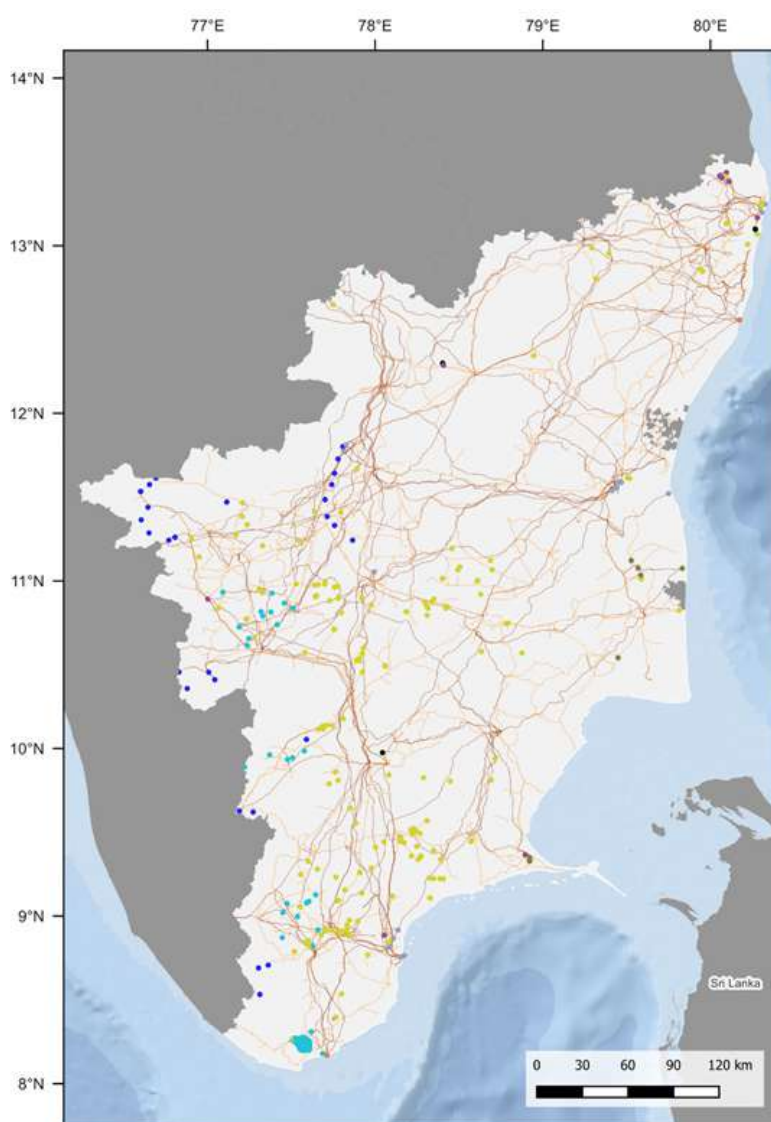
Distribution networks are closely linked to population density. They tend to be denser in areas with high population density and sparser in less populated regions. Furthermore, there is often a lack of data on the actual locations and characteristics of distribution network elements (such as cable posts, buried lines, and transformers). It is worth mentioning that no official information was received during the execution of this assignment. Therefore, we apply the framework developed by Cardona et al. (2023) to construct an exposure proxy for the distribution network based on population data.

Cardona et al. (2023) propose that the valuation of the distribution subsector should be considered as a factor of the transmission subsector.¹² This yields an overall valuation that must be distributed geographically using the raster-based population grid from the Global Human Settlement Layer (GHSL) (GHSL n.d.). This population grid is then transformed to reflect the population with access to electricity, based on data from the 2011 Census of India (Census of India n.d.). This procedure yields higher exposure values in denser populations and a bulk infrastructure value that is consistent with real access to electricity.

Exposure Database

The resulting exposure model comprises geolocated vector entities, each with attributes relevant to risk evaluation. Key fields include the replacement cost and the element archetype, which together help define the level of exposure. Figure 5.7 shows a general overview of the sector for Tamil Nadu.

Figure 5.7: Exposure Database for Energy Sector in Tamil Nadu



¹² The factor is 2.26. See Cardona et al. (2023) for further details.

Road Sector

The road sector addressed in this assignment comprises highway infrastructure, including expressways, national highways, state highways, major district roads, and bridges. The design of road infrastructure varies with design conditions, including topography, weather, and traffic. Furthermore, highway segments comprise various elements, including pavement structures, retaining walls, gutters, and box culverts. The same diversity applies to bridges, as each bridge is unique. Although bridges can be categorized into archetypal types, they are among the few infrastructure elements that do not readily fit into standardized classifications. In addition, the available data has significant limitations. It is important to note that no official data was received during the execution of this assignment. Therefore, the exposure model developed is only a rough approximation of the sector for risk assessment purposes.

According to the OpenStreetMap (OSM) dataset, Tamil Nadu has approximately 220,000 km of roads, including expressways, national highways, state highways, and major district roads. In addition, there are 7,000 km of bridges within these same categories. Minor district or rural roads, as well as private roads and bridges, are not included in this assignment.

Roads segment

The procedure for determining the replacement cost of components in the road sector is based on the method proposed by Cardona et al. (2023) and is used to value exposed elements in the GIRI model of CDRI. This process employs the Global Roads Network dataset from OSM, which is processed to eliminate wrong or incomplete records. The roads are segmented into sections no longer than 300 m to increase the model's granularity. The basic value of each segment is assessed based on its length, with a nominal cost of \$1.09 million per km.

The basic value of a road segment is adjusted based on four main features: road type, number of lanes, pavement type, and slope. Each feature has a multiplicative factor that modifies the segment's base value.

The road type reflects the operational level of the road within the country's network. This feature is crucial for accounting for variations in replacement costs, as it accounts for the overall importance of the road. The corresponding multiplication factors are presented in Table 5.6.



Table 5.6: Road Type Multiplier

Road type	Factor
National highways	1.50
State highways	1.00
Major district roads	0.83
Other roads	0.67

The number of lanes on a road segment serves as an indicator of the demand it meets. We use the factor proposed by Cardona et al. (2023), which is calculated as half the number of lanes in the segment. Therefore, a two-lane road is used as the baseline condition, with a multiplication factor of 1. Roads with more lanes entail higher exposure beyond the basic replacement cost.

The pavement type also affects the segment cost. It is evident that replacing a segment of paved road would be more expensive than replacing a segment of gravel road. We apply the factors proposed by Cardona et al. (2023), which are divided into three general categories: paved, affirmed, and loose. The factors are presented in Table 5.7.

Table 5.7: Pavement Type Multiplier

Pavement type	Factor
Paved	1.00
Affirmed	0.34
Loose	0.18

Finally, slope is a strong modifier of the value of a road segment. Replacing a road segment with similar characteristics in a steep terrain is much more expensive than doing so in a flat terrain. Furthermore, some critical elements, such as retaining walls, are much more likely to be found in steep terrain compared to flat terrain, where such structures may not exist. We use the slope factors proposed by Cardona et al. (2023) that are presented in Table 5.8.

Table 5.8: Slope Multiplier

Slope type	Slope angle(°)	Factor
Plain	0-10	1.00
Rolling	10-15	1.43
Hilly/Mountainous	15-25	1.82
Steep	>25	2.16

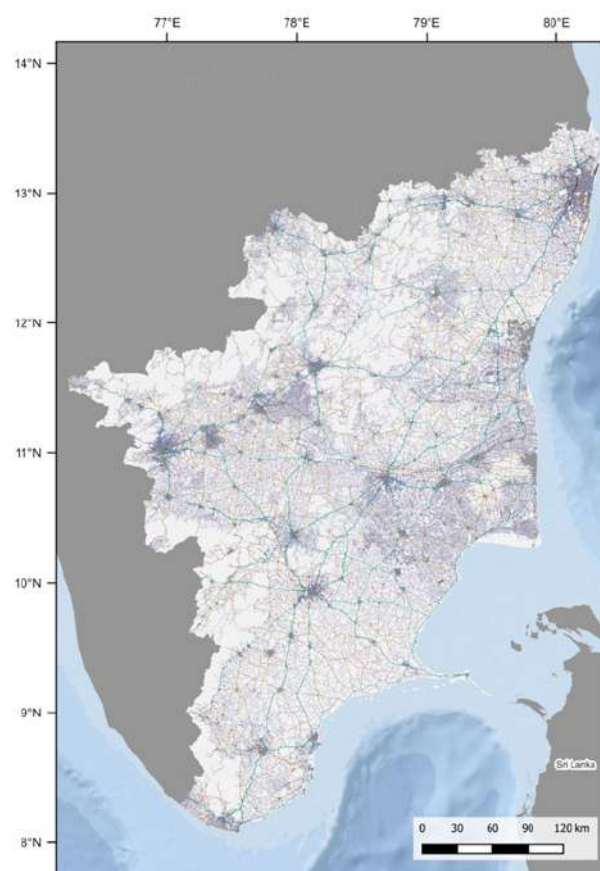
Bridges and Tunnels

Bridges are infrastructure elements that are particularly challenging to categorize. One could assert, with considerable certainty, that there are as many types of bridges as there are bridges in the world. This variety complicates any attempts to classify them. Currently, the available data are insufficient to clearly distinguish structural differences among existing bridges. Important characteristics such as span, gauge, support type, number of pillars and abutments, foundation type, and board structure, among others, are often unknown. The data from the OSM dataset allows identification of the bridge length only. We use this attribute to estimate the replacement cost, applying the cost indicator proposed by Cardona et al. (2023), which is \$9.84 million per km. Finally, tunnels present similar challenges to bridges with respect to generalization and the lack of detailed information. However, using the length of each identified tunnel in the OSM dataset, we can approximate the exposed value based on the average price indicator proposed by Cardona et al. (2023), which is \$19.8 million per km.

Exposure Database

The resulting exposure model comprises geolocated vector entities, each with attributes useful for risk evaluation. Key fields used to characterize each element include the replacement cost and its archetype. Figure 5.8 shows a general overview of the sector for Tamil Nadu.

Figure 5.8: Exposure Database for Road Sector in Tamil Nadu



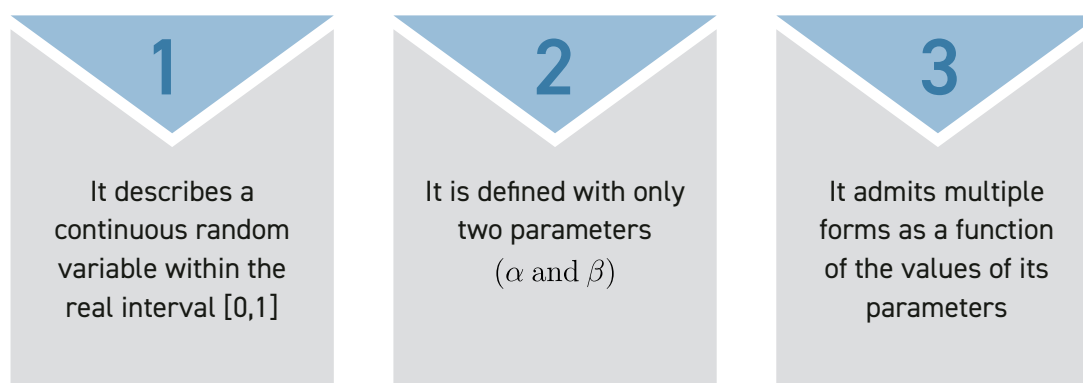
Vulnerability Models

The physical vulnerability of exposed elements can be quantified using vulnerability functions. These functions effectively capture the complexity of the loss-generation process when exposed elements are subjected to a hazardous event. Additionally, vulnerability functions quantify potential loss probabilistically, facilitating the application of a conceptual framework for risk assessment.

Probability Model for the Loss

In catastrophic risk modelling, losses are treated as random variables. This approach allows for the uncertainty inherent in the amounts of loss caused by any hazard to be directly incorporated into the calculations. Vulnerability is assessed on an item-by-item basis within the exposure portfolio, meaning that the loss described here refers to an individual exposed element. In general, loss is a variable ranging from 0 to 1, representing 0 percent to 100 percent of the element's exposed value (e.g., the replacement cost of a property or infrastructure component). Thus, when we discuss vulnerability, the term 'loss' always indicates a relative loss in relation to the degree of damage, reflecting a fraction of the exposed value.

In general, there is insufficient information about the damage and losses from historical events to calibrate a probability model based on statistical estimates. As a result, defining a probability model that captures the randomness of loss is a reasonable and appropriate choice, though it remains somewhat arbitrary. The most widely used model is based on a Beta distribution, as proposed by Anne Kiremidjian and other authors in developing the ATC-13 document and its commentary, ATC-13-1 (ATC 1985). The document aimed to develop probability models for earthquake-induced damage in California. Since then, the Beta distribution has been widely adopted worldwide as a probability model for loss across various hazards and types of exposed elements due to its practicality under the following criteria:

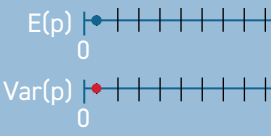
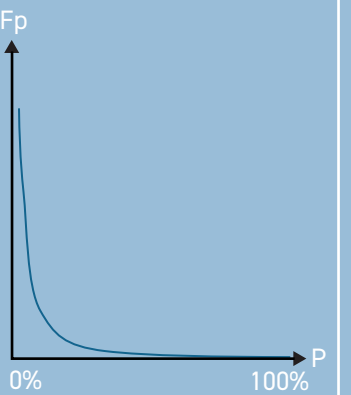
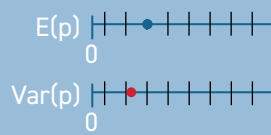
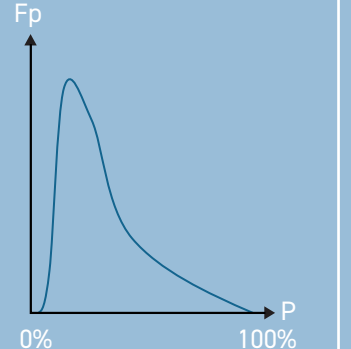
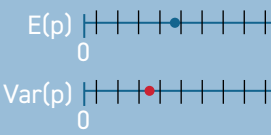
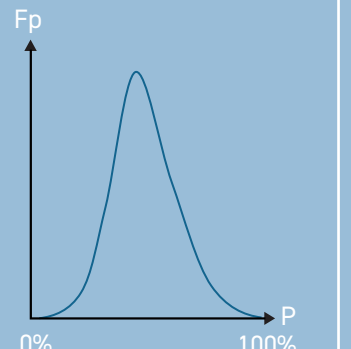


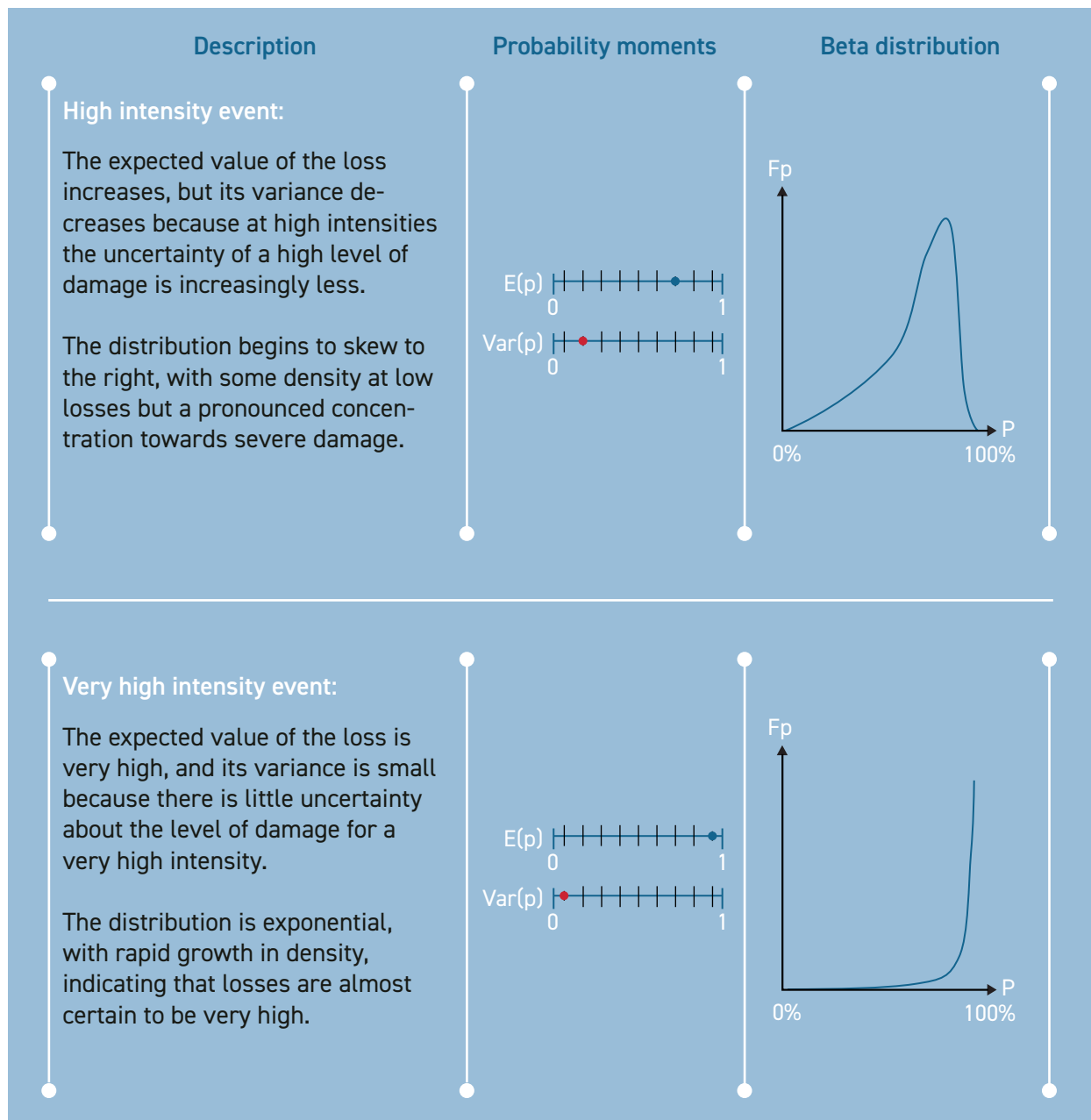
Since the Beta distribution is characterized by two parameters, at least two probability moments are required to characterize it. This implies that vulnerability models must account for at least two probability moments. Typically, these models are defined by the expected value and variance of the loss. The shape of the Beta distribution varies with the values of these probability moments, as defined by the vulnerability model. One of the key features of the Beta distribution is its ability to adjust its shape within the defined interval, which is why it is widely used in catastrophe risk modelling.

Table 5.9 illustrates the expected shapes of the Beta distribution for various combinations of expected value and variance for the loss. The table provides an overview of the expected characteristics of hazard events at different intensity levels. It includes illustrations of the expected value and variance within the interval $[0,1]$, and the anticipated shape of the Beta distribution. It can be concluded that the Beta distribution appropriately fits the shapes in which the loss is expected to be distributed for events of different characteristics.



Table 5.9: Illustration of the Variation of the Beta Distribution in Response to Events of Different Intensity Levels

Description	Probability moments	Beta distribution
Very low intensity event: A low-loss value is expected with low dispersion. That is, if the intensity is very low, the loss will be low and relatively stable. The distribution exhibits negative exponential behaviour, with a rapid decrease. That is, the highest probability density is concentrated near zero loss, as expected for a very low intensity.		
Low intensity event: The expected value of the loss increases, and its variance also increases (i.e., the loss is more uncertain). The distribution is wider, more right-skewed, but still skewed towards low losses.		
Intermediate intensity event: The expected value of the loss is much higher, and the variance is also as high as possible. The distribution is now symmetrical, bell-shaped, and as wide as possible, indicating that this is the point of greatest possible variability for the loss.		

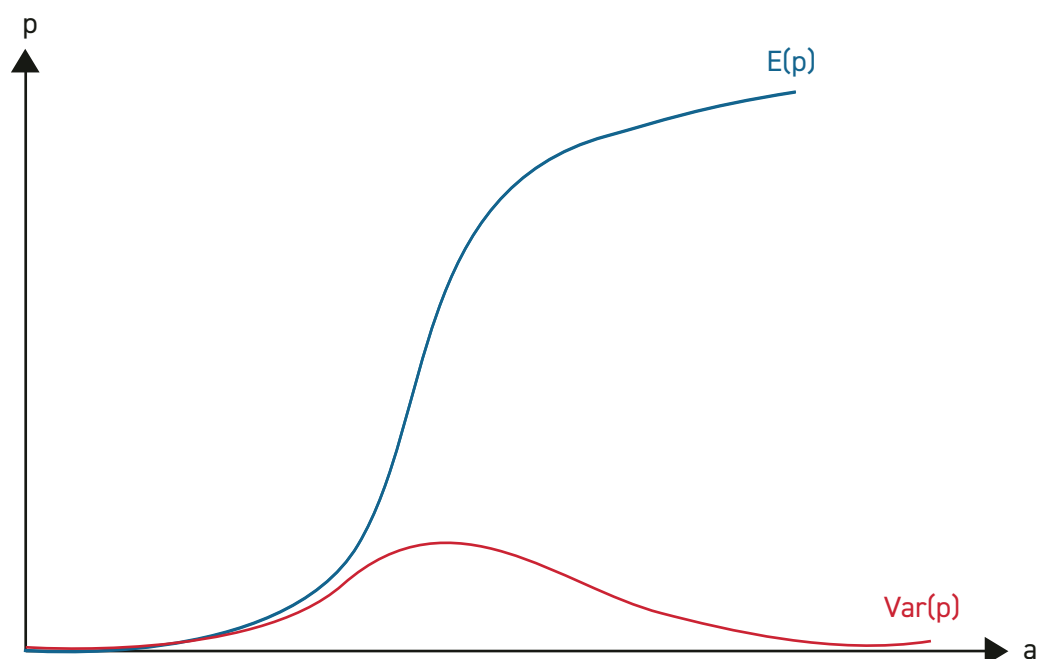


Vulnerability Functions

Vulnerability functions are mathematical representations of physical vulnerability. They are composed of two distinct components: one function describes how the expected value of loss changes with the intensity of a hazard, while the other outlines the variation in that loss's variance. Vulnerability functions are widely used in catastrophe risk assessments of property or infrastructure, as they effectively capture the potential losses.

The expected value and variance functions have specific properties that must be satisfied. As illustrated in Table 5.9, the expected value function is required to be an increasing function. In contrast, the variance function should initially increase before eventually decreasing. This behaviour accurately reflects the variability of the phenomenon being measured. Figure 5.9 shows an example of the typical shape of vulnerability functions.

Figure 5.9: Illustration of a Vulnerability Function



Vulnerability functions are defined for various types of exposed elements based on specific categories. This means that a single function can effectively describe the behaviour of multiple exposed elements within the same category. This approach aligns with the probabilistic nature of probability functions, which enables the modelling of similar exposed elements' behaviours. The categorization of exposed elements is typically determined in the exposure model based on their construction or functional characteristics.

The vulnerability functions developed by Cardona et al. (2023) for various infrastructure archetypes are used in this assignment. These functions are the same as those employed in the GIRI model of the CDRI. The GIRI library of archetype functions is the most comprehensive resource for infrastructure vulnerability models used in catastrophe risk assessments. The vulnerability functions applied to the risk assessment for Tamil Nadu in this assignment are presented in Figure 5.10 to Figure 5.15. As previously mentioned, no vulnerability functions are applied to landslide hazards because it is assumed that the occurrence of a landslide necessarily leads to the destruction of the affected infrastructure element. This assumption is especially valid for road infrastructure, which is the only type affected by landslides in this assignment.



Energy Infrastructure

Figure 5.10: Earthquake Vulnerability Functions for the Infrastructure of the Energy Sector

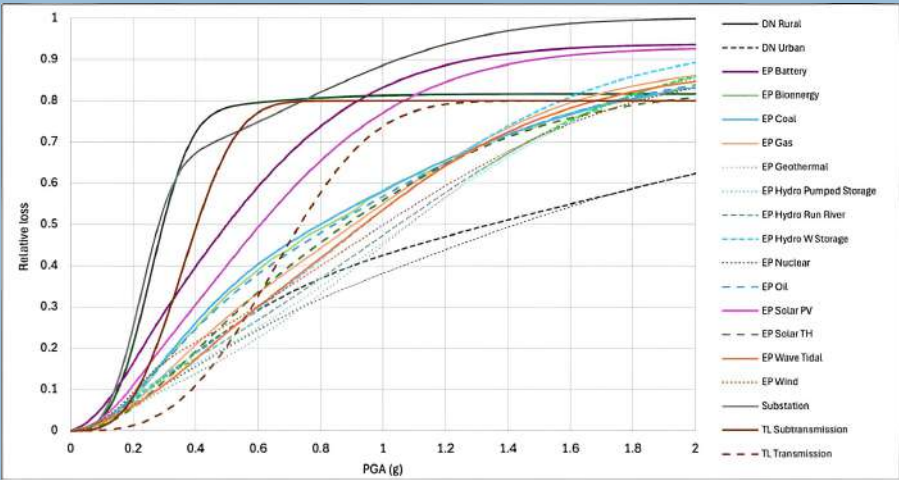


Figure 5.11: Flood Vulnerability Functions for the Infrastructure of the Energy Sector

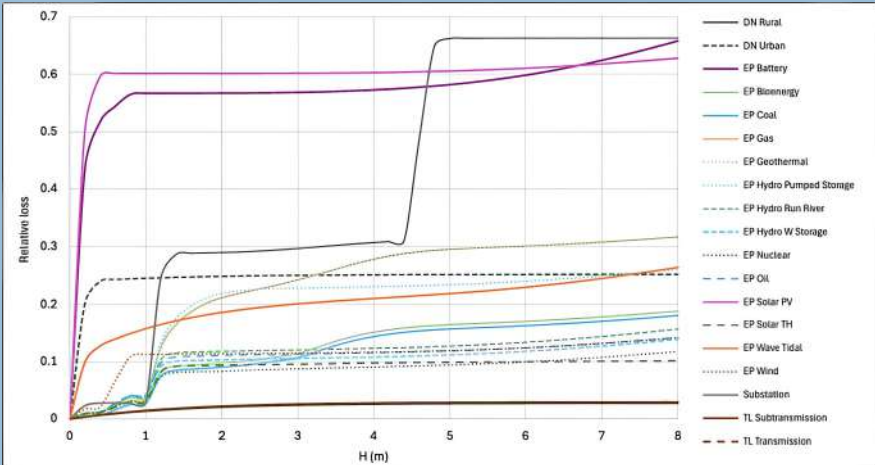


Figure 5.12: Storm Surge (Cyclone) Vulnerability Functions for the Infrastructure of the Energy Sector

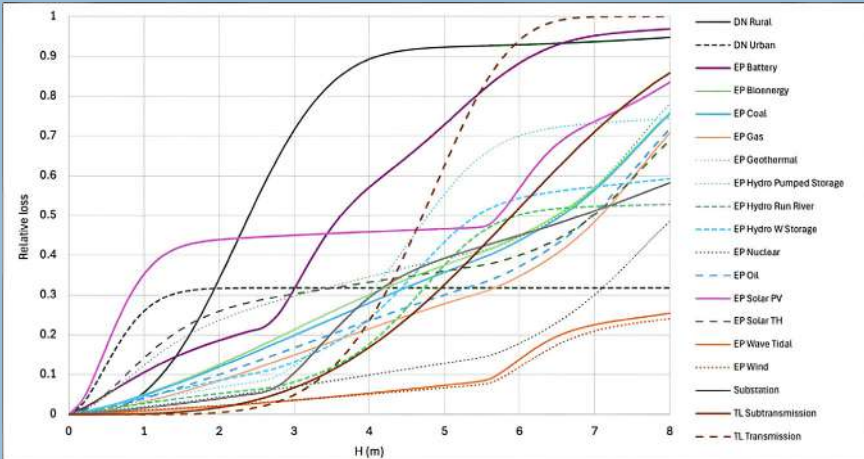
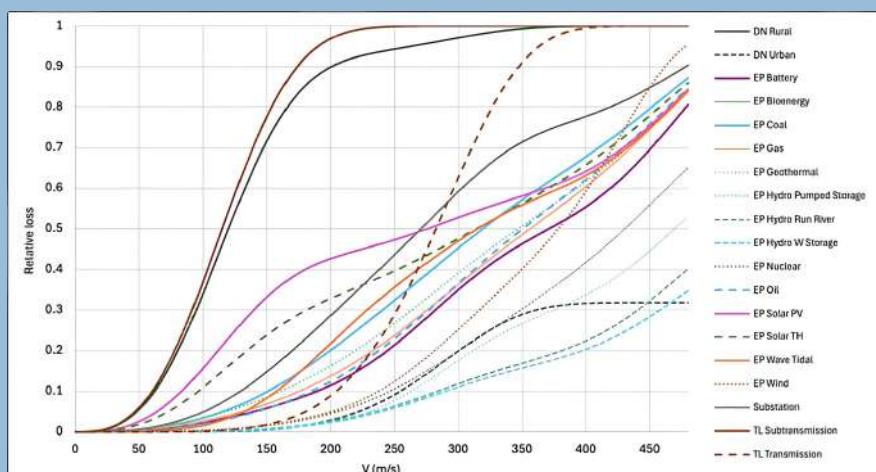


Figure 5.13: Wind (Cyclone) Vulnerability Functions for the Infrastructure of the Energy Sector



Road Infrastructure

Figure 5.14: Earthquake Vulnerability Functions for Infrastructure of the Road Sector

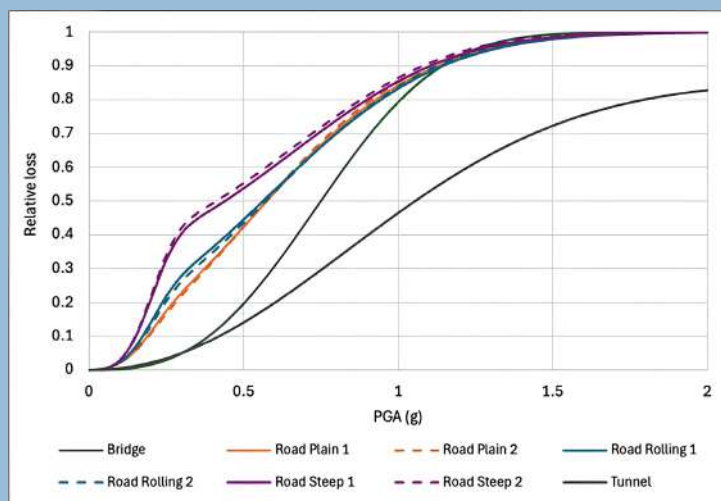
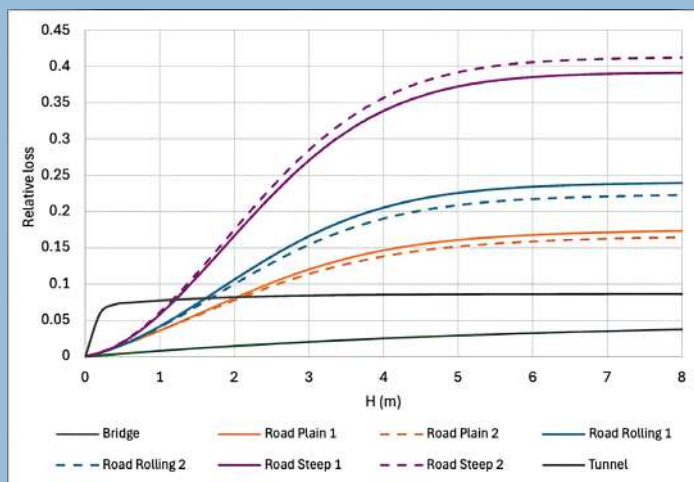
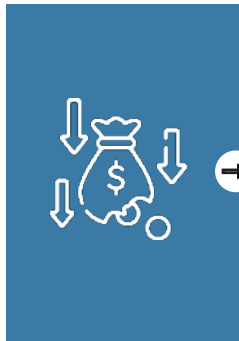


Figure 5.15: Flood Vulnerability Functions for Infrastructure of the Road Sector



Risk Assessment Results

Risk assessments express results using the Average Annual Loss (AAL) and the Probable Maximum Loss (PML), standard risk metrics commonly used in catastrophe risk assessments and in the insurance industry.



Average Annual Loss:

The AAL is an important indicator that consolidates the impact of various hazard scenarios on vulnerable exposed elements into a single value. It is considered the most reliable risk indicator because it summarizes loss over time into a single number and has low sensitivity to uncertainty. The AAL represents the expected value of the annual loss, the amount needed to compensate for all future losses over the long term. In a simple insurance scheme, the AAL would be equivalent to the annual pure premium.



Probable Maximum Loss:

This is a loss that does not occur frequently, typically associated with long return periods. Instead of a single PML value, there is a complete curve (loss vs return period). However, it is common practice to define a specific PML value by selecting a return period. There are no universally accepted standards for what constitutes 'not very frequently'. In the insurance industry, for example, the return periods used to define the PML can range from 200 to 2,500 years.

The AAL is presented as a total for each combination of hazard and sector and is further disaggregated by subsector and other key characteristics. Furthermore, the AAL is depicted in risk maps that illustrate the geographical variation of expected losses. In all these types of results, AAL values may be presented as absolute or relative. Absolute AAL represents the modelled amount in monetary units. In contrast, relative AAL is calculated by dividing or normalizing the absolute AAL by the exposure value under consideration. For example, if the AAL is presented as the total for a specific sector within a territory, the relative AAL is normalized by the total exposed value of that sector. On the other hand, if the AAL pertains to a single exposed element (for example, in risk maps), the relative AAL is normalized by the exposure value of that particular element. In this report, relative AALs are consistently presented as per-thousand fractions, indicated by the symbol ‰.

The PML is presented as a function of loss relative to return periods for each hazard and sector. The report presents both absolute and relative PML values to facilitate comparison across hazards. For the AALs, absolute PMLs are calculated, whereas relative PMLs are normalized by the sector-exposed value. Given that PMLs are derived from high quantiles of probability distributions, they cannot be disaggregated for present mapping purposes. In this report, relative PMLs are consistently expressed as per-hundred fractions with the symbol %.

Energy Infrastructure

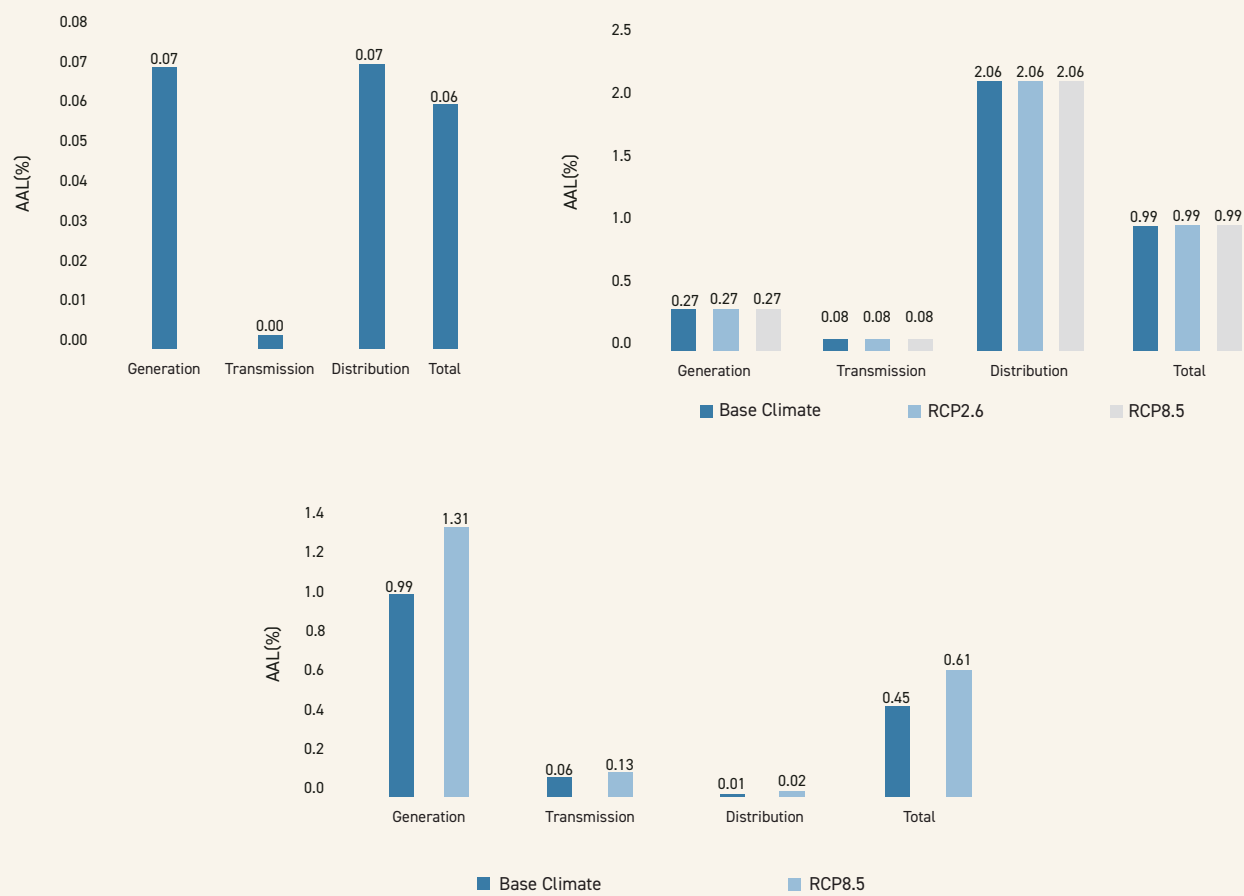
Table 5.10 presents the AAL for Tamil Nadu's energy sector, based on the hazards evaluated in this assessment, both in absolute and relative terms. Notably, the highest losses are attributed to tropical cyclones, with the current climate 5 implying the higher losses. In the case of floods, all climates return very similar risk figures, showing no significant variation among them. Earthquakes pose a lower AAL in Tamil Nadu due to the relatively low seismic hazard.

Table 5.10: Absolute and Relative AAL for the Energy Sector Infrastructure

Hazard	Average Annual Loss	
	\$	%
Earthquake	3,505,000	0.07
Flood	119,378,000	2.50
Flood (RCP2.6)	118,188,000	2.48
Flood (RCP8.5)	134,236,000	2.82
Tropical cyclone	94,779,000	1.99
Tropical cyclone (RCP8.5)	51,944,000	1.09

The relative AAL among subsectors is distributed as follows. For earthquake hazards, the generation and distribution subsectors experience the highest relative AAL. This is logical, as earthquakes can cause correlated losses across multiple locations in a single event. Regarding floods, the highest AAL occurs in the distribution subsector, followed closely by the generation subsector. The AAL for transmission is relatively low, as expected, since most of this subsector, particularly transmission lines, are elevated off the ground. In the case of tropical cyclones, the generation subsector shows a more significant impact, while both transmission and distribution (see [Figure 5.16](#)) subsectors experience low AAL values. This is attributed to the greater sensitivity of power plants and facilities to wind damage, as they contain more vulnerable components than transmission or distribution infrastructure, such as transmission towers and substations.

Figure 5.16: Relative AAL from Earthquake (A), Flood (B), and Rain-Triggered Landslides (C) for the Energy Infrastructure Portfolios



The AAL of each subsector is determined by aggregating the individual losses calculated for each exposed element. Each element within the exposure portfolio has unique characteristics, including its location, price, and vulnerability, which make its risk evaluation distinct. The AAL is further decomposed by element to illustrate these differences and the unique profile of each element within the risk landscape. The maps presented next illustrate the variation in relative AAL among the exposed elements. From Figures 5.17 to 5.22, the relative AALs are presented for the energy sector elements, considering all hazards and climate scenarios analyzed.



Figure 5.17: Map of Relative AAL from Earthquakes for the Energy Portfolios

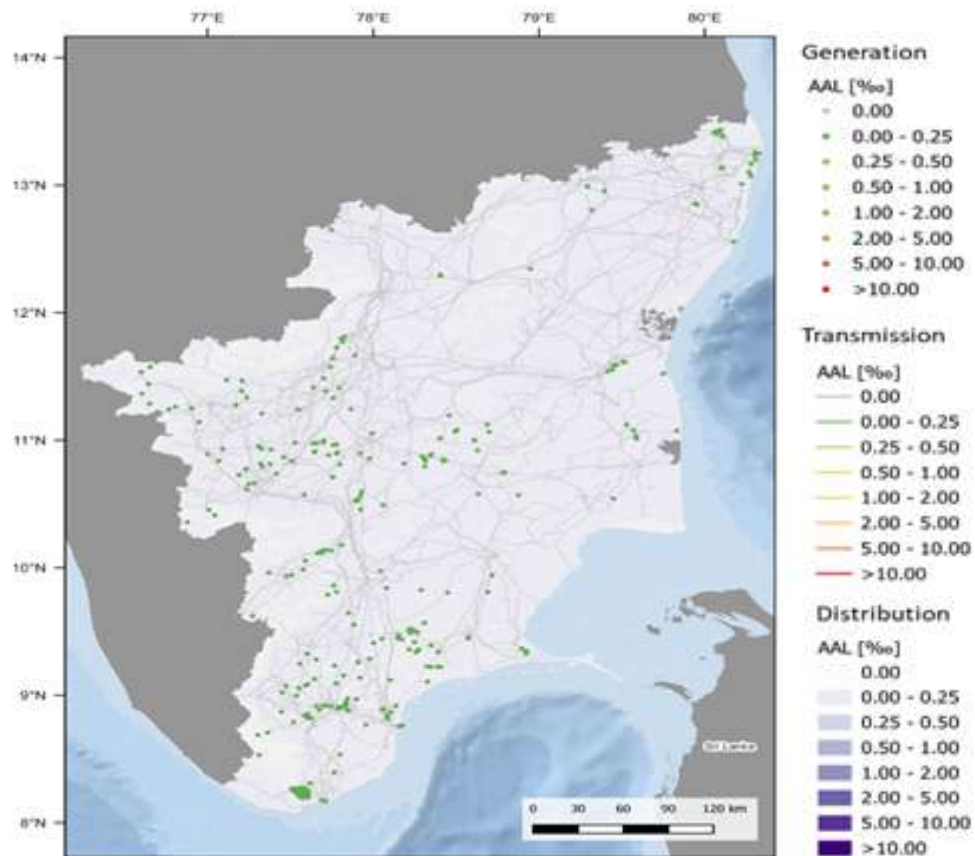


Figure 5.18: Map of Relative AAL from Floods for the Energy Portfolios

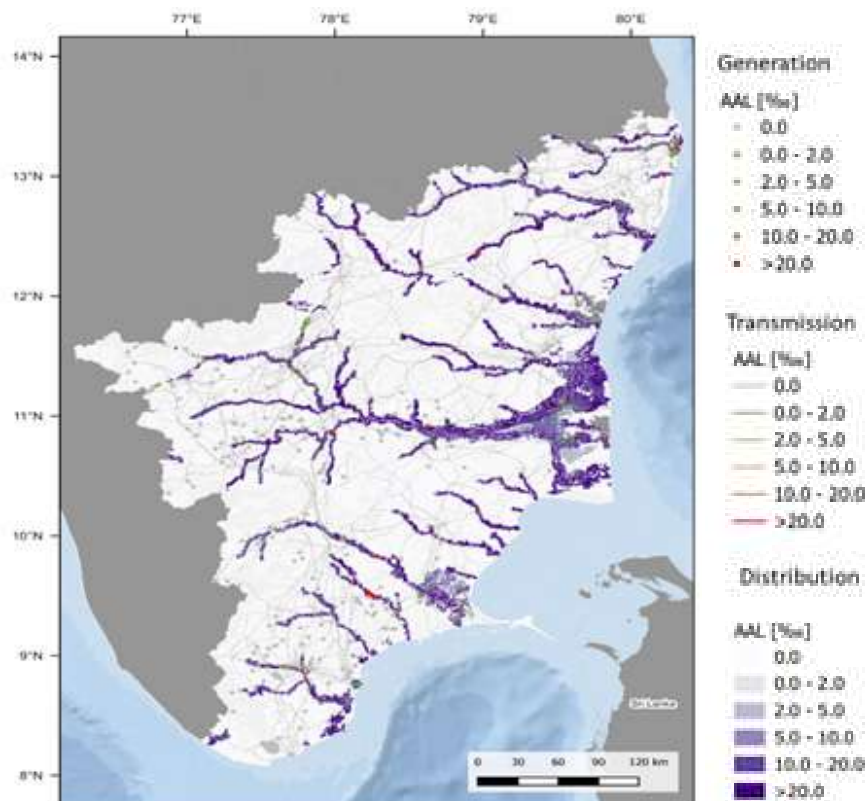


Figure 5.19: Map of Relative AAL from Floods (SSP1-RCP2.6) for the Energy Portfolios

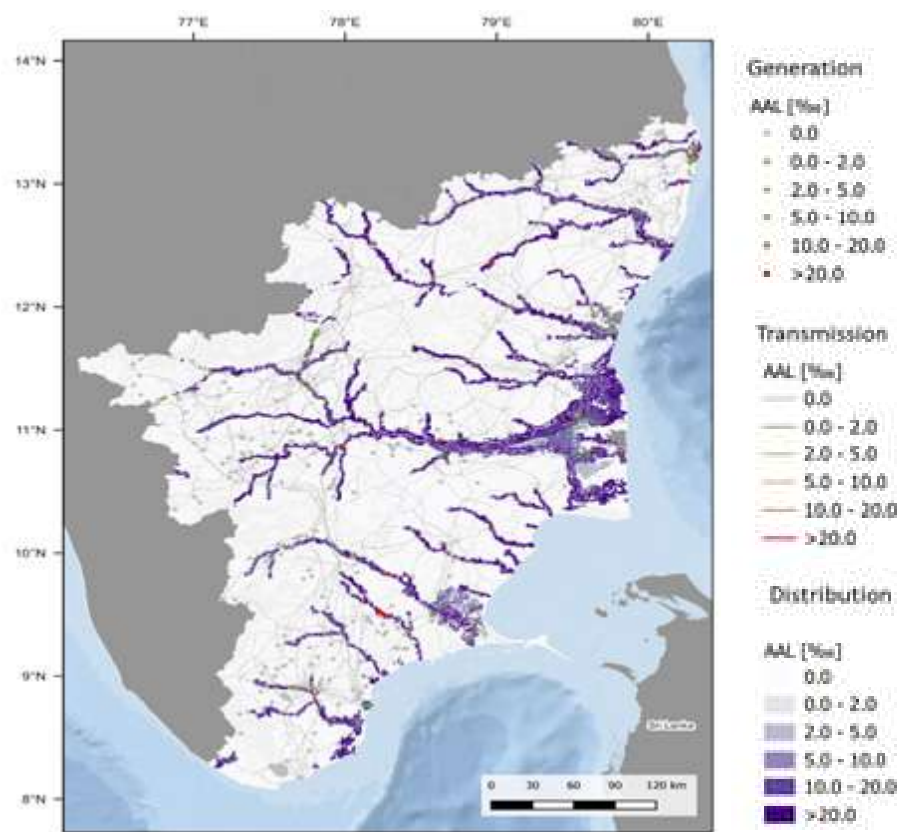


Figure 5.20: Map of Relative AAL from Floods (SSP5-RCP8.5) for the Energy Portfolios

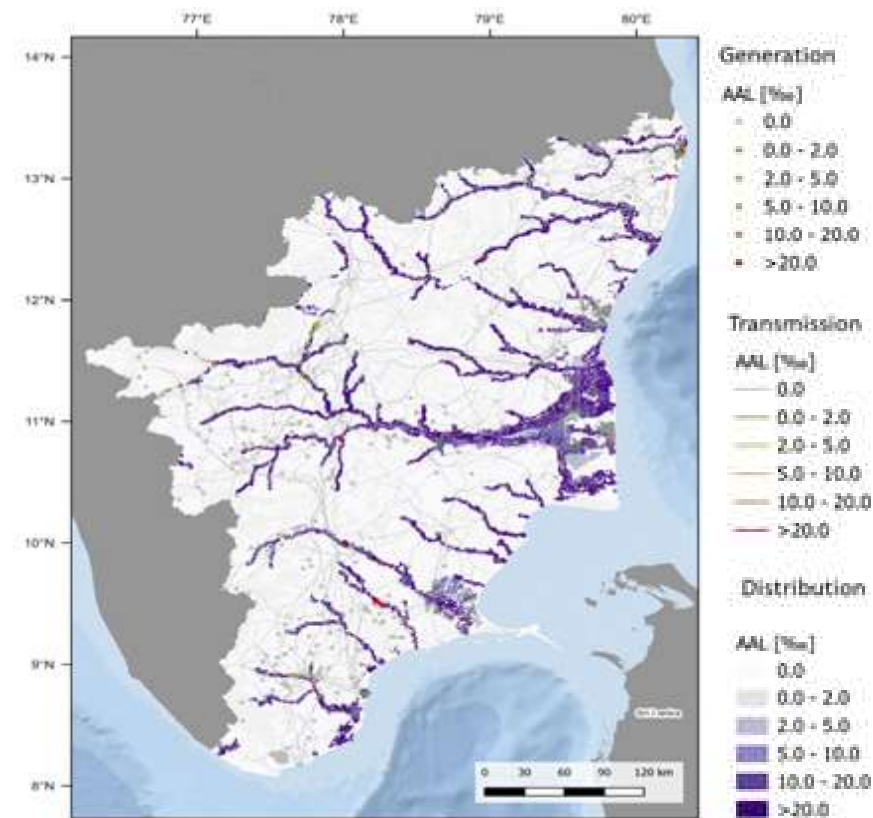


Figure 5.21: Map of Relative AAL from Tropical Cyclones for the Energy Portfolios

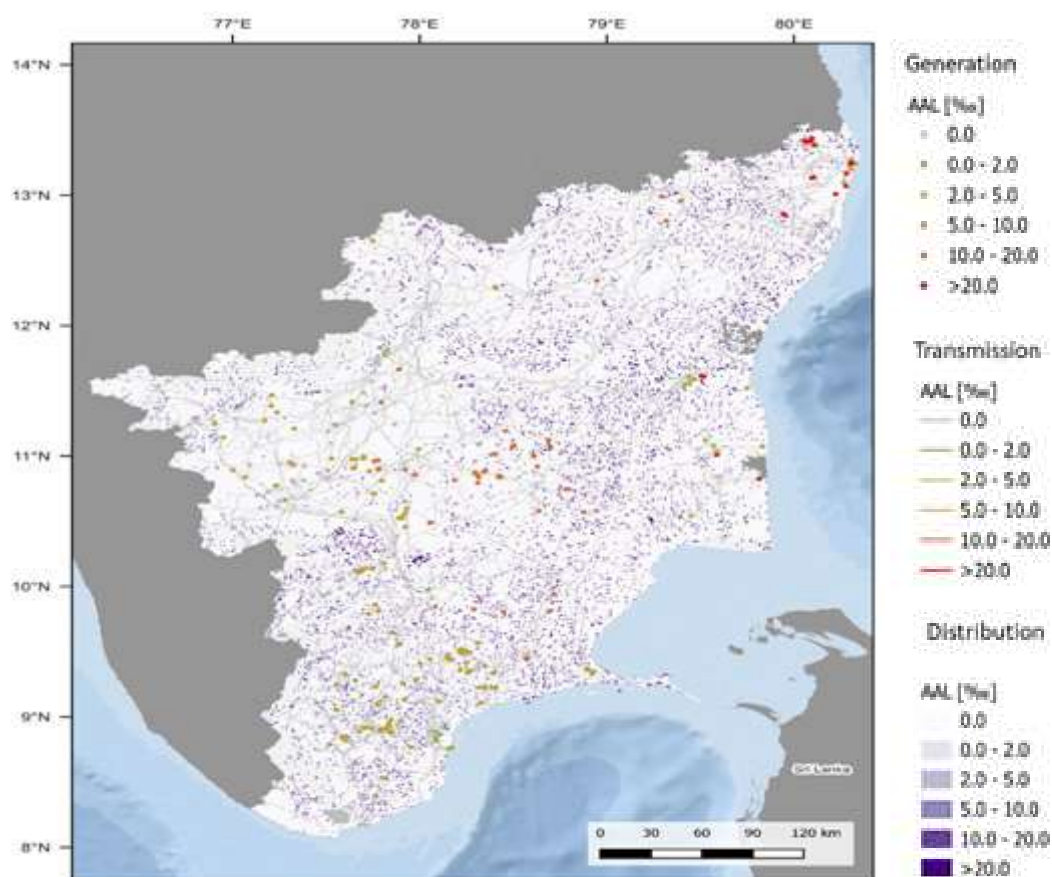


Figure 5.22: Map of Relative AAL from Tropical Cyclones (SSP5-RCP8.5) for the Energy Portfolios

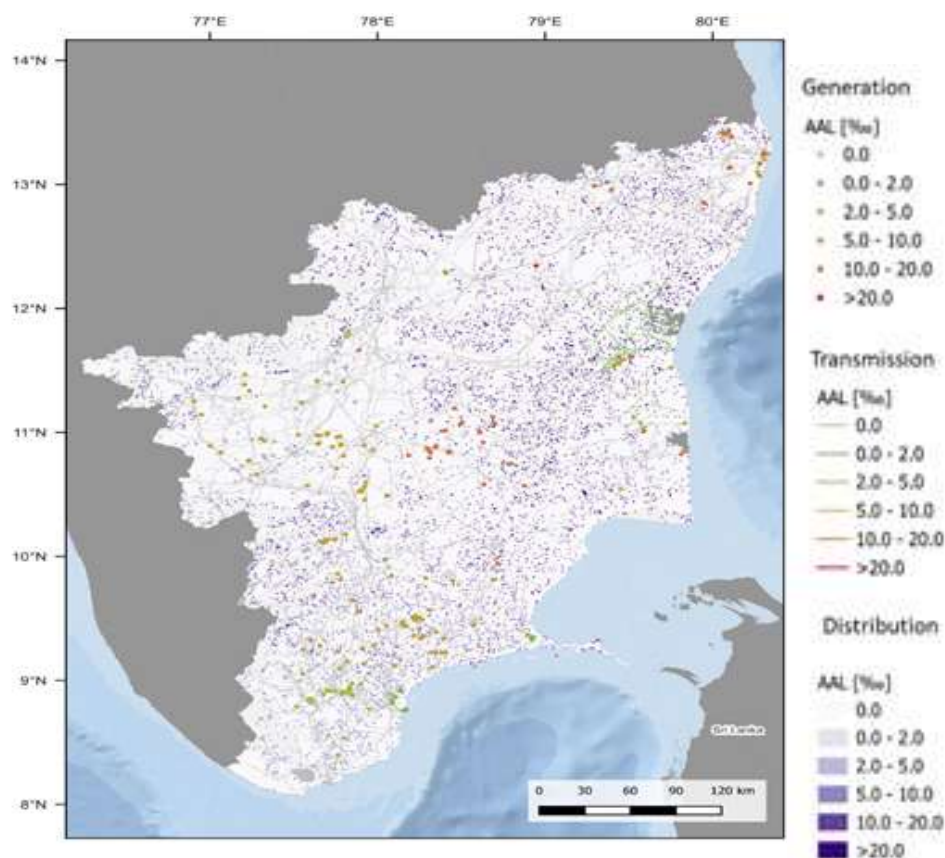
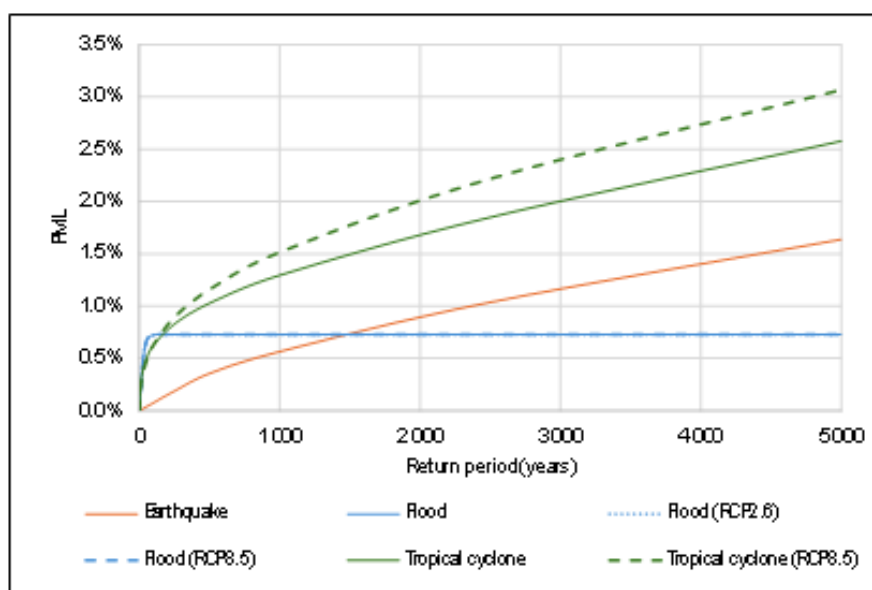


Table 5.11 presents the PML values for the energy sector of Tamil Nadu, categorized by hazard and for selected return periods. PML values are consistently higher than AALs because of their definitions and the way they are calculated. Figure 5.23 illustrates these PML values as a function of return period, showing the full variation of the metric across the PML curves. As anticipated, the risk posed by tropical cyclones is the most significant on the curve for Tamil Nadu, followed by earthquake risk. Flooding is a concern only for very short return periods, being overtaken by cyclone risks beyond 100 years and by earthquake risks beyond 1,500 years. It is important to note the rapid increase in PML values for earthquakes and tropical cyclones, in contrast to the relatively flat PML curve for floods. This difference is attributed to the frequency of the hazard events.

Table 5.11: PML for the Energy Sector Infrastructure (Values in \$)

Return period (years)	Eartquake	Flood	Flood (RCP2.6)	Flood (RCP8.5)	Tropical cyclone	Tropical cyclone (RCP8.5)
10	\$6,438,000	\$188,903,000	\$188,563,000	\$189,100,000	\$227,649,000	\$194,497,000
25	\$16,094,000	\$407,214,000	\$406,482,000	\$407,639,000	\$332,261,000	\$302,424,000
50	\$32,189,000	\$569,504,000	\$568,480,000	\$570,099,000	\$425,856,000	\$407,732,000
100	\$64,377,000	\$618,633,000	\$617,521,000	\$619,279,000	\$533,523,000	\$537,931,000
250	\$160,943,000	\$620,948,000	\$619,832,000	\$621,596,000	\$707,420,000	\$762,529,000
500	\$304,437,000	\$620,948,000	\$619,832,000	\$621,596,000	\$877,042,000	\$989,547,000
1,000	\$482,553,000	\$620,948,000	\$619,832,000	\$621,596,000	\$1,104,421,000	\$1,292,551,000
2,500	\$884,565,000	\$620,948,000	\$619,832,000	\$621,596,000	\$1,577,641,000	\$1,891,378,000
5,000	\$1,397,098,000	\$620,948,000	\$619,832,000	\$621,596,000	\$2,199,430,000	\$2,616,445,000

Figure 5.23: PML Curve for the Energy Sector Infrastructure



Road Infrastructure

Table 5.12 presents the AAL for Tamil Nadu's road sector based on the hazards considered in this assessment, both in absolute and relative terms. The highest losses are attributed to floods and rain-triggered landslides, with somewhat greater figures for the SSP1-RCP2.6 scenario. However, there is no significant variation among different climatic conditions. Earthquakes account for the lowest contribution to the AAL, while earthquake-triggered landslides have no impact at all. This discrepancy is primarily due to event frequency: hydrometeorological hazards such as floods and rain-triggered landslides occur more frequently, whereas earthquakes and their associated landslides are rare, especially in low-seismicity regions such as Tamil Nadu.

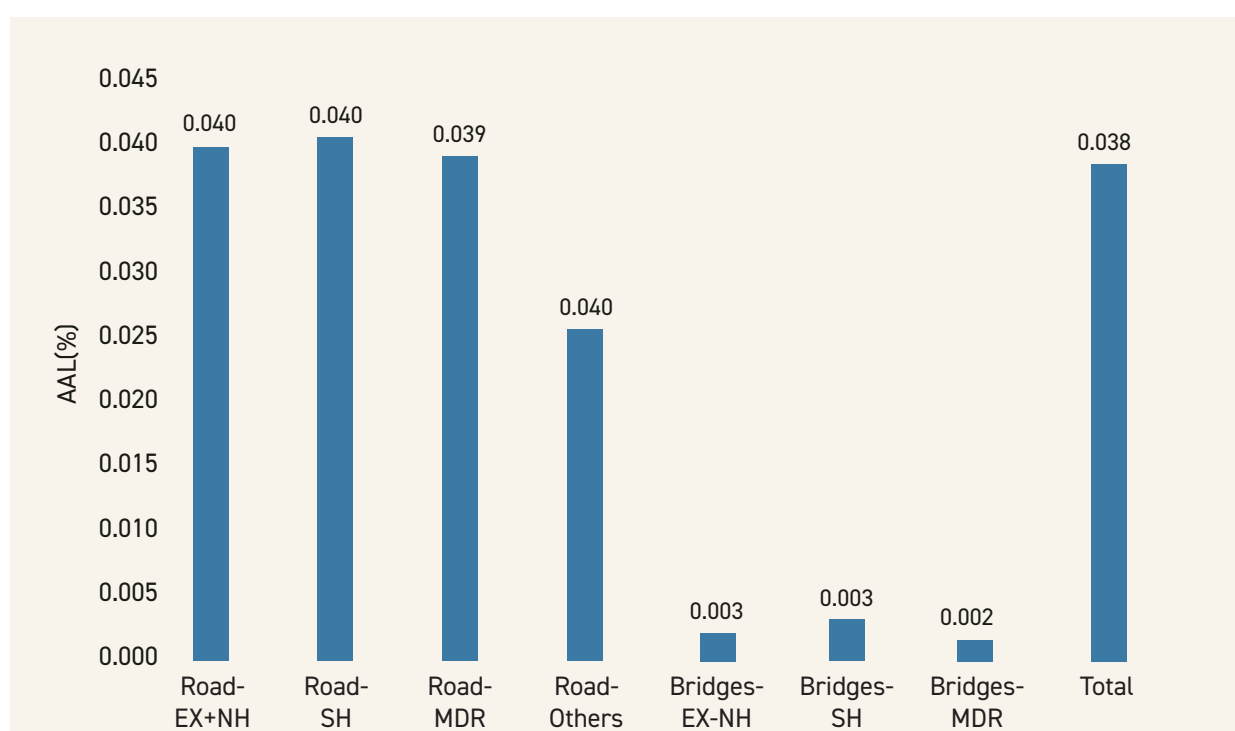


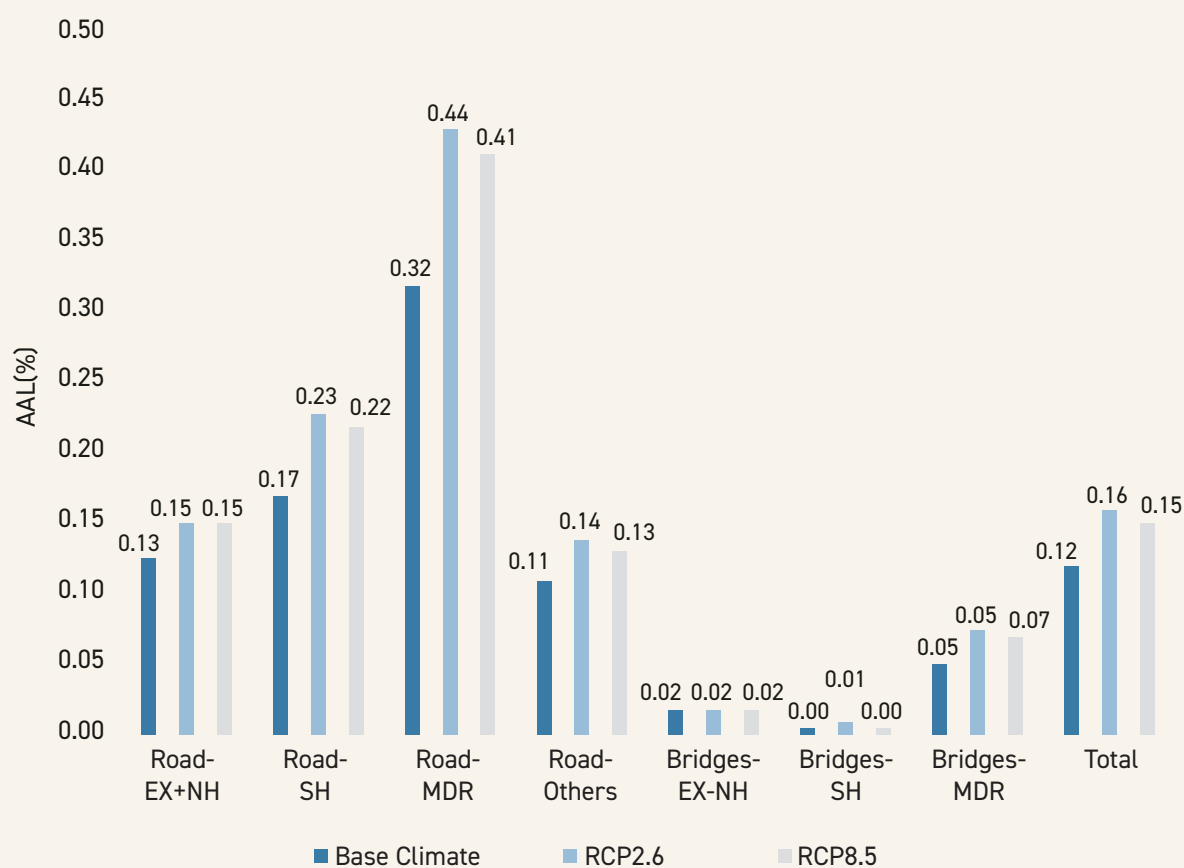
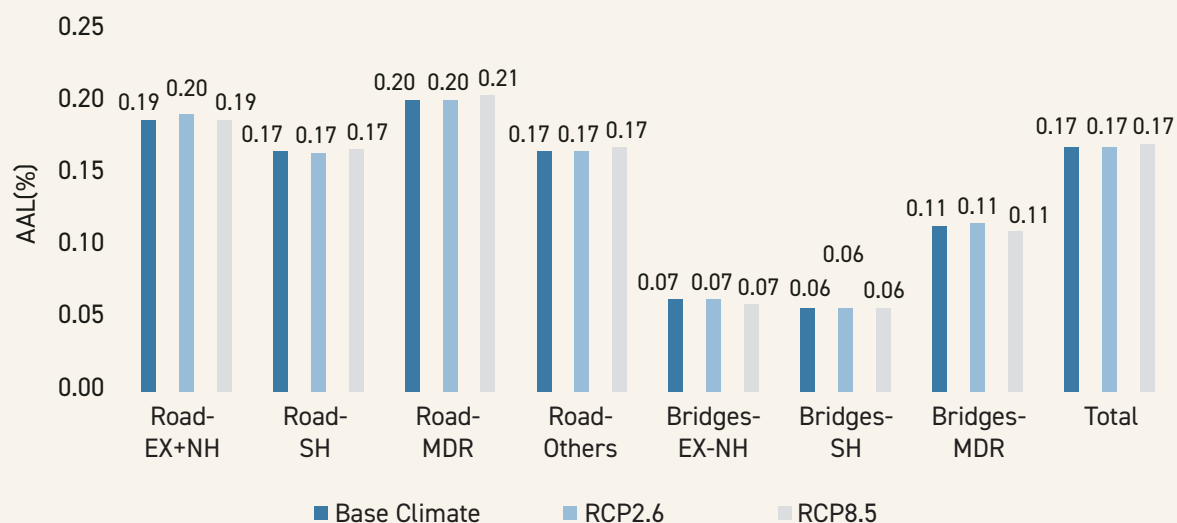
Table 5.12: Absolute and Relative AAL for the Roads and Bridges Infrastructure

Hazard	AAL	
	\$	%
Earthquake	\$5,528,000	0.04
Landslide - Earthquake	\$0	0.00
Flood	\$24,456,000	0.21
Flood (RCP2.6)	\$24,521,000	0.21
Flood (RCP8.5)	\$24,680,000	0.21
Landslide - Rain	\$17,623,000	0.15
Landslide - Rain (RCP2.6)	\$23,371,000	0.20
Landslide - Rain (RCP8.5)	\$21,916,000	0.19

The relative AAL among subsectors is distributed as follows. For earthquake hazards, all AAL values are comparable and very low. In the case of floods, AALs are fairly even distributed across sectors, with bridges showing lower values. It is important to note that there is no significant variation among different climates. This differs from the AALs for rain-triggered landslides, where the higher values are observed for major district roads, likely due to the greater variability within this portfolio (see Figure 5.24). Note that AAL tends to be higher under the climate scenario SSP1-RCP2.6, indicating a strong non-linearity between greenhouse gas (GHG) emissions and disaster risk.

Figure 5.24. Relative AAL from (A) Earthquake, (B) Flood, and (C) Rain-Triggered Landslides for the Road and Bridge Infrastructure Portfolios





The AAL of each road segment in the model is presented from Figures 5.25 to 5.31, categorized by hazard. These maps illustrate the variation in relative AAL among the exposed elements of the road network, despite the country's large size. As previously mentioned, a comprehensive geolocated dataset will be provided to ADPC, enabling more detailed analysis and consultation.

Figure 5.25: Map of Relative AAL from Earthquakes for the Road Portfolios

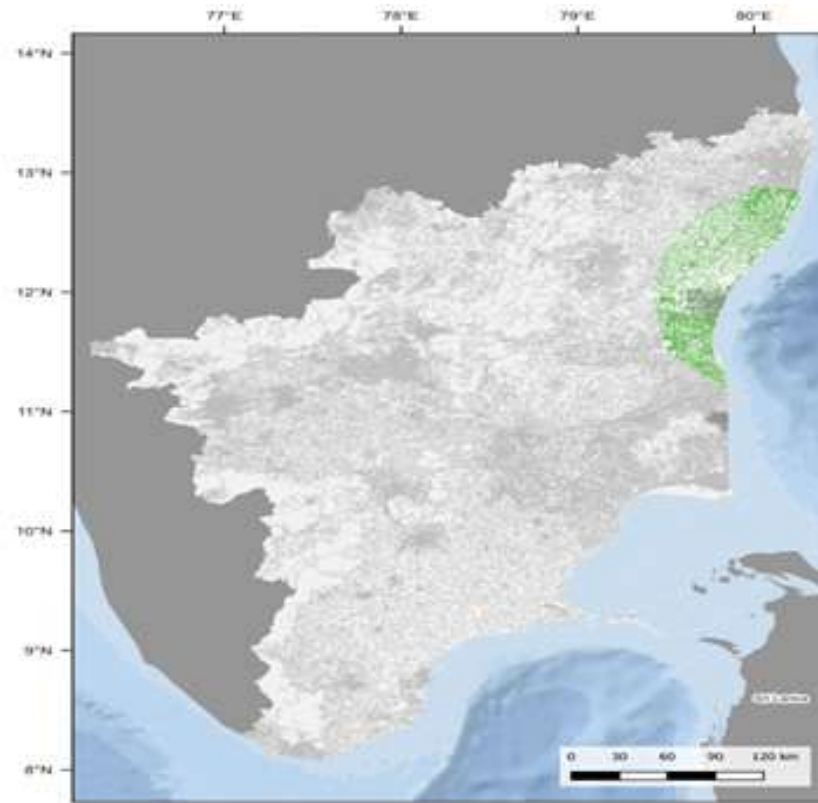


Figure 5.26: Map of Relative AAL from Floods for the Road Portfolios



Figure 5.27: Map of Relative AAL from Floods (SSP1-RCP2.6) for the Road Portfolios



Figure 5.28: Map of Relative AAL from Floods (Ssp5-Rcp8.5) for the Road Portfolios

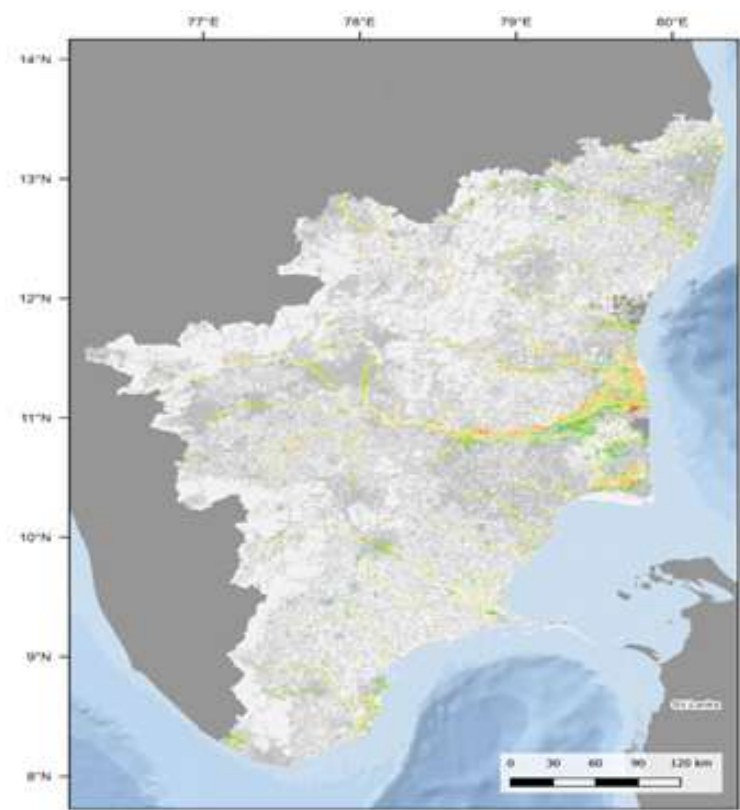


Figure 5.29: Map of Relative AAL from Rain-Triggered Landslides for the Road Portfolios

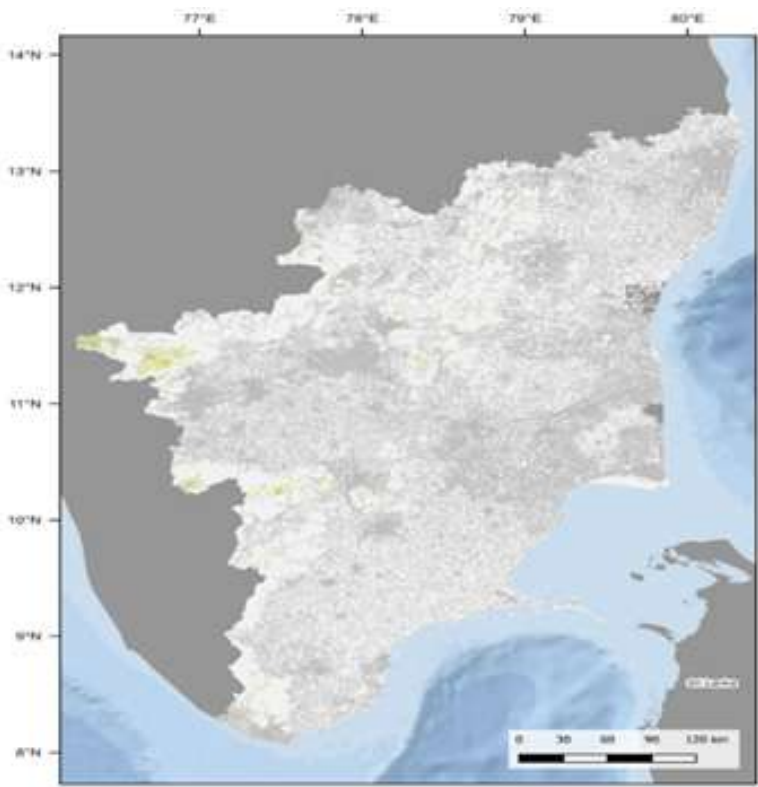


Figure 5.30: Map of Relative AAL from Rain-Triggered Landslides (SSP1-RCP2.6) for the Road Portfolios

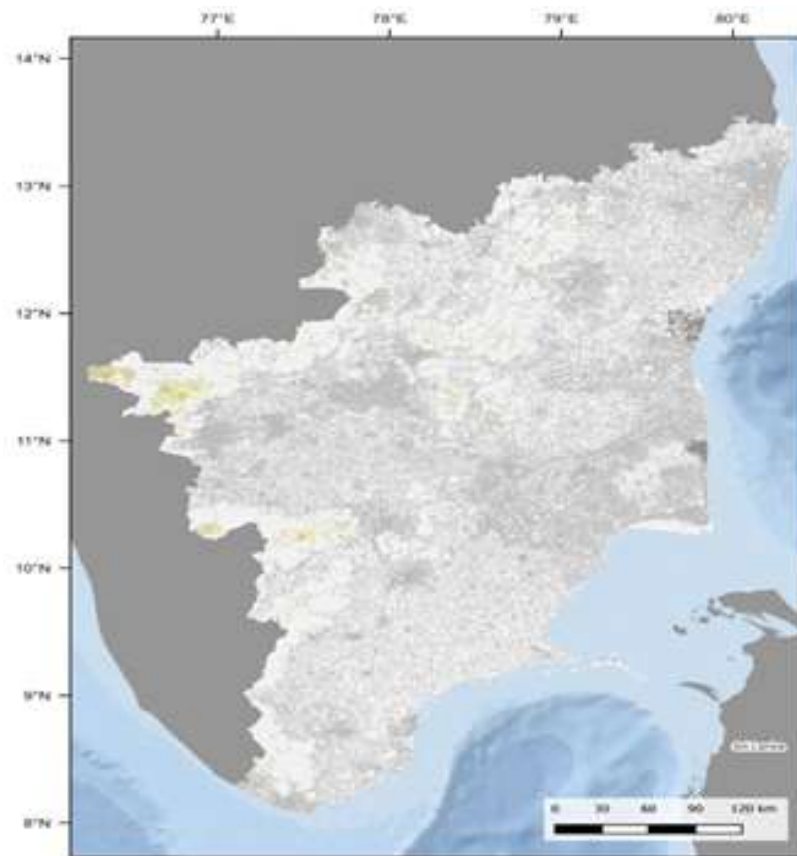


Figure 5.31: Map of Relative AAL from Rain-Triggered Landslides (Ssp5-Rcp8.5) for the Road Portfolios

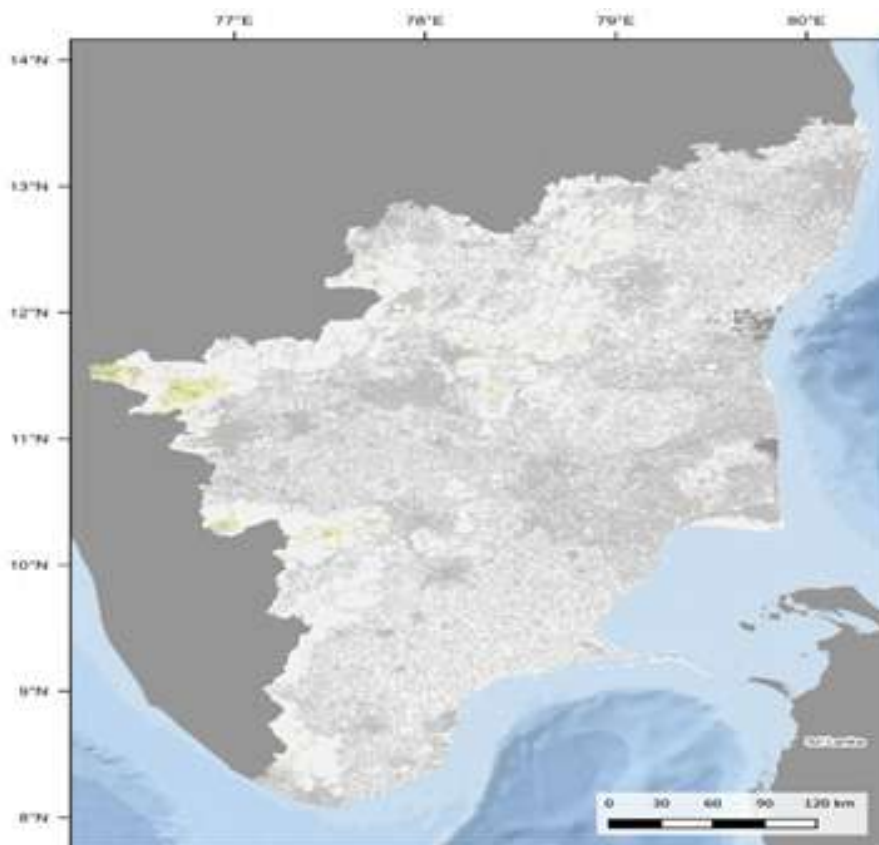


Table 5.13 presents the PML values for the road sector in Tamil Nadu by hazard for selected return periods. As mentioned, PMLs are always higher in magnitude than AALs along all the return periods calculated.

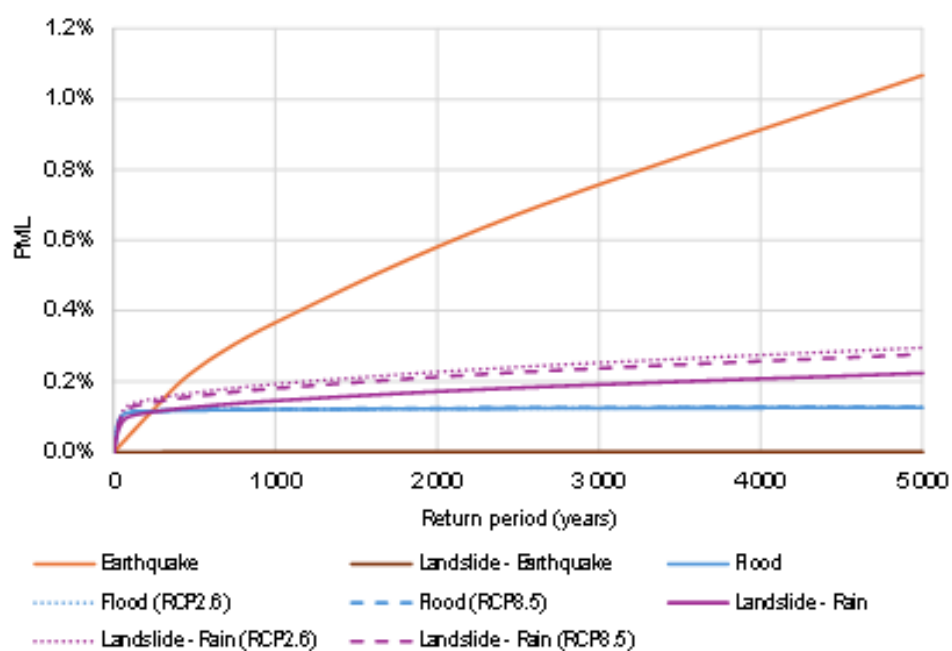
Table 5.13: PML for the Roads and Bridges Infrastructure (Values in Thousand \$)

Return period (years)	Earthquake	Flood	Flood (RCP2.6)	Flood (RCP8.5)	Landslide Rain	Landslide Rain (RCP2.6)	Landslide Rain (RCP8.5)
10	\$7,082	\$52,733	\$52,882	\$53,191	\$36,645	\$48,597	\$45,572
25	\$17,704	\$108,260	\$108,591	\$109,132	\$79,666	\$105,648	\$99,072
50	\$35,408	\$149,811	\$150,274	\$151,003	\$121,482	\$161,102	\$151,074
100	\$70,815	\$164,310	\$164,803	\$165,658	\$146,804	\$194,683	\$182,564
250	\$177,038	\$168,677	\$169,150	\$170,152	\$165,185	\$219,058	\$205,422
500	\$334,802	\$171,770	\$172,223	\$173,350	\$184,089	\$244,128	\$228,931
1000	\$531,775	\$175,052	\$175,482	\$176,750	\$210,842	\$279,605	\$262,200
2500	\$977,489	\$179,696	\$180,090	\$181,569	\$263,943	\$350,025	\$328,237
5000	\$1,547,125	\$183,455	\$183,818	\$185,477	\$323,797	\$429,400	\$402,671

Figure 5.32 illustrates the relative PML curves for all the hazards considered. While rain-triggered landslides and floods pose significant risks for very short return periods, the earthquake PML quickly exceeds these hazards beyond the 200-year mark, indicating that earthquakes have a greater impact on the risk of large or catastrophic events. As previously mentioned, the rate of increase for the earthquake PML is much steeper compared to the PML curve for rain-triggered landslides and the relatively flat curve for floods. In any case, all the PML values for Tamil Nadu are quite low.



Figure 5.32: Probable Maximum Loss Curve for the Roads and Bridges Infrastructure



The study reveals that tropical cyclones have the highest AAL for energy infrastructure in Tamil Nadu, whereas floods have the greatest AAL for roads and bridges. Based on the data presented in the previous tables, Table 5.14 displays the combined absolute AAL for the selected sectors across the identified hazards.

Table 5.14: Absolute AAL

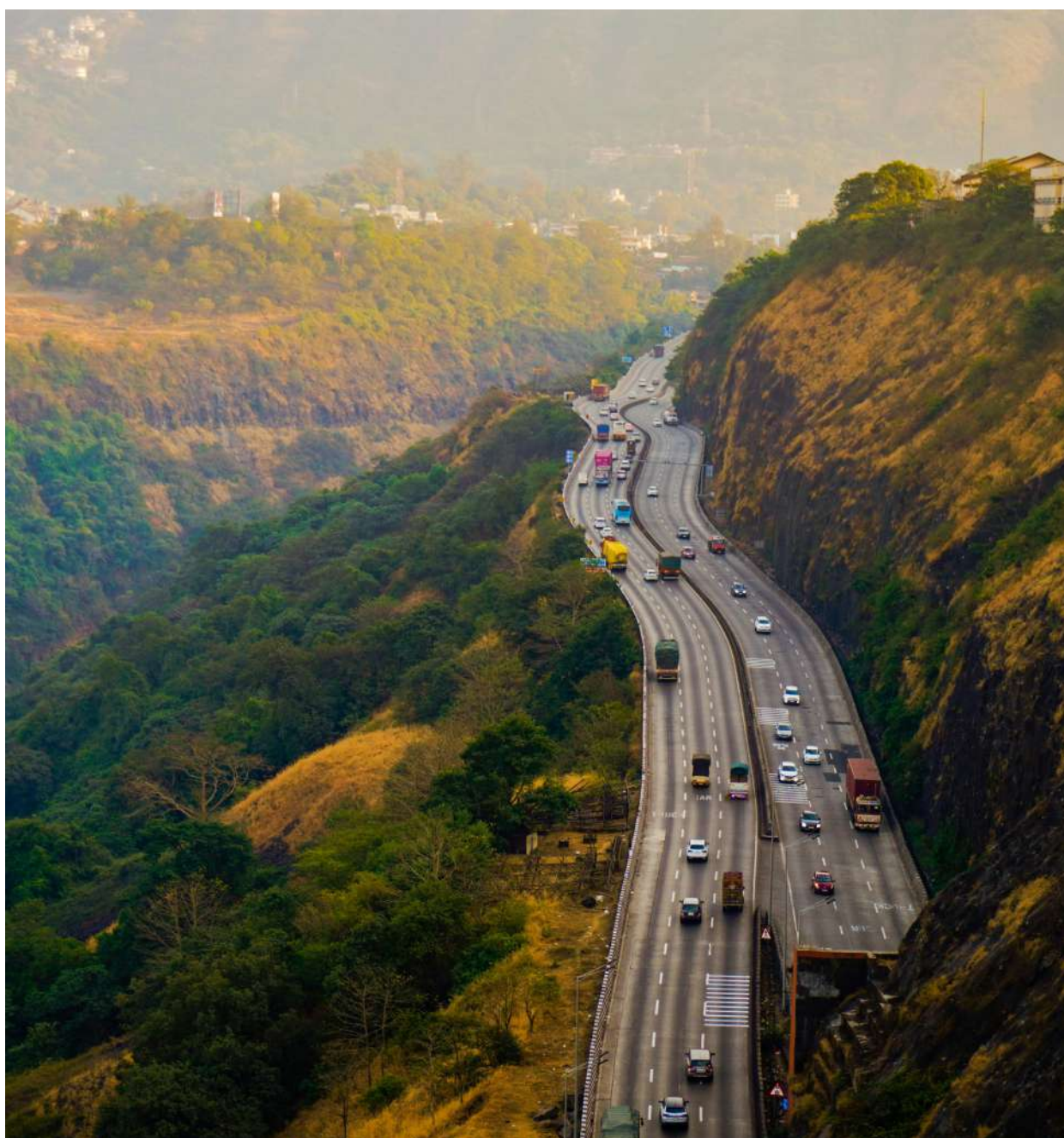
Hazard	Average Annual Loss (\$)	
	Energy infrastructure	Roads and Bridges
Earthquake	5,023,000	5,528,000
Flood	84,289,000	24,456,000
Flood (RCP2.6)	84,138,000	24,521,000
Flood (RCP8.5)	84,377,000	24,680,000
Tropical cyclone	129,686,000	-
Tropical cyclone	108,513,000	-
Landslide - Rain	-	17,623,000
Landslide - Rain	-	23,371,000
Landslide - Rain	-	21,916,000

Probable Maximum Loss for Energy Infrastructure

Tropical cyclones with a return period of 10 years are expected to cause the highest PML for energy infrastructure. However, floods with return periods of 25-100 years are likely to yield even higher PML for the energy sector. Only tropical cyclones with a return period of 5,000 years would lead to a greater PML than those associated with the floods.

Probable Maximum Loss for Roads and Bridges

For roads and bridges, floods with return periods of 100 years or less pose the highest PML. Additionally, rain-induced landslides (at RCP2.6) with return periods exceeding 100 years will pose higher PML risks.





Chapter 6

Post-Disaster Funding Gap Assessment



Post-Disaster Funding Gap Assessment

Post-disaster funding gap assessment is the systematic process of identifying available financial resources for recovery and reconstruction and estimating any additional funding requirements. Conducting a timely funding gap assessment is crucial to ensuring that affected sectors receive the resources necessary to rebuild and recover effectively and efficiently. This process is multifaceted and requires input from various perspectives to ensure fiscal resilience. There are benefits to conducting a funding gap assessment *ex ante*. These assessments can be the following:

1

Provide decision-makers with the essential data to make informed choices about resource allocation during different stages of recovery. By identifying funding gaps and understanding the financial requirements of various recovery initiatives, stakeholders can systematically prioritize projects and reallocate funds to address emerging or increasing needs, enhancing efficiency and impact.

2

Provide a structured, data-driven approach to identifying the specific financial needs for recovery. It equips decision-makers, governments, and organizations with the information needed to mobilize resources effectively. This includes advocating for additional funding from a range of sources, such as government budgets, international donors, private-sector partnerships, grants, and loans.

3

Can be used to advocate for additional funding from governments, international organizations, donors, and the private sector. Resource mobilization is a pivotal component of ensuring efficient disaster recovery and conducting funding gap assessments. These assessments help stakeholders identify the most critical resources and determine how to leverage them strategically to support recovery initiatives.

4

Enhance transparency and accountability in the recovery process. Stakeholders can monitor the allocation and utilization of funds, which reduces the risk of corruption and mismanagement.

5

Help ensure that there are no unnecessary bottlenecks in funding availability, enabling a more rapid and efficient response to recovery needs without delay.

6

Enable international donors and humanitarian organizations to effectively target their aid and donations. They can channel their resources to areas with the greatest need, maximizing the impact of their assistance.

Institutional Framework for Disaster Risk Management

In Tamil Nadu, the primary institutions responsible for managing all aspects of disaster management – ranging from mitigation to response and recovery – are the Tamil Nadu State Disaster Management Authority (TNSDMA), the Revenue & Disaster Management Department, and the Office of the Special Relief Commissioner (SRC). The TNSDMA is tasked with promoting an integrated and coordinated disaster management system that includes prevention and mitigation efforts by the state, local authorities, stakeholders, and communities. The Office of the SRC facilitates relief, restoration, and rehabilitation in the event of a disaster and coordinates an effective emergency response. The district administration is responsible for coordinating with line departments and Panchayati Raj Institutions (PRI) at the district level. This role includes managing both pre- and post-disaster management activities, as well as facilitating community training, awareness programmes, and the installation of emergency facilities. The district administration receives support from PRIs, non-governmental organizations, and the private sector to carry out these activities effectively. Major stakeholders, including state government line departments, the district administration, UN agencies, technical institutions, PRIs, urban local bodies, the community, and NGOs, all play vital roles in disaster risk management.

Post-Disaster Financing Mechanisms in Tamil Nadu

The SDRMF and the NDRMF

The current disaster risk finance mechanism in India is to be based on the recommendations of the 16th Finance Commission (2026-31), which builds upon the larger mechanism established by the 15th Finance Commission (FC-XV 2020-25). The FC-XV proposed the establishment of two major funds: the SDRMF and the NDRMF. Consequently, disaster risk financing is a shared responsibility between the state governments and the Union government. The following are the salient features of the finance sharing arrangement:

State governments are required to establish an SDRF under Section 48 (1) of the Disaster Management Act 2005. These governments are primarily responsible for covering most immediate disaster-related costs and for leading disaster responses. This includes conducting rescue operations, facilitating evacuations, organizing relief efforts, and providing aid to those affected. The Union government provides financial and technical assistance as needed.

When the funds available in the corpus are insufficient to address severe calamities, states can request additional central assistance from the NDRF by submitting a memorandum. The allocation of funds to state relief funds is based on the recommendations of successive Finance Commissions. Factors considered for allocating funds over a five-year period include the state government's expenditure on relief operations over the past 10 years, its susceptibility to disasters, and its economic status.

Additional sources of funding include the Prime Minister's National Relief Fund, the Chief Minister's Relief Fund, emergency credit from international financial institutions, international aid, and private sector financing. As a state-owned fund under the SDRMF, the SDRF serves as a readily available resource for the state's post-disaster efforts.

Other ex-post mechanisms

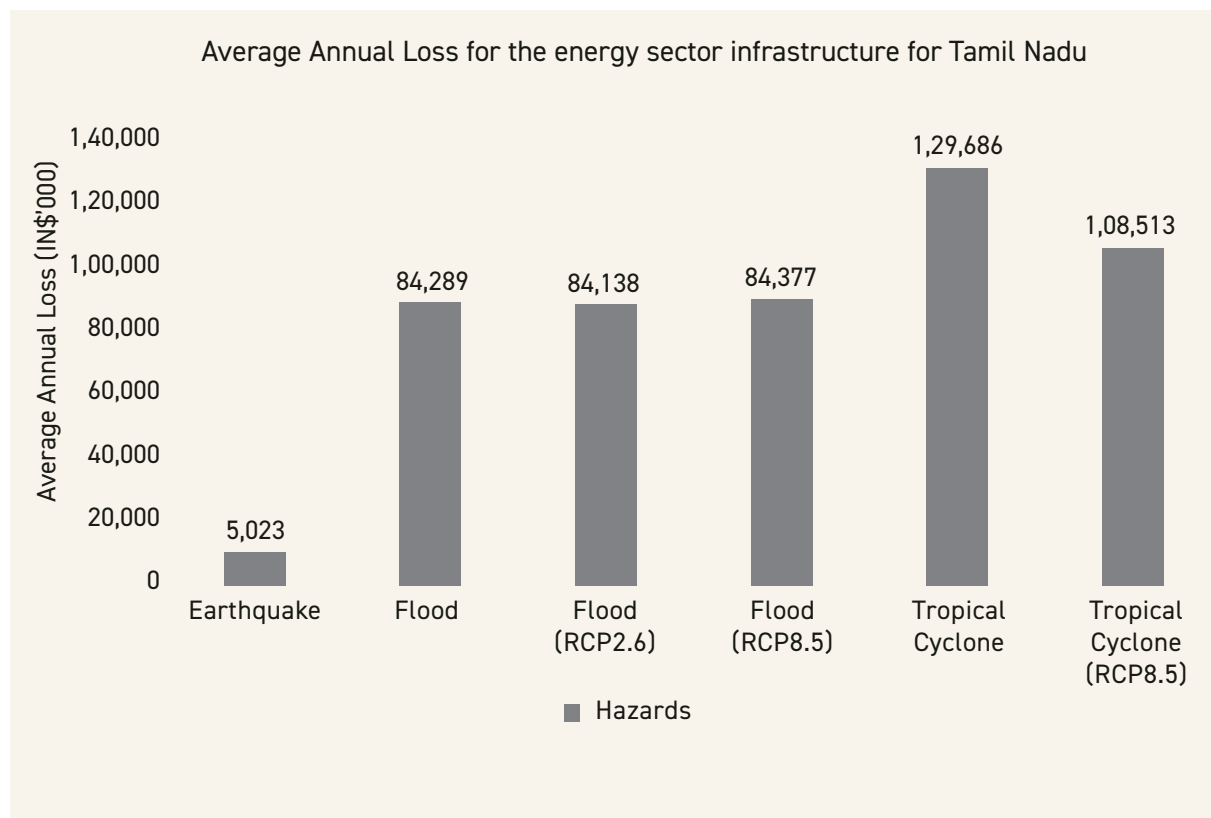
The recovery and reconstruction expenditure on the state's infrastructure assets is incurred by the respective state line departments. Barring some initial recovery & reconstruction expenditure financed through SDRF/NDRF. Most of this expenditure is financed through ex post budgetary reallocations or supplementary demands for grants. The expenditure is also financed through development support packages from the centre, additional provisions for centrally sponsored schemes or interest-free 50-year loans under Scheme for Special Assistance to States for Capital Investment (SASCI).

Post-disaster Funding Gap in Tamil Nadu

The 2015 Tamil Nadu Floods had a devastating impact, displacing over 1.8 million people and affecting millions more. The estimated total loss was approximately INR 14,602 crore (about \$1.7 billion) due to heavy rainfall that overwhelmed the city's infrastructure, resulting in severe flooding and a tragic loss of life. Additionally, Cyclone Thani in 2011 caused significant damage, resulting in estimated losses exceeding INR 2,000 crore (\$232 million). The 2018 floods also resulted in substantial financial losses of approximately INR 3,500 crore (\$407 million).

- **Post-disaster loss estimates:** According to the catastrophe model, the AAL from various hazards affecting energy sector infrastructure is depicted in Figure 6.1. Tropical cyclones have an AAL of approximately \$130 million.

Figure 6.1: AAL for the Energy Sector in Tamil Nadu (\$ '000)



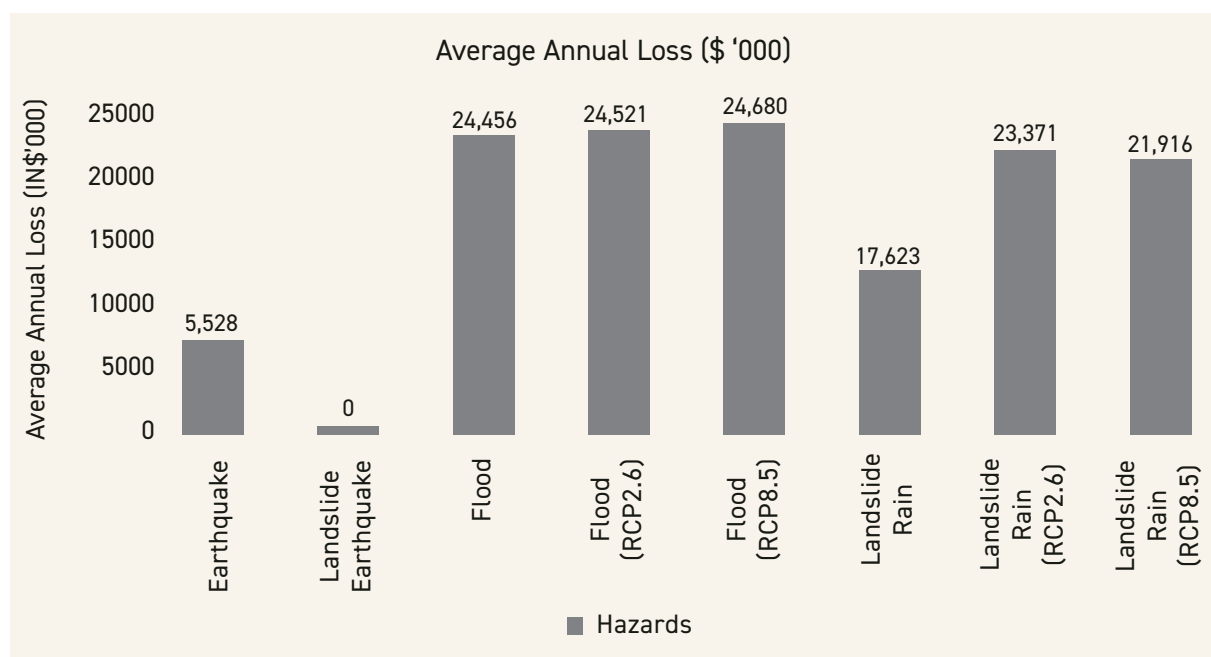
Amongst the energy sector assets, distribution is entirely owned by the state, whereas the transmission & generation sector assets are owned by both the Centre and state entities.

The contingent liability for these assets lies with the Centre and states, depending on the ownership

The AAL values for the distribution sector stand at \$73.3 million for floods, \$3.28 million for cyclones, and \$2.48 million for earthquakes

Similarly, the AALs for the roads and bridges sector are illustrated in Figure 6.2.

Figure 6.2: AAL for the Roads and Bridges Infrastructure in Tamil Nadu (\$ '000)



Amongst the Roads & Bridges assets, contingent liabilities for major district roads, state highways, and rural & urban roads lie with the state government, while for the rest (national highways & expressways) they lie with the national government.

The total estimated AALs for rural & urban roads stand at \$17 million (for floods at \$8.5 million, landslides at \$6.3 million, and earthquakes at \$2.2 million), whereas for state highways & major district roads it stands at \$9.7 million (for floods at \$3.9 million, landslides at approximately \$5 million, and earthquakes at \$0.8 million).

For financing, the estimated losses, both a combination of *ex ante* & *ex post* mechanisms are available.

- **Funding Gap Scenarios:** *Ex ante* disaster risk financing mechanisms in the state are essentially composed of the SDRF and NDRF funds available as per the recommendations of the Finance Commissions of India. Expenditures from SDRF and NDRF funds are based on MHA guidelines on items and norms of assistance. In the context of the infrastructure sector, SDRF provides only for immediate recovery and reconstruction expenses, with the rest of the reconstruction cost essentially funded by *ex post* departmental expenditures by State line ministries.

The Central share and the state contribution of Tamil Nadu in the SDRF as per the 16th FC Report are as follows:

Table 6.1: SDRF of Tamil Nadu

Fiscal year	Total SDRF	
	(INR Crore)	\$ (million)
2026-27	1,638	197,35
2027-28	1,720	207,23
2028-29	1,806	217,59
2029-30	1,896	228,43
2026-2031	1,991	239,76

Source: 16th FC report (2026), 1\$ =83 INR

The SDRF, as per the 15th FC's recommendations, is comprised of three funding windows of Relief and Response, Recovery and Reconstruction, and Preparedness and Capacity Building. This has been revised by the 16th FC, with the window of Preparedness and Capacity Building being shifted to SDMF and only the other two windows remaining under the SDRF.

As per the 15th FC, the reconstruction and recovery window amounted to 30 percent of SDRMF or 37.5 percent of SDRF. It provided for expenditure on immediate recovery and reconstruction of infrastructure. However, the items and norms for assistance for SDRF expenditure as laid out by the MHA constitute a mere fraction of the actual recovery and replacement costs, with a major chunk of the expenditure incurred out of the budgets of infrastructure departments.

Simple Case

Based on the contingent liability estimates across the two infrastructure sectors highlighted above in post-disaster loss estimates subsection and the *ex ante* sources of financing subsection, a funding gap assessment is undertaken below using certain simplifying assumptions to illustrate the magnitude of the gap.

Assumptions:

The recovery and reconstruction window is used entirely for infrastructure repairs of the two sectors and not for *ex gratia* compensation for Housing or for other infrastructure sectors.

Out of the two sectors considered, the distribution assets in the Energy sector and State highways / major district roads (MDR) and rural road assets in the Roads and bridges sectors are considered.

Table 6.2 indicates that *ex ante* SDRF reserves lack sufficient funds to support reconstruction and recovery expenditure, even for just two infrastructure sectors – Energy, and Roads and Bridges. However, it is important to highlight that *ex ante* NDRF mechanisms are available along with several other ex-post mechanisms that help finance this expenditure. However, longer disbursement time for NDRF funds and ad hocism and higher economic costs associated with ex-post mechanisms such as developmental expenditure remain a challenge.

Figure 6.2: AAL for the Roads and Bridges Infrastructure in Tamil Nadu (\$ '000)

Fiscal year	Total SDRF	Central Share 75%	State Share 25%	Total SDRF (US\$ Mill)	Recovery & Reconstruction window (US\$ Mill) 37.50%	Energy (Distribution Assets)	Roads and Bridges (State Highway, MDR, Rural & Urban Roads)	Gap (US\$ Mill)	NDRF (Graded cost sharing norm for amount between 250-500 CR INR))	
									State share (20%) (US\$ Mill)	Centre share (80%) (US\$ Mill)
2026-27	1,638	1228.5	409.5	197.35	74.01	79.11	26.91	32.01	6.40	25.61

Extreme cases

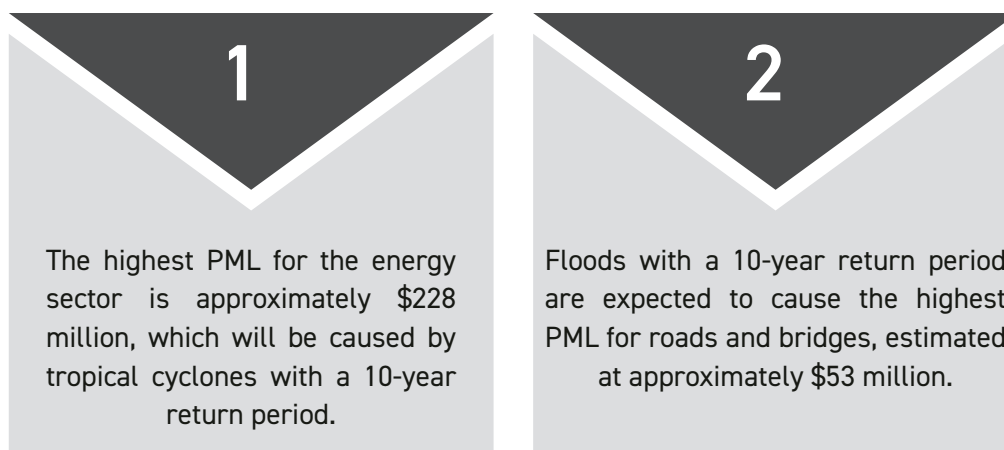
Assumptions for extreme case scenarios:

The recovery and reconstruction window is used entirely for infrastructure repairs of the two sectors and not for ex gratia compensation for Housing or for other infrastructure sectors.

The two Sectors – Roads and Bridges, and Energy – are considered in entirety. Assets have not been segregated based on contingent liabilities lying with the state or Centre, as in these extreme cases, both the state and Central liability and funding sources need to be analyzed together.

Scenario 1.

Hazards with a return period of 10 years, excluding climate change effects, are projected for the years 2026-27. This analysis assumes the least-cost scenario, as hazards with longer return periods have higher PMLs.



Based on the aforementioned considerations, Table 6.3 calculates the funding gap for Tamil Nadu.

Table 6.3: Annual SDRF and the Highest PMLs for Energy and Roads and Bridges for Hazards with a 10-Year Return Period

SDRF (INR Crore)			SDRF (\$ Million)		PML (\$ Million)		Gap/Surplus (\$ Million)	NDRF (Graded cost sharing norm for amount above INR 500 Crore)	
Total SDRF	Central Share (75%)	State Share (25%)	Total SDRF	Recovery & Reconstruction Window (37.5%)	Energy	Roads and Bridges		State Share (25%) (\$ Million)	Centre Share (25%) (\$ Million)
1638	1228.5	409.5	197.35	74.01	228	53	-207	51.75	155.25

Table 6.3 indicates that the SDRF cannot accommodate even 50 percent of the PML for the energy and roads and bridges sectors if such 10-year return period hazards occur in the same year. Furthermore, the NDRF mechanism gets stretched, with state share under NDRF exceeding \$50 million just for these two sectors.

Scenario 2.

Hazards with various return periods, without climate change projected impacts and with the highest PMLs occurring in the same year, say 2026-27. This scenario considers the following data from the catastrophe model:

1

In the energy sector, among hazards with 10-year return periods and those with return periods of 250 years or more, tropical cyclones will cause the highest PML. Floods with a 25- to 100-year return period will have the highest PMLs.

2

For roads and bridges, floods with a return period of 100 years or less are expected to result in the highest PML. Conversely, earthquakes with return periods of 250 years or more will produce the highest PMLs.

Considering the factors mentioned above, Table 6.4 indicates that if hazards with the highest PMLs occur within the same year across various return periods, there will be a significant funding gap for the state, which would require a lot of ex-post mechanisms & considerable impact on state and Central finances.

Table 6.4: Funding Gap Based on the Highest PMLs by Return Period (No Climate Change)

Return Period	SDRF (INR Crore)			SDRF in (\$ Million)	Recovery & Reconstruction Window (\$ Million)	PML (\$ Million)		Gap/Surplus (\$' Million)	NDRF (Graded cost sharing norm for amount above INR 500 Crore)	
Year	Total SDRF	Total SDRF	Total SDRF	Total SDRF	37.50%	Energy	Roads and Bridges		State Share (25%) (\$ Million)	Centre Share (25%) (\$ Million)
10	1638	1228.5	409.5	197.35	74.01	228	53	-207	52	155
25	1638	1228.5	409.5	197.35	74.01	407	108	-441	110	331
50	1638	1228.5	409.5	197.35	74.01	570	150	-645	161	484
100	1638	1228.5	409.5	197.35	74.01	619	164	-709	177	532
250	1638	1228.5	409.5	197.35	74.01	707	177	-810	203	608
500	1638	1228.5	409.5	197.35	74.01	877	335	-1,138	284	853
1000	1638	1228.5	409.5	197.35	74.01	1,104	532	-1,562	391	1172
2500	1638	1228.5	409.5	197.35	74.01	1,578	977	-2,481	620	1861
5000	1638	1228.5	409.5	197.35	74.01	2,199	1,547	-3,673	918	2754







Chapter 7

Recommendations

Recommendations

Based on the discussions above, here are some recommendations that Tamil Nadu can consider to reduce fiscal risks from disasters.

1 Ensure the availability of funds for disaster response

- a The key challenge facing state is to mobilize financing at scale in the disaster response phase after the occurrence of natural hazards. The state's rapid economic expansion has allowed it to make substantial provision in the SDRF. However, Tamil Nadu does not lean heavily on the SDRF for meeting the financing needs in the post disaster response phase. In addition, the state makes substantial budgetary provision (*ex ante*) and transfers (*ex post*) to provide financing support for post disaster response. Higher SDRF allocations and federal transfers can help to support the state's resource mobilization efforts to mitigate the impact of disasters, protect its infrastructure assets and improve their efficiency.

2 Enhance the resilience of critical infrastructure

To reduce adverse impacts across sectors, it is essential to identify hazards and implement risk-reduction investments to ensure critical infrastructure can withstand future hazards.

a Improve the structural integrity of the infrastructure of the power grid and roads and bridges

Building more robust infrastructure with higher design standards would enable power grids and road networks to withstand more intense hazards. Although the initial costs may be high, investing in stronger infrastructure will ultimately reduce repair costs, service interruptions, and ongoing maintenance costs. Additionally, it is important to review the structural designs of roads and bridges to ensure they can effectively withstand the projected impacts of climate change, particularly regarding the increased intensity and frequency of natural hazards. Regular check-ups and maintenance of the infrastructure within the power grid and roads and bridges should be conducted to confirm that vulnerabilities have not increased over time.



b Identify and assess specific critical infrastructure assets while estimating the potential damage from disasters and their subsequent effects on other sectors

The state should identify these critical assets, assess their vulnerability to both frequent and extreme disasters, and analyze the impacts on other vital sectors of the economy. This evaluation will help determine suitable risk management mechanisms. Ultimately, this assessment should guide further analysis to strengthen infrastructure and identify investments in risk reduction that enhance the resilience of critical assets.

c Update and upgrade hazard maps

Upgraded and updated hazard maps will improve the accuracy of estimating potential damage to identified critical infrastructure. These estimates will also assist the government in budgeting for emergency response. Moreover, hazard maps are necessary to encourage insurance companies to expand their disaster-related insurance coverage, as they play a crucial role in risk assessment, pricing, and underwriting. By identifying high-risk areas prone to floods, earthquakes, cyclones, and other disasters, insurers can determine risk levels and coverage eligibility based on property exposure. This information allows them to design customized policies for different risk zones, estimate potential losses, maintain adequate financial reserves or reinsurance, and set appropriate premiums for policyholders.

d Update building codes and regulations and incorporate disaster and climate risks in development planning and investment decisions to minimize adverse disaster effects and impacts

To institutionalize social and economic resilience, it is essential to revise and integrate building codes, land-use plans, and zoning regulations into the design of both public and private investments. Moreover, disaster risk management and potential climate change impacts should be integrated into development plans and investments of both the government and the private sector. This initiative will ensure that every new public infrastructure investment incorporates disaster-proof designs that can withstand extreme weather events. For instance, the construction of elevated roads and climate-resistant bridges, along with improvements to drainage systems to prevent flooding, should be thoroughly analyzed. Such investments are critical to ensuring safer transportation and reducing the fiscal burden of frequent infrastructural damage. Additionally, older structures may need to be retrofitted to enhance their durability and resilience, ultimately decreasing their vulnerability to future hazards. Moreover, resilient infrastructure can lead to customized insurance products with more favourable terms, such as higher coverage limits, lower deductibles, or more comprehensive coverage options at reduced costs. Insurers also typically use reinsurance to protect themselves. When a country or sector demonstrates reduced vulnerability due to resilient infrastructure, reinsurers may offer better terms, which can indirectly lower overall insurance costs (Swiss Re Institute 2024).

e Build a state-wide disaster risk database

The state should establish a comprehensive digital disaster database that consolidates historical data on the impacts of disasters. This includes detailed assessments of expenditures and infrastructure damages. Such a database would be instrumental in conducting macroeconomic analyses of disaster impacts across sectors and for developing accurate catastrophe risk models. By mapping essential infrastructure and analyzing their vulnerabilities to frequent and severe disasters, the government can better understand inter-sectoral risks and design effective risk financing and management strategies. Moreover, a comprehensive disaster database, supported by up-to-date hazard maps, will enable the government to conduct informed risk assessments, formulate risk financing strategies, enhance budget planning for contingencies, and improve national disaster preparedness.

3 Explore the possibility of establishing contingent credit lines or insurance

a Tamil Nadu should consider establishing additional funding sources for post-disaster recovery, such as contingent credit lines or insurance for extreme hazards with longer return periods. For example, the 2015 Chennai floods, which had a 100-year return period and caused approximately \$2 billion in damages, could be considered for a contingent credit line or insurance. Given the significant funding gap for potential damage and losses from extreme disasters, expanding contingent credit sources will help accelerate the implementation of post-disaster recovery activities. However, under Article 293 of the Constitution, Indian states cannot independently secure loans from international financial institutions without the Central Government's consent, and, in some cases, they also require guarantees. Therefore, we can look at TNGCC to set up a facility that can provide contingency financing. TNGCC is mandated to leverage carbon markets, forge global partnerships, and tap public-private models to fund transformative climate action. The state also has set up a Green Climate fund. It can look to augment this fund, as well as look at introducing climate risk mitigation instruments within this facility. This approach would broaden the state's financing options, reduce reliance on ex-post budget reallocations, and help address the significant funding gap for disaster recovery.



4

Study further the expansion of insurance coverage to micro, small, and medium enterprises (MSMEs)

a

Tamil Nadu has 5 million MSME units (90% of which are micro-enterprises), but only 2 million are registered (formal), employing more than 14.506 million people. Including those in the informal sector, MSMEs in Tamil Nadu could exceed 25 million people. Disasters, such as floods and cyclones, have severely impacted MSMEs and continuously jeopardize the livelihoods of these 25 million people (Department of Industries and Commerce, Government of Tamil Nadu 2020). Currently, the NDRF and SDRF focus primarily on immediate post-disaster assistance for affected individuals and on restoring critical infrastructure. Support for MSMEs typically comes in the form of temporary tax exemptions, rebates on government dues, loan repayment deferrals, and concessional credit lines. However, these measures are often contingent on various factors and do not guarantee consistent or sufficient relief for enterprises (Department of Industries and Commerce, Government of Tamil Nadu 2020). Consistent with the Tamil Nadu State Disaster Management Perspective Plan 2018-2030, which identifies risk transfer through insurance as an important non-structural disaster mitigation mechanism, the state should initiate a comprehensive study on how to effectively implement insurance coverage for MSMEs against disasters.

5

Study further the expansion of the coverage of parametric insurance

a

The state can further review the Afat Vimo microinsurance scheme. The All-India Disaster Mitigation Institute (AIDMI) survey on this scheme found that policyholders used their payouts to repair damaged homes and that the insurance coverage had strengthened their resilience to extreme weather events. However, the same survey found limited awareness among the target community of insurance's potential benefits and confusion regarding the claims process. On the other hand, the state can examine the parametric insurance in Nagaland. Parametric insurance will reduce the government's financial burden for post-disaster rehabilitation, and it also encourages policyholders to practice preparedness and mitigation measures.



6 Explore the possibility of mandatory insurance

- a In India, there is no mandatory insurance requirement when purchasing a property, whether residential or commercial. Currently, less than 1 percent of residences in India are insured. A mandatory insurance for properties can be a subject of a study, like the requirements for auto insurance as a loan protection insurance by banks and financial institutions, at the time property loans are secured (Upadhyay 2023). The state may consider requiring residential homes, commercial buildings, and specific industries operating in defined disaster-prone areas, such as businesses in cyclone- and flood-prone areas, to carry insurance.

7 Expand and Formalize the Use of Risk Layering through a Multi-Tiered Financing Framework

The study reveals that there is heavy reliance on ex-post budget reallocations and central assistance, with limited pre-arranged financing and growing post-disaster funding gaps, particularly in the power and transport sectors. The state may adopt a three-tier risk layering framework:

a Low-risk/high-frequency events:

Budget contingencies and dedicated reserve funds (e.g., augment or allocate relief and rehabilitation fund beyond the SDRF with clear trigger rules).

b Medium-risk/moderate-impact events:

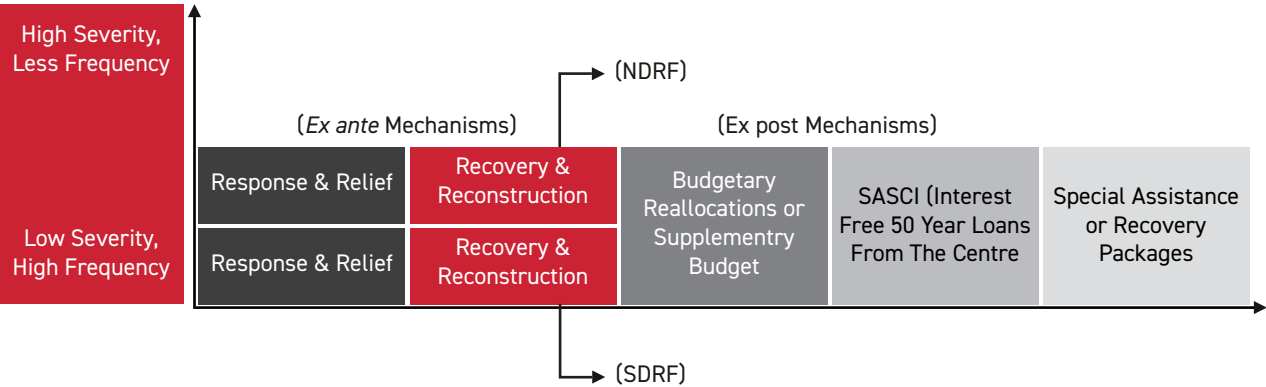
Expand existing parametric insurance coverage or explore and other schemes.

c High-risk/low-frequency catastrophic events:

Secure contingent credit lines and standby loans from other sources for rapid liquidity in accordance with existing laws.

Additionally, annual risk-layering reviews should a part of the budget process, integrated into the state's fiscal strategy.

The Disaster Risk Finance layering in the state is as follows (Indicative):



Adding a layer of risk transfer mechanisms such as infrastructure Asset & property insurance especially for high severity but low frequency tail disaster events could help better address these risks.

8 Continue to advocate for disaster preparedness and climate-friendly practices among the population to build resilience

- a Knowledge of disaster and climate risks, and community-based disaster risk management, will help local governments and communities prepare for and mitigate the adverse effects of natural hazards. This will lessen the fiscal risks associated with natural hazards.



Chapter 8

Annexure



Annexure

Annex A: Disaster-related Insurance Schemes in Selected Countries

Sri Lanka¹³

Very recently, the global advisory, broking, and solutions company WTW (NASDAQ: WTW) has launched Asia's first 4-peril parametric insurance to protect Sri Lanka's shrimp farms against weather risks, marking a crucial turning point in Asia's aquaculture development. The unique solution was designed and implemented for Taprobane Seafood Group, Sri Lanka's largest seafood company, helping it meet a critical condition to secure \$15 million in project financing from the Dutch entrepreneurial development bank FMO.

Shrimp farming is associated with a diverse range of risks and uncertainties, most prominently the exposure to weather risks across coastal regions where farms are traditionally located. To safeguard Taprobane against such vulnerabilities and mitigate potential bottlenecks that constrain the injection of much-needed capital, WTW has structured the region's first 4-peril parametric insurance solution, covering four key weather risks: **earthquake, typhoon, excess rainfall, and heat stress**. This has enabled Taprobane Seafood Group to meet a critical condition for securing \$15 million in project financing from the Dutch entrepreneurial development bank FMO.

WTW has also recently launched Nitrogen Risk Insurance, the world's first parametric insurance solution that allows sugarcane farmers in Queensland, Australia, to cover the risk of yield shortfall from reduced applications of nitrogen fertilizer on ratoon crops.

Thailand¹⁴

Since 2011, the Thailand Rice Disaster Relief Top-up Crop Insurance Scheme, which uses weather-index insurance for rice, has been available to farmers. The 'Remote-sensing based information and insurance for crops in emerging economies' project is a public-private partnership that is being implemented by the Swiss Agency for Development and Cooperation, the German Agency for International Cooperation, and others to reduce the vulnerability of smallholder rice farmers. In collaboration with the GeoInformatics and Space Technology Development Agency, the project integrates remote sensing and advances crop-yield modelling to develop a rice production monitoring system that provides accurate, timely information on rice areas, yields, and disaster-affected rice areas.

¹³ Press Release. "WTW Launches Asia's First 4-Peril Parametric Insurance Solution to Unlock Financing for Aquaculture Development," July 2023, <https://www.wtwco.com/en-ph/news/2023/07/wtw-launches-asias-first-4-peril-parametric-insurance-solution-to-unlock-financing-for-aquaculture>.

¹⁴ United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), Disaster Risk Transfer Mechanisms: Issues and Considerations for the Asia-Pacific Region (Bangkok: UNESCAP, 2017).

India

Modified Area Crop Insurance Scheme of India (2010)

The National Agricultural Insurance Scheme (NAIS) established by the Government of India is the world's largest crop insurance programme, covering approximately 25 million farmers and managed by the Agriculture Insurance Company of India (AICI). It provides insurance for food crops, oilseeds, and a few other commercial crops, using an area yield-based approach.¹⁵ By comparing current crop yields with historical data, this indexed strategy provides indemnity payments to farmers insured in specific locations when actual yields are below historical levels. In addition to addressing issues with tiny landholdings, the plan lessens moral hazard and adverse selection. NAIS, however, depends on government contributions made after a disaster and subsidized premiums. As a result, the government faces unlimited financial risk, and delays in claims settlement could lead to hardship for farmers. To enhance the programme's effectiveness and address these challenges, the government collaborated with AICI and sought technical assistance from the World Bank in 2005 to modify and improve insurance coverage.

India's First Weather Index Insurance Pilot by ICICI Lombard General Insurance Company (2003)

The first weather insurance product in India, and indeed in the developing world, was a rainfall insurance contract underwritten in 2003 by ICICI-Lombard General Insurance Company for groundnut and castor farmers of Hyderabad-based micro-finance institution BASIX's water user associations in the Mahbubnagar district of Andhra Pradesh. This innovative insurance programme provided coverage contingent on rainfall levels, helping farmers mitigate risks associated with unpredictable weather. It serves as a significant mechanism for disaster risk financing and insurance by offering innovative coverage based on weather indices. This pilot programme provides protection to farmers against adverse weather conditions, such as droughts or excessive rainfall, which can lead to crop losses and financial instability. By using weather indices to trigger payouts, the insurance scheme ensures timely compensation for farmers, thereby mitigating the economic impact of climate-related disasters. Since then, weather-based crop insurance has evolved significantly in India, with various programmes and approaches aimed at supporting farmers during adverse weather events.

For instance, more recent initiatives include heat-linked parametric insurance systems that offer a lifeline to Indian women in the informal sector.^{16,17} This approach not only promotes resilience among agricultural communities but also helps stabilize livelihoods and fosters sustainable development in vulnerable regions. Additionally, by pioneering such initiatives, ICICI Lombard contributes to the evolution and expansion of weather index insurance markets, paving the way for broader adoption and enhanced disaster risk management strategies across India.

¹⁵ World Bank, Disaster Risk Financing and Insurance Case Study: National Agricultural Insurance Scheme in India (Washington, DC: World Bank, 2011), https://www.farm-d.org/app/uploads/2019/05/DRFI_India_mNAIS_Jan11

¹⁶ Daniel J. Clarke, Olivier Mahul, N. K. Rao, and N. Verma, Weather-Based Crop Insurance in India, Policy Research Working Paper (Washington, DC: World Bank, 2012), <https://documents1.worldbank.org/curated/en/693741468269445619/pdf/WPS5985.pdf>.

¹⁷ ICICI Foundation, "Financial Inclusion," n.d.

Pradhan Mantri Fasal Bima Yojana (PMFBY) in India (2016)

A flagship agricultural insurance programme in India, the Pradhan Mantri Fasal Bima Yojana (PMFBY) uses an 'Area Approach Basis'¹⁸ to provide farmers with reasonably priced crop insurance against inevitable natural risks from pre-sowing to post-harvest. The programme includes oilseeds, food crops, horticulture, and commercial crops. Farmers without institutional credit are not required to participate, but those who have bank loans are required to do so. The Ministry of Agriculture oversees the programme, which has been redesigned to expedite claim processing and payment, enhance technology interventions, and provide states with greater flexibility in selecting risk covers and distributing premium subsidies. PMFBY aims to stabilize farm revenue, facilitate farmers' self-sufficiency in risk management, and encourage the adoption of contemporary farming techniques. The plan does not cover losses from riots, war, or nuclear hazards, but it does cover a variety of natural hazards and pests. It also seeks to use smartphones and remote sensing technologies to expedite the estimation of crop losses.¹⁹ In general, PMFBY seeks to uphold contemporary farming methods, maintain stable farmer incomes, encourage sustainable agricultural production, and ensure adequate financing for the agricultural sector to enhance competitiveness and food security. Through its comprehensive coverage and government support, PMFBY plays a significant role in mitigating the financial impact of agricultural disasters on farmers and promotes sustainable agricultural production in India.



¹⁸ Government of India, "Pradhan Mantri Fasal Bima Yojana (PMFBY)," 2020, <https://www.mygov.in/campaigns/pmfbby/>.

¹⁹ Sandeep Kaur, Hem Raj, Harpreet Singh, and Vijay Kumar Chattu, "Crop Insurance Policies in India: An Empirical Analysis of Pradhan Mantri Fasal Bima Yojana," *Risks* 9, no. 11 (2021): 191, <https://doi.org/10.3390/risks9110191>.

Philippines²⁰

Aside from the multiple-peril crop insurance (MPCI), the country also has an all-peril property cover for public assets, provided by the Government Service Insurance System General-Insurance Group (GSIS-IG), a state-owned entity. The insurance covers all property in which the government has an interest (e.g., government offices, hospitals, schools, and public markets).

Contingent credit for disasters is also in place, and insurance for public assets is in use. On 17 November 2021, the World Bank approved the Fourth Disaster Risk Management Development Policy Loan with a Catastrophe-Deferred Drawdown Option (CAT-DDO 4) of \$500 million for the Government of the Philippines. Through a CAT-DDO, the Philippines can access funds upon the declaration of a national state of calamity due to an imminent or ongoing natural catastrophe or upon the declaration of a state of public health emergency. The loan is available for three years and may be renewed for up to 15 years in total. All past CAT-DDOs have been successfully disbursed to support the Philippines in its recovery from disasters such as Tropical Storm Washi (2011), Tropical Cyclone Mangkut (2018), and the COVID-19 pandemic. The latest CAT-DDO 4 has also been disbursed after Typhoon Rai, which battered the country in December 2021. On 16 November 2023, a \$500-million development policy loan for the country was approved by the World Bank to finance the Philippines Disaster Risk Management and Climate Development Policy Loan with a Catastrophe Deferred Drawdown Option (DDO), which has set aside \$500 million that the Philippine government can immediately draw upon in times of disasters and health crises, mitigating their impact on the economy. Funds may be disbursed when the president declares a state of calamity in response to a disaster or public health emergency.

Catastrophe Bond.²¹ In November 2019, the World Bank issued two tranches of cat bonds to capital market investors, providing the Philippines with insurance coverage of up to \$225 million (\$75 million for earthquakes and \$150 million for tropical cyclones) for three years. The types of events that trigger a payout are predefined by the country's requirements. If and when a qualifying event occurs, the Philippines will issue a notice to an independent calculation agent to determine the insurance payouts. The World Bank will transfer the payouts to the Philippines as soon as a calculation report is available, within approximately one month for earthquake and five months for tropical cyclone events, without the need to assess real losses incurred by the country. The Philippines pays an insurance premium for the coverage, which the World Bank transfers to the cat bond investors. The premium is fixed during the life of the bond, removing the uncertainty of the cost.

²⁰ Philippines, Department of Finance, Annual Report 2023 (Manila: Department of Finance, 2023).

²¹ World Bank, "Case Study: The Philippines – Transferring the Cost of Severe Natural Disasters to Capital Markets," World Bank, n.d.

Mongolia

In 2006, the Government of Mongolia, with assistance from the World Bank, implemented a pilot programme in three provinces for an index-based insurance programme to address death rates in the livestock population. Shocks to animal well-being have devastating implications for the rural poor and the overall economy. The scheme combines self-insurance, market-based insurance, and social insurance. Herders pay a premium for a commercial risk product (base insurance product) with specified trigger thresholds for livestock mortality rates, whereas the government finances and provides a social safety net product (disaster response product). In addition, a syndicated pooling arrangement for insurance companies protects the domestic insurance market, as the government fully covers insured losses beyond the pool's financial capacity through a reinsurance treaty with the World Bank.

Mexico²²

Mexico has considerable capacity for financial resilience and disaster response based on a wide range of financial instruments for risk management and risk transfer, among which several different insurance schemes and the following funds and trusts stand out:

The **Natural Disaster Fund (Fondo de Desastres Naturales, FONDEN)** consists of the Emergency Fund (Fondo para la Atención de Emergencias FONDEN), the Natural Disaster Fund Programme of Branch of the Federal Budget, and the Natural Disaster Fund Trust. The Emergency Fund is a financial instrument for immediate and timely disaster response, providing relief, aid, and assistance to severely affected populations. Funds from FONDEN could be used for the rehabilitation and reconstruction of (i) public infrastructure at the three levels of government (federal, state, and municipal); (ii) low-income housing; and (iii) certain components of the natural environment (e.g., forestry, protected natural areas, rivers, and lagoons).

Natural Disaster Prevention Fund (Fondo para la Prevención de Desastres Naturales, FOPREDEN) includes the **Preventive Trust (Fideicomiso preventivo, FIPREDEN)**, aimed at promoting and strengthening preventive actions for disaster risk reduction (DRR), diminishing the effects and impacts of natural phenomena, as well as fostering DRR research. FIPREDEN provides resources to agencies and federal and state units for unscheduled preventive actions.

²² United Nations Development Programme (UNDP), Mexico: Country Case Study Report – How Law and Regulation Support Disaster Risk Reduction (New York: UNDP, June 2014); World Bank, FONDEN: Mexico's Natural Disaster Fund – A Review (Washington, DC: World Bank, 2012)

The Fund for Rural Assistance to Climatic Contingencies (Fondo de Apoyo Rural por Contingencias Climatológicas) is operated by the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) within its Natural Disaster Assistance Programme for the agricultural, livestock, and fisheries sector (Programa Atención a Desastres Naturales en el Sector Agropecuario y Pesquero, CADENA) as one of the components of the Disaster Management Prevention Programme (Programa de Prevención y Manejo de Desastres). This fund aims to provide assistance, through insurance, to mitigate the adverse effects of disasters on agricultural, livestock, aquaculture, and fisheries activities. The legal foundation for this fund is established under the Sustainable Rural Development Law, including Art. 129.

The Fund for Assistance to Micro, Small, and Medium Enterprises (Fondo de Apoyo para la Micro, Pequeña y Mediana Empresa (MIPYMES) (Fondo PyME), among many other modalities, provides resources to relieve the effects caused by disasters to affected firms. This facilitates timely attention in an emergency. The National Entrepreneur Institute (Instituto Nacional del Emprendedor, INADEM) operates the PyME Fund. It provides assistance to damaged firms through the Special Programme for Economic Reactivation in the event of contingencies (Programa especial de reactivación económica por contingencias).

The Federal Budget Law requires that an amount of no less than 0.4 percent of the annual federal budget should be available to FONDEN, FOPREDEN, and the Agricultural Fund for Hazards at the beginning of each fiscal year.

FONDEN resources are leveraged through market-based risk-transfer instruments. Despite a stable annual budget appropriation, funding needs arising from one or more disasters can cause a shortfall in any given year. To manage the volatility of demand for its resources, FONDEN is permitted to transfer risks through insurance and other risk-transfer mechanisms, such as catastrophe bonds. FONDEN is not, however, allowed to contract debt.

Mexico's First Sovereign Catastrophe Bond (2006)

The FONDEN employs a range of tools to assist local governments and organizations in responding to disasters, including risk transfer programmes and reserve funds. To transfer Mexico's seismic risk to the global capital markets, FONDEN issued a \$160 million catastrophe bond (CatMex) in 2006. Mexico decided to further diversify its coverage by pooling multiple risks across multiple regions after CatMex matured in 2009. Using the World Bank's recently established MultiCat Program, which assists sovereign and sub-sovereign entities in pooling multiple perils across multiple regions and reducing insurance costs, it issued a multi-peril catastrophe bond in October 2009.²³ With this bond, Mexico transferred a pool of disaster risk to the market for the first time; secured multi-year protection for the covered risks at a fixed price; and reduced potential pressure on public budgets. By leveraging the expertise of the insurance-linked securities market, Mexico effectively diversifies its risk and ensures access to timely funds for disaster management, reducing reliance on traditional post-disaster financing mechanisms.²⁴ This sovereign catastrophe bond not only enhances Mexico's financial resilience to disasters but also sets a precedent for other countries seeking innovative approaches to disaster risk financing and insurance.

²³ World Bank, A Case Study of Insuring Against Natural Disaster Risk in Mexico (Washington, DC: World Bank, 2015), <https://documents1.worldbank.org/curated/en/170311468056076924/pdf/81172-REVISED-Mexico-MultiCatBond-2015>.

²⁴ World Bank, Disaster Risk Financing and Insurance Case Study: Mexico MultiCat Bond (Washington, DC: World Bank, 2013), <https://openknowledge.worldbank.org/server/api/core/bitstreams/42f4a9ed-6f3d-5bbb-bb5b-e5c2cc6703ae/content>

Component for the Attention of Natural Disasters (CADENA) Mexico (2003)

In Mexico, disasters, particularly affecting agriculture, have increased in frequency and severity, with over 80 percent of economic losses occurring in the agricultural sector over the past two decades. Challenges include segmenting the farming sector, where small-scale farmers constitute a significant portion but face difficulties accessing affordable insurance due to high transaction costs. To address this, the Mexican government has categorized farmers into three groups and developed tailored agricultural insurance programmes: commercial farmers require insurance to finance, farmers able to pool risks and access credit, and small-scale, vulnerable farmers lacking access to credit or insurance. The CADENA Program, launched in 2003, operates as a crucial mechanism for disaster risk financing and insurance by providing formal parametric crop and livestock insurance solutions at the state level, primarily targeting small-scale, vulnerable farmers who lack access to traditional insurance or credit. It uses macro-level catastrophe, climatic, and agricultural index products to provide social safety net coverage, thereby replacing traditional post-disaster relief schemes with formal insurance solutions at the state level under the Ministry of Agriculture, Livestock, and Fisheries (SAGARPA).²⁵ By doing so, it replaces ad hoc post-disaster relief schemes with a structured insurance approach, mitigating the financial impacts of disasters on agriculture. This programme not only provides financial protection but also promotes resilience among vulnerable farming communities, contributing to Mexico's overall disaster preparedness and response capabilities.

Mexico Indemnity-based Excess of Loss Insurance for Public Assets

Mexico has established an innovative insurance scheme to lessen the financial damage that natural catastrophes cause to public property. This programme evaluates fiscal risks for the government by quantifying both explicit and implicit contingent liabilities. It does this by fusing historical data with simulated-loss data. It has an excess-of-loss insurance component based on indemnification that activates when disaster-related claims exceed a defined threshold. To increase resilience to disasters, Mexico's programme works in combination with risk reduction initiatives, such as strengthening early warning systems, while also prioritizing the protection of the government budget.²⁶ The indemnity-based coverage kicks in when disaster-related costs exceed a certain threshold, shielding the government from excessive financial burdens. Moreover, the programme's integration with risk reduction measures, such as supporting early warning systems, enhances resilience to disasters, further emphasizing its role in comprehensive disaster risk management and financial protection.

²⁵ World Bank, Mexico Agriculture Insurance Market Review (Washington, DC: World Bank, 2013), <https://documents1.worldbank.org/curated/en/124521468287160777/pdf/881000BRIOP1300urance04Pager0Cadena>.

²⁶ World Bank, Quantifying Contingent Liabilities Associated with Natural Disasters (Washington, DC: World Bank, 2013), <https://documents1.worldbank.org/curated/en/672271467997574054/pdf/97977-BRI-Box391499B-PUBLIC-Short-Note-1-Risk-Assessment-04Nov2013>.

Türkiye

Turkish Catastrophe Insurance Pool (TCIP-2000)

The Turkish Catastrophe Insurance Pool (TCIP) is a key mechanism for disaster risk financing and insurance, providing coverage against disasters such as earthquakes, floods, and landslides. In 2000, the Turkish government instituted a mandatory earthquake insurance system for all residential structures on registered urban land. This initiative aimed to shift the financial burden from the government to private insurers. To facilitate this transition, the World Bank provided crucial financial and technical support to establish the Turkish Catastrophe Insurance Pool (TCIP). The TCIP stands as a pioneering endeavour, becoming the world's first national catastrophe insurance pool among World Bank client countries. It offers standalone earthquake insurance coverage to homeowners and small-to medium-sized enterprises, marking a significant step towards bolstering disaster resilience and reducing the burden on government resources amid seismic risk. By transferring risk from individuals and businesses to a pooled system, TCIP significantly enhances Turkey's disaster preparedness and recovery efforts, ensuring swift and effective responses in times of crisis while fostering long-term resilience and sustainability.²⁷

Taiwan

Taiwan Residential Earthquake Insurance Program (2002)

The Taiwanese government established and promoted the Taiwan Residential Earthquake Insurance Program (TREIP) in response to the 1999 Chi-Chi Earthquake. TREIP offers basic insurance protection against earthquakes starting from 1 April 2002.

The programme serves as a vital mechanism for disaster risk financing and insurance by providing earthquake-specific coverage for residential properties. Homeowners who experienced earthquake damage can get financial assistance to improve the stability of their properties. The government established the Taiwan Residential Earthquake Insurance Fund (TREIF) and designated it as the central organization of this statutory insurance programme and the managing entity for the Risk Spreading Mechanism of Residential Earthquake Insurance to implement TREIF and provide homeowners with basic earthquake insurance protection.²⁸ This not only provides financial protection for individual

²⁷ World Bank, Disaster Risk Financing and Insurance Case Study: Turkish Catastrophe Insurance Pool (Washington, DC: World Bank, n.d.), www.gfdrr.org/drfi.

²⁸ Taiwan Residential Earthquake Insurance Fund (TREIF), "About TREIF," accessed February 4, 2026, <https://www.treif.org.tw/>

homeowners but also contributes to overall community resilience by encouraging earthquake-resistant construction practices and facilitating rapid recovery after seismic events. By pooling resources and spreading risk across a broad base, the programme enhances Taiwan's disaster preparedness and response capabilities, ultimately fostering a more resilient society.



Caribbean Catastrophe Risk Insurance Facility (CCRIF-2007)

The Caribbean Catastrophe Risk Insurance Facility, the world's first multi-country risk pool, was established in 2007 and was the first insurance product to successfully develop parametric policies backed by both traditional and capital markets. To enable the introduction of new products and expansion into new geographic areas, the facility underwent a restructuring in 2014 and became a segregated portfolio company (SPC), now known as CCRIF SPC. It is registered, owned, and operated in the Caribbean. The CCRIF SPC helps governments in the Caribbean and Central America mitigate the financial impact of natural-hazard catastrophes by providing short-term liquidity upon a policy activation. For tropical cyclones, earthquakes, excessive precipitation, the fisheries industry, and public utilities, CCRIF provides parametric insurance coverage. Through its parametric approach, CCRIF triggers payouts based on predetermined parameters such as wind speed or rainfall intensity, enabling swift and efficient response to disasters. By providing timely financial assistance, CCRIF helps member countries bridge the gap between immediate humanitarian needs and long-term recovery efforts, ultimately promoting resilience and sustainable development in the Caribbean. Moreover, CCRIF's risk pooling and reinsurance mechanisms enhance the affordability and availability of disaster insurance for small island states with limited resources, thus bolstering their capacity to manage and mitigate the impacts of disasters.²⁹



²⁹ CCRIF SPC, Annual Report 2022–2023 (Grand Cayman: CCRIF SPC, 2023), https://www.ccrif.org/sites/default/files/publications/annualreports/CCRIFSPC-Annual-Report-2022-2023_lowres



Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI-2007)

A regional initiative, the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) programme, was launched in 2007 to strengthen the Pacific region's financial resilience to disaster and climate change risks. The PCRAFI facility and the PCRAFI Technical Assistance Programme are the two main pillars of Phase II, which was started in April 2016. The holistic approach of PCRAFI helps countries better understand and quantify their vulnerability to natural hazards by facilitating the development of risk assessment tools, such as the Pacific Risk Information System (PacRIS). The Secretariat of the Pacific Community (SPC) is undertaking a project under the technical assistance programme that focuses on capacity building for the Hazard and Exposure Database. Through in-country surveys, enhanced data-collection capabilities, and case studies highlighting the value of risk information, this project seeks to update data in the Pacific Risk Information System (PacRIS) and ultimately enable nations to independently manage data and improve their future exposure.³⁰



Catastrophe Deferred Drawdown Option (CAT-DDO) of the World Bank (2008)

The World Bank's Flexible Loan product, the Drawdown Option (CAT-DDO), is designed to improve countries' crisis preparedness and responsiveness to natural catastrophes and public health emergencies. It offers swift disbursement contingency finance in the case of a disaster, providing liquidity up front while additional funding is raised. Approved prior to a disaster event, the CAT-DDO provides immediate liquidity once triggered, serving as early budget support while additional funds are mobilized. By disbursing quickly and efficiently, the CAT-DDO helps mitigate the financial impact of disasters, enabling governments to respond promptly to emergencies. This mechanism complements existing risk retention and transfer tools and provides early budget help as part of a larger risk management plan. The Disaster Risk Management Development Policy Loan with a Catastrophe-Deferred Drawdown Option (CAT-DDO) Project aims to improve technical capacity, support policy reforms, and fortify Serbia's institutional and legal framework for managing the financial and physical effects of disasters. The CAT-DDO also helps Serbia's catastrophe insurance industry grow by offering financial safety nets and short-term funding for emergency response.³¹

³⁰ World Bank, PCRAFI: Catastrophe Risk Assessment Methodology (Washington, DC: World Bank, 2013), <https://reliefweb.int/report/world/pacific-catastrophe-risk-assessment-and-financing-initiative-pcrafi-risk-assessment>.

³¹ World Bank, A Product Note of IDA Catastrophe Deferred Drawdown (Cat-DDO) (Washington, DC: World Bank, 2018), <https://thedocs.worldbank.org/en/doc/563361507314948638-0340022017/original/productnotecatddoidaenglish2018>



Asia Pacific Disaster Response Fund by Asian Development Bank (2009)

Established in 2009, the Asia Pacific Disaster Response Fund (APDRF) provides developing member countries (DMCs) of the Asian Development Bank (ADB) with loans that can be disbursed promptly for life-saving measures in the immediate aftermath of significant natural catastrophes. This funding helps DMCs augment relief from other donors during emergencies and help restore life-saving services to impacted individuals. This mechanism enhances countries' crisis-response capabilities, particularly when emergencies exceed their capacity to cover immediate expenses. Additionally, APDRF supports DMCs in mitigating the financial impacts of disasters by providing essential funding for urgent relief efforts, thereby contributing to the broader objectives of disaster risk management and resilience building in the Asia-Pacific region.³² Assistance is eligible if certain emergency requirements are met, including a disaster, an official declaration of emergency beyond the nation's capacity to respond, and the confirmation by the UN humanitarian/resident coordinator (H/RC) of the disaster's scope and consequences. The geographic scope of the damage, preliminary estimates of the number of dead and displaced, response capability, and the cumulative effect of previous catastrophes on the country's ability to respond are among the factors that influence the size of the award.³³



Contingent Credit Facility for Natural Disaster Emergencies (CCF) by Inter-American Development Bank (IDB) (2009)

One of the Inter-American Development Bank's (IDB) most important tools for assisting member nations in managing the financial risks associated with natural catastrophes is the Contingent Credit Facility (CCF) for Natural Disaster Emergencies. It functions as a critical mechanism for disaster risk financing insurance, providing IDB member countries with access to contingent loans following verified disaster events. It provides contingent loans that are repaid in the event of a catastrophic event, providing funds for essential amenities and humanitarian relief. Countries need to have a Comprehensive Natural Disaster Risk Management Programme (CDRMP) in place in order to be eligible for the CCF. The CCF, which incorporates parametric triggers based on preset event characteristics, symbolizes the IDB's approach towards proactive disaster risk management. It focuses on giving prompt financial support during the emergency phase of disasters.³⁴

³² Asian Development Bank, "Funds and Resources — Asia Pacific Disaster Response Fund," accessed February 4, 2026, <https://www.adb.org/what-we-do/funds/asia-pacific-disaster-response-fund-apdrf>

³³ NDC Partnership, "Asia Pacific Disaster Response Fund," accessed February 4, 2026, <https://ndcpartnership.org/knowledge-portal/climate-funds-explorer/asia-pacific-disaster-response-fund-apdrf>

³⁴ G. Collich, R. Rosillo, J. Martínez, D. J. Wald, and J. J. Durante, "Financial Risk Innovation: Development of Earthquake Parametric Triggers for Contingent Credit Instruments," in *Natural Disasters and Climate Change*, ed. J. Durante and R. Rosillo (Cham: Springer, 2020), https://doi.org/10.1007/978-3-030-43708-4_1..



South-eastern Europe and Caucasus Catastrophe Risk Insurance Facility (SEEC CRIF) (2009)

To address the lack of insurance coverage for natural hazards in Southeast Europe (SEE), a region highly vulnerable to disasters, Europa Reinsurance Facility Ltd. collaborated with the World Bank to implement the Southeastern Europe and Caucasus Catastrophe Risk Insurance Facility (CRIF). The project launches operations to provide small enterprises and homeowners with catastrophic insurance coverage through regional insurance providers, with the funding totalling more than \$12 million.³⁵ The project's goals are to develop new insurance products for weather and catastrophe risk, streamline insurance procedures, and raise public awareness of disaster risk in the SEE member nations. The project comprises two components: participation in the SEEC CRIF, which supports countries in their efforts to join Europa Re, and the provision of technical assistance from donors, delivered by Europa Re. This assistance includes risk mapping, product design, weather monitoring, and legislative reforms.³⁶ The project's ultimate goal is to make financial insurance against climate change and geological risks in the area more accessible to government organizations, businesses, farmers, and households.



Global Index Insurance Facility (GIIF) launch by the World Bank, International Finance Corporation (IFC), and Private Sector (2009)

The European Union, Japan, and the Netherlands support the Global Index Insurance Facility (GIIF), managed by the World Bank Group, which aims to improve access to financing for microfinance institutions, small-scale farmers, and microentrepreneurs in developing countries. GIIF was established in 2009 with a primary focus on sub-Saharan Africa, the Caribbean, and the Asia-Pacific region. It uses index insurance solutions to manage catastrophic risks in agriculture, food security, and catastrophe risk reduction.³⁷ Through its initiatives, GIIF has enabled billions of dollars in funding, millions of contracts affecting tens of millions of people globally, and promoted resilience and financial inclusion in disadvantaged communities.³⁸ A crucial component of GIIF is index-based insurance, which eliminates the need to estimate individual losses by relying on predetermined indices to trigger payouts, thereby enabling faster claims processing. Index-based insurance can help mitigate catastrophic risks associated with agriculture, food security, and disaster risk reduction. This approach enables faster claims processing and ensures timely financial assistance to disaster-affected individuals, thereby promoting resilience and financial inclusion in vulnerable communities worldwide.

³⁵ Global Environment Facility (GEF), "Regional – Southeastern Europe and Caucasus Catastrophe Risk Insurance Facility (CRIF)," 2012, <https://www.thegef.org/newsroom/news/regional-southeastern-europe-and-caucasus-catastrophe-risk-insurance-facility-crif>.

³⁶ World Bank, "Southeast Europe and Caucasus Catastrophe Risk Insurance Facility (Serbia and Macedonia)," 2024, <https://projects.worldbank.org/en/projects-operations/project-detail/P110910>.

³⁷ The World Bank. Global Index Insurance Facility – Overview. 2024. <https://www.indexinsuranceforum.org/overview>.

³⁸ InsuResilience Global Partnership. The Global Index Insurance Facility (GIIF). 2017.



African Risk Capacity Agency (ARC) (2012)

The African Risk Capacity (ARC) Group comprises ARC Agency, a Specialized Agency of the African Union, founded in 2012, and ARC Insurance Company Limited (ARC Ltd), a hybrid mutual insurer and the commercial affiliate of the Group, founded in 2014. The ARC Group, comprising ARC Agency and ARC Ltd, was founded to improve African governments' planning, preparation, and response to epidemics and disasters caused by extreme weather events. With an emphasis on inclusivity and gender equality, ARC offers member states facilities for risk pooling and transfer,³⁹ early warning systems, and capacity building to enhance resilience to natural hazards such as tropical cyclones and droughts. ARC seeks to establish pan-African climate response systems that shift the cost of climate risks from governments to ARC, thereby ensuring more timely and equitable disaster aid through modern financing mechanisms such as risk pooling and transfer. Through ARC, member states can access readily available response funds, reducing reliance on external aid and ensuring timelier and more equitable disaster relief. By merging traditional disaster relief approaches with modern financial mechanisms such as risk pooling and transfer, ARC offers a sustainable African-led strategy for managing extreme climate risks and disease outbreaks, thereby promoting resilience and reducing the financial burden on governments and vulnerable populations.



Southeast Asia Disaster Risk Insurance Facility (SEADRIF) (2019)

Through SEADRIF, ASEAN nations can enhance their financial resilience to climate and catastrophe risks and access to financing options for disaster risk. SEADRIF was founded in Singapore as a trust to own a general insurance business. It provides financial and consultancy services for rapid post-disaster funding, with an emphasis on flood risk in Myanmar, Cambodia, and Lao PDR. It is also aiming to take its financial solutions to other ASEAN nations with middle-class incomes, such as Indonesia.⁴⁰ SEADRIF facilitates cooperative approaches to improving preparedness for climate and disaster risks and helps member countries prevent catastrophes from becoming crises by pooling resources and knowledge. With the COVID-19 pandemic adding to the stress of catastrophes and climate change intensifying extreme weather events, SEADRIF offers customized programmes and products that address a range of needs across the ASEAN region at varying stages of development. Through programmes like the ASEAN+3 Disaster Risk Financing Initiative, SEADRIF also provides a forum for information sharing, the development of technical solutions, and the investigation of insurance and other financial products.⁴¹

³⁹ African Risk Capacity. About ARC. <https://www.arc.int/about>.

⁴⁰ World Bank, "Southeast Asia Disaster Risk Insurance Facility (SEADRIF) Technical Briefing for Japanese Insurance Industry," 2019, <https://www.worldbank.org/en/news/feature/2019/01/17/southeast-asia-disaster-risk-insurance-facility-seadrif-technical-briefing-for-japanese-insurance-industry-drmhubtokyo>.

⁴¹ World Bank, Project Information Document on Southeast Asia Disaster Risk Insurance Facility (SEADRIF): Strengthening Financial Resilience in Southeast Asia (Washington, DC: World Bank, 2019), <https://documents1.worldbank.org/curated/en/772221601306153071/pdf/Project-Information-Documents-Southeast-Asia-Disaster-Risk-Insurance-Facility-SEADRIF-Strengthening-Financial-Resilience-in-Southeast-Asia-P170913>



Pandemic Emergency Financing Facility of the World Bank (2016)

The Pandemic Emergency Financing Facility (PEF) – a World Bank-managed mechanism that is now officially closed – was designed to provide an additional source of financing to help the world's poorest countries respond to cross-border, large-scale outbreaks. The PEF complemented the much larger role that IDA, the World Bank's fund for the poorest countries, and other international organizations and donors played in financing outbreak response. The PEF's design was unique in that it allowed payments to be sent directly through its cash window or, once triggered, through its insurance window to governments and frontline responder organizations that had been pre-approved, such as UNICEF and WHO.⁴²



Central Emergency Response Fund (CERF) established by the UNGA (2005)

The Central Emergency Response Fund (CERF), which was established by the United Nations General Assembly (UNGA) in 2005 as the United Nations' global emergency response fund, enables humanitarian actors to provide life-saving assistance to the most vulnerable people at the most appropriate time and location. CERF funding enables UN agencies and partners to jointly initiate relief efforts in emerging or escalating crises before other funding sources become available.⁴³ It serves as a crucial mechanism for disaster risk financing and insurance by providing rapid, predictable funding for humanitarian response to sudden-onset emergencies. Additionally, CERF is a strategic tool for addressing significant budget gaps in emergencies that receive insufficient funding. Furthermore, the flexible financing mechanism of CERF allows for quick allocation of resources based on assessed needs, enhancing the effectiveness and efficiency of humanitarian interventions in disaster-affected areas.⁴⁴ Through its proactive approach to financing emergency response, CERF plays a vital role in strengthening global disaster preparedness and resilience, ultimately contributing to more effective disaster risk management worldwide.

⁴² World Bank and World Health Organization, Report on Pandemic Emergency Financing Facility (PEF) Framework (Washington, DC: World Bank, 2022), <https://thedocs.worldbank.org/en/doc/24dce6fdf04a1313a07f7c24f539f4c7-0240012017/pandemic-emergency-financing-facility-pef-framework>.

⁴³ United Nations Central Emergency Response Fund (CERF), "About CERF," accessed February 4, 2026, <https://cerf.un.org/>.

⁴⁴ United Nations, Annual Report of CERF 2022 (New York: United Nations, 2022), https://cerf.un.org/sites/default/files/resources/CERF_ARR_2022_20230904.

Annex B: Various Risk Financing Mechanisms, Their Usage, Advantages, and Disadvantages⁴⁸

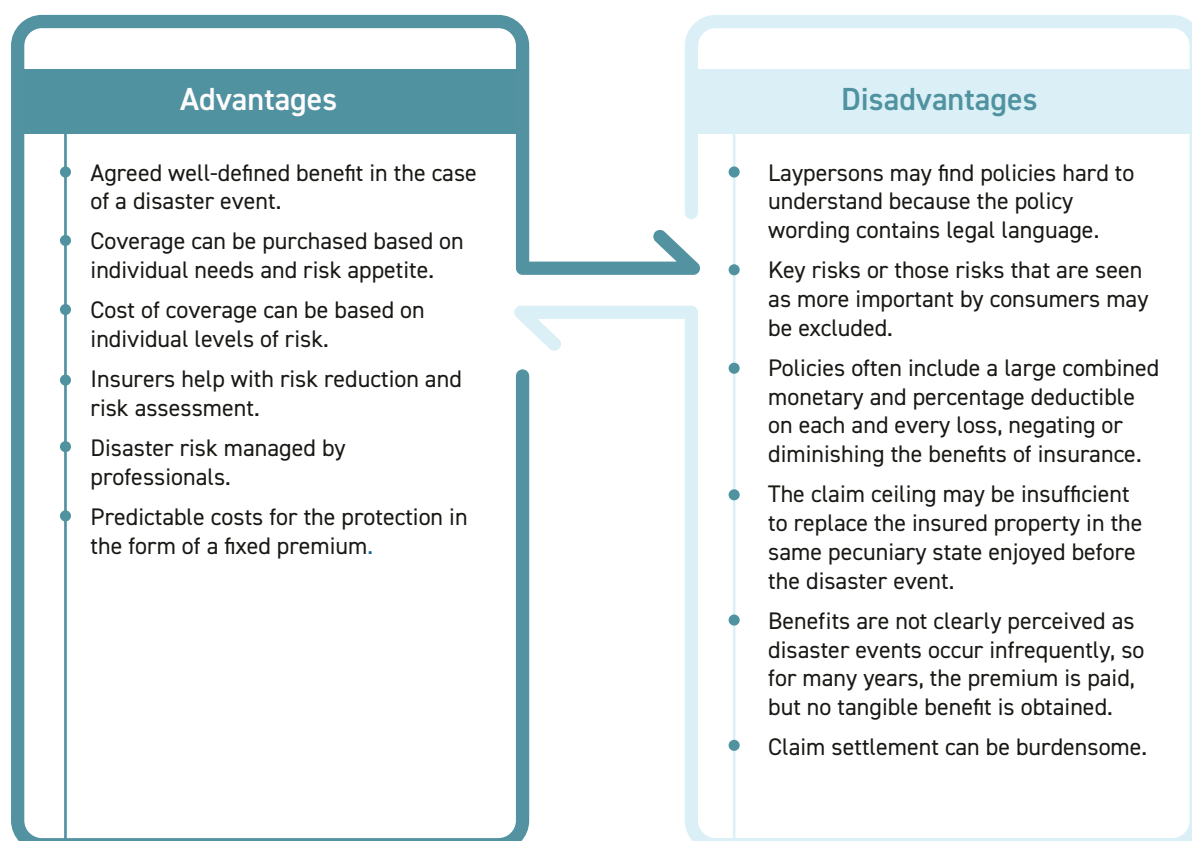
1 Disaster Insurance

Definition

Insurance is a financial transaction by which the insured, a physical or legal person, transfers to an insurer their natural hazard risk in exchange for a payment (insurance premium). Insurance providers are licensed and supervised insurance companies, captive insurers, and insurance pools, entities exclusively dedicated to insurance activity. In some jurisdictions, non-licensed insurance activity exists. Depending on how this activity is controlled, it could result in an inability to fulfil the claim payment after a disaster due to insufficient funds by the entity acting as an unlicensed insurer.

Main usage

Major disaster risk refers to a low-frequency, high-severity event (e.g., earthquake, flood, cyclone, tsunami, and drought). Although exposure and vulnerability to these events can be reduced, significant residual risk may remain, making insurance a viable risk management strategy.



Preconditions

- Disaster risk awareness.
- Enabling government policy with respect to the development of disaster insurance instruments, potentially including mandatory insurance cover and tax benefits on the premium payments.
- Disaster risk product availability and affordability, including products for corporates, individual households, and low-income populations.
- Credibility of the insurance sector, including the regulatory environment, the solvency and reputation of the insurance markets, and the availability of support from professionals such as actuaries, risk assessors, auditors, brokers, and loss adjusters.
- Complementary social protection solutions, allowing low-income populations to enjoy social protection or support in the acquisition of insurance, while avoiding crowding out insurance solutions for people who can afford premiums.
- No unlicensed competition. Insurance credibility and resilience depend on all insurance providers being licensed and supervised by the insurance regulator.

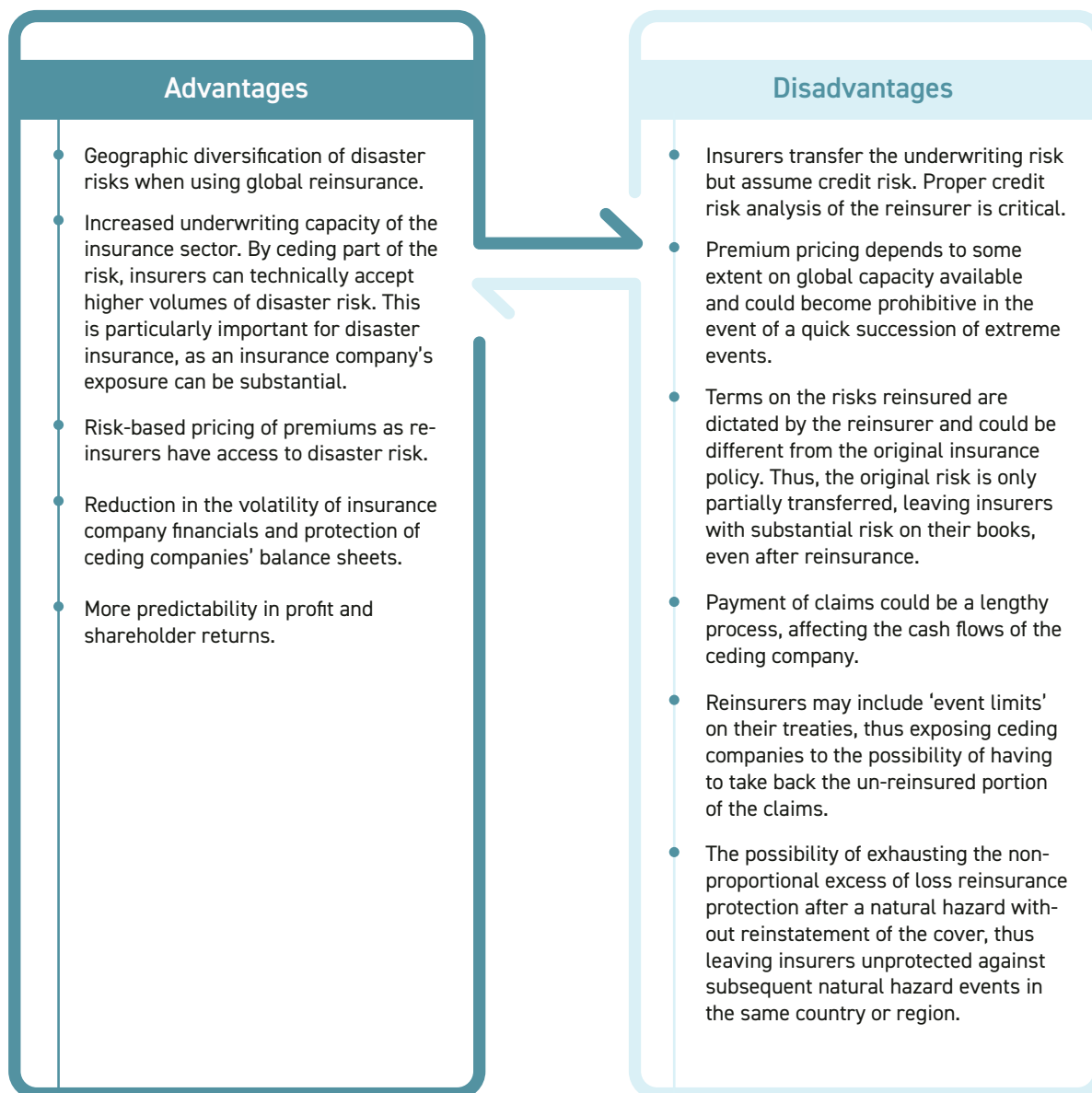
2 Disaster Reinsurance

Definition

Reinsurance is a financial transaction by which disaster risk and other insured risks assumed by an insurer in the original insurance policy are transferred (ceded) from the insurance company (cedent) to a reinsurance company (reinsurer) in exchange for a payment (reinsurance premium). Providers of reinsurance are professional reinsurers, which are entities exclusively dedicated to the activity of reinsurance. In most jurisdictions, however, insurance companies can also participate in reinsurance (Wehrhahn 2009). Reinsurers can effectively assume significant disaster risk by diversifying across the world and maintaining substantial capital to support the assumed risks.

Main usage

Major disaster risk refers to a low-frequency, high-severity event (earthquake, floods, cyclone, tsunami, drought, etc.). This risk is difficult to diversify at the primary insurer level. Hence, without additional risk-transfer options, insurers would not be in a financial position to accept this type of risk. Insurers mitigate disaster risk on their balance sheets by entering into reinsurance agreements.



Preconditions

- Sound supervision of the insurance and reinsurance markets to guarantee effective products and timely claims payments.
- Availability of international reinsurers interested in acting in the given country.
- Availability of data and risk maps.
- Minimum credit rating of the reinsurers by reputable rating agencies such as AM Best, Fitch, and Standard & Poor's Global Ratings.
- Appropriate supervision of reinsurance brokers operating in the region/country.

3 Insurance-Linked Securities

Definition

Insurance-linked securities (ILS) are investment instruments that transform insurance risk into transparent, tradable capital-market products. Investors accept insurance risk in exchange for a higher rate of return as compared with other securities that are free of that risk. The insurance risk materializes when a predefined disaster event occurs, such as an earthquake or tropical cyclone of a certain intensity. ILS includes categories like catastrophe bonds, longevity or mortality bonds, fully collateralized reinsurance agreements, and industry loss warranties.

Main usage

Catastrophe or cat bonds and other types of ILS are usually issued to provide (re)insurance coverage for insurers, reinsurers, governments, and corporations. ILS offers protection from new pools of capital separate from traditional reinsurers, such as hedge funds and pension funds. Investor capital provides collateralized cover. The capital is held in a segregated collateral account with dedicated funds available to make a payment in the event of a qualifying event. This virtually eliminates the credit risk inherent in traditional (re)insurance (Swiss Re 2012).

Advantages

- Immediate access to funds once the trigger event has been verified.
- Limited concern about counterparty credit in the event of an extremely large event as the claim amount is fully collateralized.
- Predictable budgetary costs for the issuer of the bonds.
- Tailor-made triggers to cover individual disaster risk contexts.
- A diversified source of disaster risk financing, which is especially beneficial when there is shortage of retrocession capacity or complex pricing cycles in traditional reinsurance markets.
- Multiyear pricing stability (terms of three to five years are typical for cat bonds).
- For investors, a source of investment that is uncorrelated to broader cycles in financial market performance, resulting in a higher degree of portfolio diversification.

Disadvantages

- Complexity of the product. Securities are already complex, and adding triggers tied to underwriting risks further complicates the instrument's structure.
- Costs may be relatively high if the volume of issuance is small. Transaction size range from approximately \$100 million to \$750 million or \$1 billion (Swiss Re 2012).
- Basis risk exists as the triggers might not be totally correlated with the actual loss suffered.
- Investor appetite may differ from the desired triggers.
- Triggers may be difficult to assess.

Preconditions

- Sophisticated securities markets that can issue ILS.
- Sophisticated investors looking to diversify their investments away from traditional forms of market risk.
- Transparent product structures.
- Transparent and robust disaster risk models.
- Clearly defined triggers.
- An enabling government policy including tax benefits for ILS investors, regulations that allow insurers, and reinsurers to use ILS for capital relief, among others.
- Attractive returns for investors in the ILS markets.
- Credibility of the securities sector, including with regard to the associated regulatory environment, credibility and reputation of sponsors, and the availability of professionals such as broker-dealers, rating agencies, actuaries, and auditors.

4 Agricultural Indemnity Insurance

Definition

Agricultural indemnity insurance is a type of insurance that indemnifies the insured person against pure agricultural loss (i.e., crop or livestock). The loss is verified by a loss assessment process. The insured person could be a farmer, a farmer group, or an agricultural lender whose delinquency risk depends on agricultural output.

The following forms of agricultural indemnity insurance products are presently popular:

- 1 **Single-risk insurance:** Covers against one peril or risk (e.g., drought).
- 2 **Combined (peril) insurance:** Covers a combination of several risks (two or more risks, mostly with hail as basic cover). In some countries, this type of insurance is also called multi-risk insurance.
- 3 **Yield insurance:** Provides a yield guarantee, based on regional average yield or on individual historic yield, covering the main risks affecting yield (e.g., drought). In some countries (e.g., the United States), this type is also called combined or multiperil insurance.
- 4 **Revenue insurance:** Combines yield and price risks coverage in a single insurance product. It can be product-specific or whole farm.
- 5 **Farm-income protection insurance:** Covers losses to future income (e.g., future droughts) based on investments in long-term production, thereby reducing reliance on government assistance in times of need and building farmers' business resilience. It includes yield and price risks as well as production costs. Usually, this type of insurance is not product-specific; instead, it covers whole-farm income.
- 6 **Whole-farm insurance:** Consists of a combination of guarantees for different agricultural types of production on a farm. Depending on the coverage selected, the guarantees, it can be whole-farm yield, revenue, or income insurance (EU 2008).

Main usage

Agricultural indemnity insurance provides coverage for farmers and agricultural lenders against losses of crops or livestock. When purchased by agricultural lenders, it can also increase their appetite to lend to farmers who are not otherwise creditworthy and to offer better terms than for uninsured risks.

Advantages

- **Low basis risk:** Indemnity insurance in comparison with index insurance has low basis risk (i.e., the claim amount nearly matches the actual loss suffered).
- **Less data requirement:** Indemnity insurance requires less data, as compared to index insurance, for the design and development of products.
- **Reasonably transparent verification processes:** Losses are verified on the ground, usually in the presence of the insured farmers, though entailing some level of subjectivity.
- **Transparent settlements:** Payouts are based on the scale of damage and losses experienced, making settlements easy to understand and communicate.

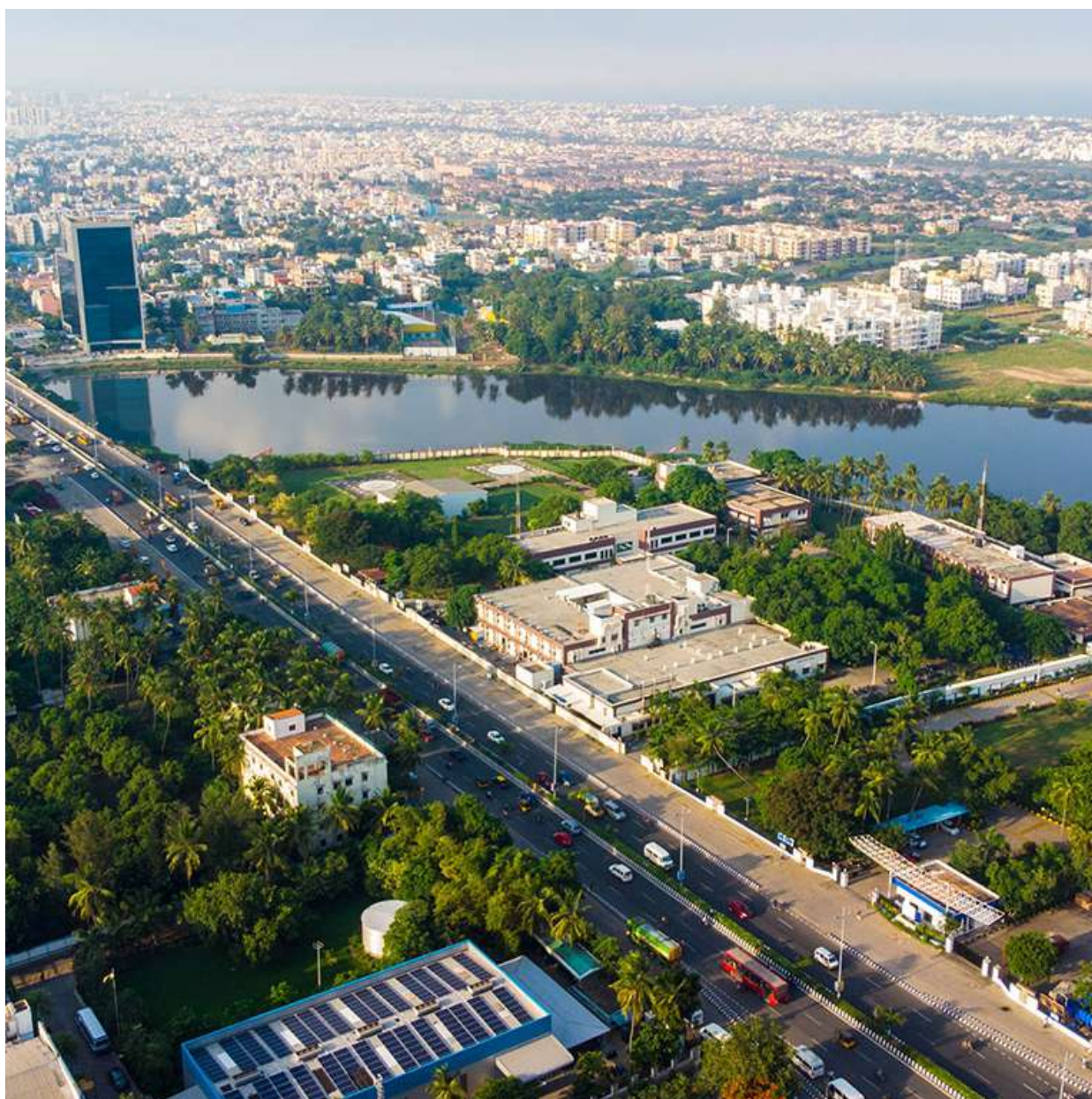
Disadvantages

- **Onerous assessment processes:** As a claim is paid after assessing each loss, the loss assessment process can be onerous and costly. However, modern and affordable technology can reduce the time for loss assessment, keeping costs in check. Technology-based tools can also provide corroborative information to reinforce human loss assessment activities.
- **Costly assessments:** The onerous loss assessment process implies high assessment costs.
- **High risk of adverse selection and moral hazard:** Claim payments often rely on crop-cutting experiments, leaving room for manipulation. Adverse selection (i.e., the purchase of insurance by farmers who are more likely to experience claims) is more likely with indemnity than with index-based insurance. Moral hazard (i.e., farmers acting in a manner that leads to greater chances of the claim becoming payable) is also more likely with indemnity than with index-based insurance.

Preconditions

- **Historical loss, modelled loss, and exposure data:** This information is required for several aspects of the product design, product evaluation, and product pricing processes. Insurance can work for risks with low frequency and high values, but the product must be designed so that risks with higher frequency and lower values are not transferred to the insurer; instead, they are retained — and ideally reduced — through risk-reduction efforts of the farmer.
- **Subject specialists:** Worthy products are usually developed with assistance from subject specialists. It is, therefore, important to ensure the product development team has access to the required expertise, either internally or externally (e.g., agronomists, modellers, underwriters, and actuaries).
- **Distribution channels:** Efficient distribution channels lead to low administrative costs for underwriting and claim settlement. The insurer may have a captive distribution channel (e.g., its own sales force to distribute credit-linked insurance for agricultural risks). The insurance product's sales process often needs to be embedded within the core business activities of the insured.

- **Availability of reinsurance:** Crop and livestock claims depend upon weather and other natural hazards, which can affect the entire region of coverage in a relatively short time span. This can lead to large, often covariate losses for the insurer and greater capital requirements to demonstrate solvency. Reinsurers can accept such risks by covering geographically diverse regions over long periods of time within their already diversified lines of business. Therefore, reinsurance capacity is necessary for agricultural insurance, which inherently faces large, covariate risks.
- **Regulatory support:** Regulation can support agricultural index-based insurance in many ways: (i) by setting lighter solvency requirements due to the extremely short tailed losses, if that is not the case under the existing solvency requirements; (ii) by providing a prompt redress mechanism on claim settlement; or (iii) by setting up data infrastructure and coordinating investment in data as a public good.



5 Agricultural Index and Parametric Insurance

Definition

Agricultural parametric insurance is a form of insurance that *ex ante* agrees to make a payment upon the occurrence of a trigger observation or event linked to the loss, rather than indemnifying the pure agricultural loss (i.e., crop or livestock). The trigger observation could be a decrease in average yield or prices in a predefined area — area yield index insurance or a trigger event based on weather-based indexes, satellite images, and so on. In developing such products, it is necessary to understand the thin dividing line between parametric insurance and index-based insurance. A parametric insurance product typically works on a binary parameter with only two possible outcomes (e.g., death or contracting a critical illness). In such cases, either a full payout or no payout is made as only two outcomes are possible. In contrast, index-based insurance is offered based on parameters that typically have multiple outcomes (e.g. wind velocity and precipitation levels) and can result in a graded scale of payouts. In such cases, claims are often linked to the trigger in a gradual manner (e.g., the farther above the observation from the trigger, the higher the claim payout) until a pre-agreed ceiling is reached. The insured person could be a farmer, a farmer group, or a lender whose delinquency risk depends on agricultural output.

The following forms of agricultural indemnity insurance products are presently popular:

- 1 **Area yield index insurance:** Indemnities are computed from the decrease in the average yield over an area without ascertaining the crop output of individual farmers.
- 2 **Area revenue index insurance:** Indemnities are computed from the decrease in the production of the average yields and prices in an area (EU 2008), without ascertaining crop output and prices of individual farmers.
- 3 **Indirect index insurance:** Indemnities are based on indexes of yields or vegetation that are computed from weather-based indexes, satellite images, and others (EU 2008).

Main usage

Agricultural parametric insurance provides security for farmers and agricultural lenders by eliminating subjectivity in loss verification and reducing claim settlement time. When purchased by agricultural lenders, it can also increase their appetite to lend to farmers who are not otherwise creditworthy and to offer them better terms.

Advantages

- **Low moral hazard:** As the amount of payment is unaffected by the loss experienced, insured farmers (both crop and livestock) have an incentive to act in a manner that minimizes their losses, reducing issues of moral hazard.
- **Low adverse selection problem:** Similarly, parametric insurance reduces the risk of adverse selection as payouts are based on widely available information, rather than on individual loss experience and related risk about which insurance companies may not have complete information.
- **Easier loss assessment:** Since the claim payment is dependent on a trigger, efforts in assessing losses (e.g., deploying loss assessors on-site and seeking inputs) are substantially minimized.
- **Prompt claim settlement:** As actual loss assessment is not needed, claim settlement can be prompt after reading off the index.

Disadvantages

- **Basis risk:** Index-based insurance, unlike indemnity insurance, carries 'basis risk'. This is the risk that the index measurements that trigger the insurance payout will not match the actual loss experienced. The payout could be less or more than the expected loss. Basis risk can reduce customer satisfaction and affect the continuity of an insurance programme.
- **Model risk:** If robust modelling tools and techniques are not used, the loss frequency results may be incorrect, leading to inappropriate pricing and, in turn, directly affecting client satisfaction and the uptake of insurance.
- **Substantial data requirements:** Rate making and trigger definition require a large amount of weather and crop yield data. Insufficient data can lead to incorrect decisions on rate making and product design.
- **Complexity:** Farmers may face difficulties in comprehending the linkage between triggers and losses and the overall benefits of index-based insurance.
- **High product development costs:** Subject experts and data infrastructure are required for the design of parametric insurance, thus increasing product development costs.

Preconditions

- **Historical and modelled weather data:** This information is required for several stages of product design, evaluation, and pricing. If such information is not available, designing a robust product will not be feasible.
- **Subject experts:** Valuable products are usually designed with assistance from subject specialists. It is important to make sure that the product development team is multi-skilled (e.g., in crop agronomy and statistical modelling) and has the necessary experience and expertise to develop the required products.
- **Historical and modelled loss data:** Especially for area yield index insurance, historical and modelled loss data are essential in pricing the product and determining the trigger.

- **Real-time hazard data:** Real-time hazard data are required to provide prompt payouts and maintain customer satisfaction.
- **Product design capabilities:** High-quality product design capabilities must be available to the insurer, either internally (in the long run) or externally (in the short run).
- **Regulatory and supervisory support:** Regulation can support agricultural index-based insurance in many ways:
 - By setting lighter solvency requirements due to the extremely short-tailed losses, if it is not the case in the existing regulations.
 - By recognizing index insurance, which could otherwise be argued as a 'derivative' product.
 - By setting up data infrastructure and coordinating investment in data as a public good, or
 - By setting up a supervisory mechanism that emphasizes the education of farmers on parametric products.
- **Distribution channels:** Proper distribution channels are required to help ensure low administrative costs for underwriting and claim settlement.
- **Availability of reinsurance:** Index insurance is normally used to transfer covariant risks that can affect a whole country or region at the same time, necessitating access of insurers to sufficient reinsurance capacity.
- **Weather infrastructure:** A sufficient network of tamper-proof weather stations and satellite imaging infrastructure is required to capture data regularly and accurately.
- **Animal mortality rates:** In the case of mortality index-based livestock insurance, historical animal mortality rates (including exposure and death events) by species, time, and geography are necessary.



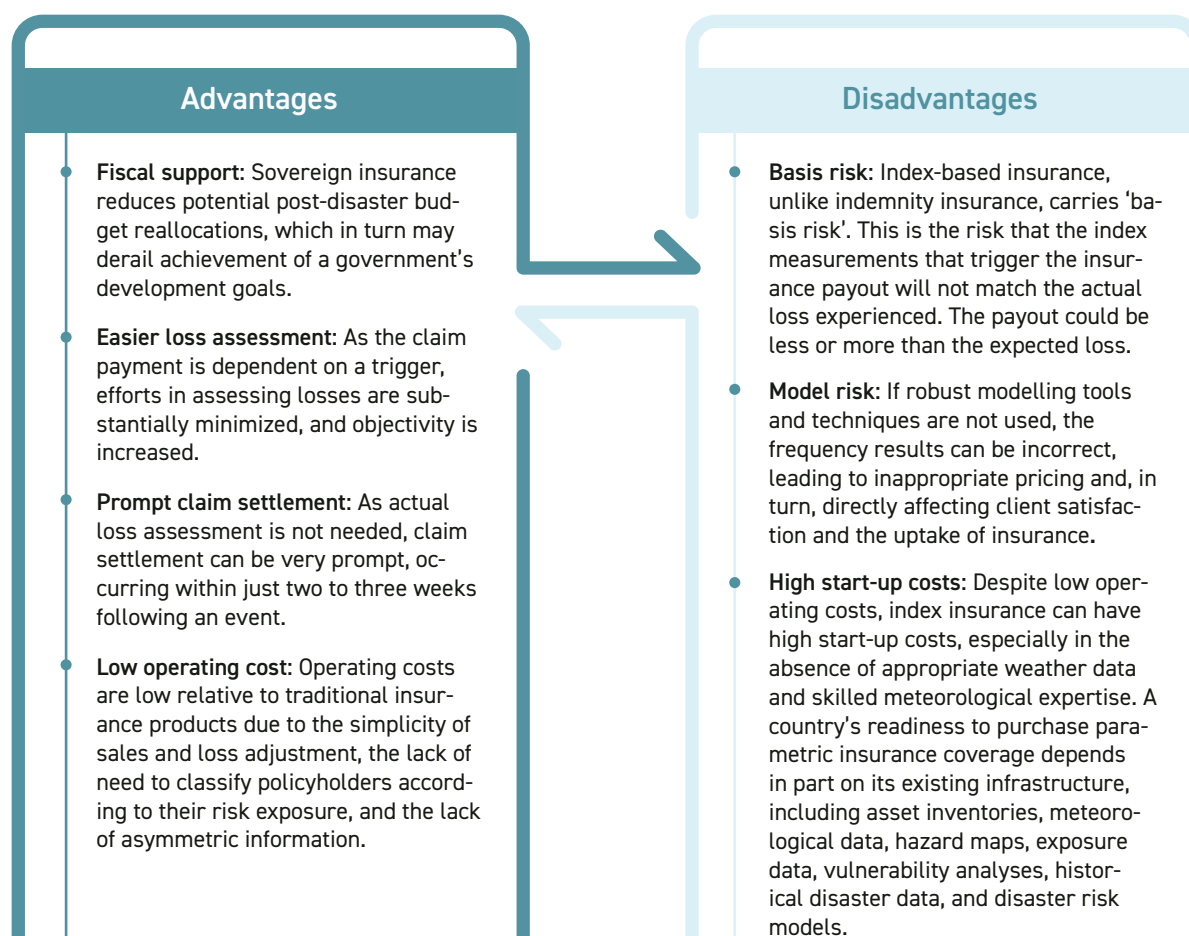
6 Sovereign Parametric Insurance

Definition

Like any parametric insurance, sovereign parametric insurance *ex ante* agrees to make a payment upon the occurrence of a trigger observation, or an event linked to the loss, rather than indemnifying the pure loss. It may be purchased by the government of a sovereign state and works on the usual insurance principles of premium payment to cover risks. Trigger observations are specified intensities of natural hazards at a specified location (e.g., rainfall level, wind speed, seismic shocks measured on the Richter scale) as measured by an independent agency. Claim payouts could be linear (i.e., gradually increasing claims paid as the actual observation moves beyond the parametric trigger) or categorical (i.e., payment of a fixed sum on the breaching of the defined parametric trigger).

Main usage

Parametric insurance may be used to provide security to a country's fiscal position while reducing the element of subjectivity in loss verification and time to settle claims. It also reduces the post-disaster fiscal stress on the insured country, hence smoothing government spending. Parametric cover is suitable for low-frequency, high-severity events.



- **Low moral hazard:** As the amount for payouts is unaffected by the loss experienced, governments have an incentive to act in a manner that minimizes losses, reducing issues of moral hazard.

- **Data requirements:** Rate making and trigger definition require a large amount of data, such as on exposed assets (including public assets), past and modelled hazard events, and weather. The absence of data can lead to incorrect decisions on rate making and product design.

Preconditions

- **Understanding of disaster risk:** Parametric cover is best applicable to very low frequency, high-severity events.
- **Data infrastructure:** Weather- and seismology-related information is required for several stages of product design, evaluation, pricing, and implementation. Information should be capable of independent verification using different tools. For example, satellite images can complement a primary weather station's information regarding precipitation. If this type of information is not available, it may not be possible to design an appropriate product.
- **Subject experts:** Valuable products are usually designed with assistance from subject specialists. It is important to ensure the product development team is multi-skilled and has the required experience and expertise. Often, there is a need to involve reinsurance companies interested in underwriting the cover to provide domain expertise.
- **Historical and modelled loss data:** Historical and modelled loss data are essential in pricing the product as well as in defining the trigger. Insufficient or inappropriate data could lead to gaps in coverage or other serious product-related issues.
- **Real-time hazard data:** In the absence of real-time data, it is difficult to gauge the amount of claim payment in a timely manner.
- **Frequency and accuracy of recording data:** Weather stations and satellite imaging infrastructure need to capture data regularly and accurately, and be highly resistant to any form of tampering. This type of infrastructure is critical to assessing whether a particular area has breached the trigger.

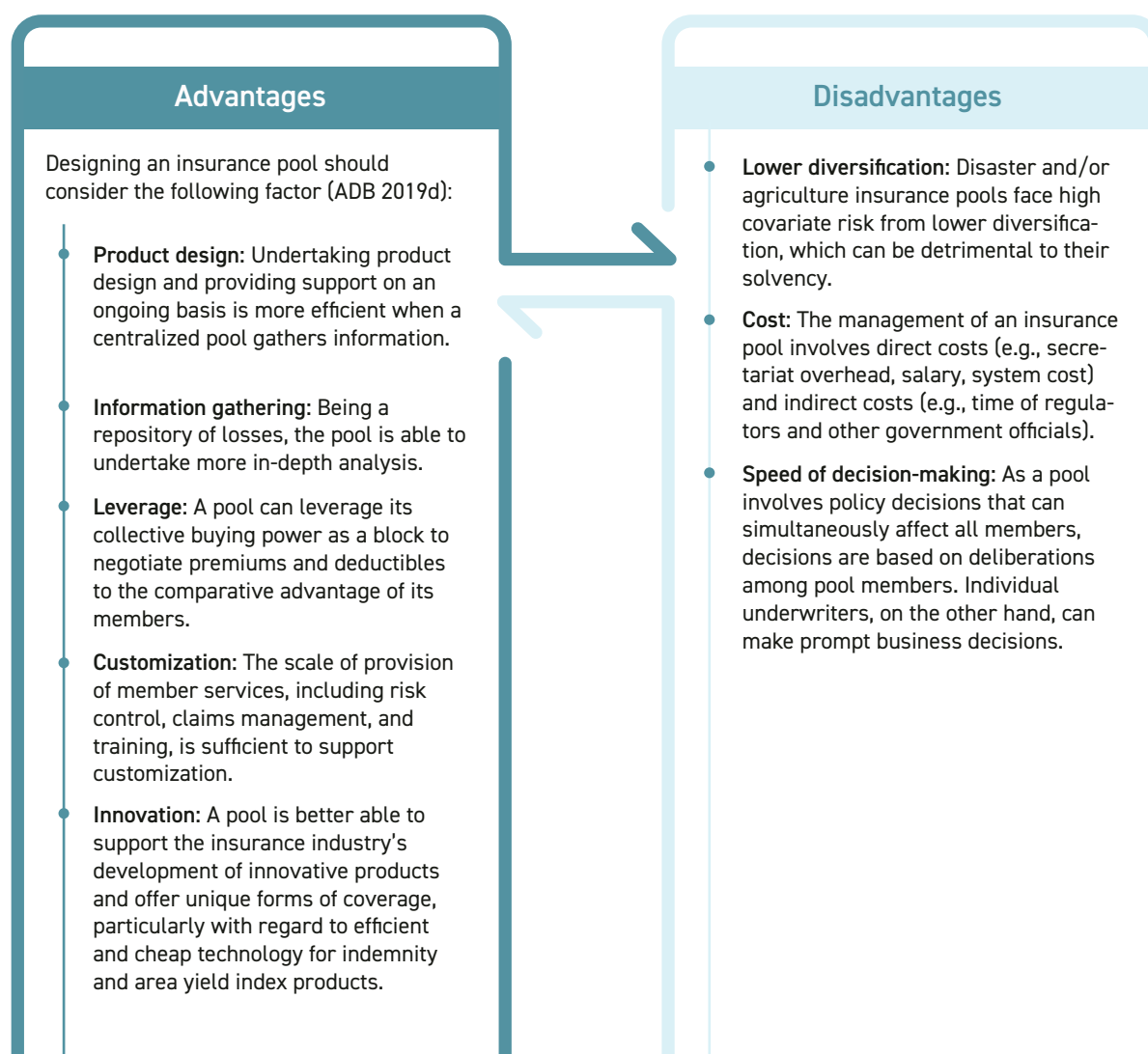
7 Insurance Pool

Definition

An insurance pool is a multiple-member risk-sharing arrangement in which organizations (often primary underwriters) pool their funds to finance exposure, liability, risk, or a combination of the three. Pools can have layers of coverage, such as insurance, excess insurance, and different deductibles for different members.

Main usage

An insurance pool can create capacity in multiple dimensions: supply of insurance for business lines that face high risks from unfavourable outcomes, underwriting of large risks by pool members, technical capacity for development of complex insurance products, advice and information gathering for loss assessment, stability of underwriting results, and reduction of the impact of single and large risks.



- **Flexibility:** A pool is better able to respond to the needs of individual insurers through variable deductibles, self-insured retention levels, and special coverage.

- **Subsidy policy:** A pool can provide data that could be useful to guide policy on premium subsidies, which, in principle, should be restricted to the cost of underwriting systemic risks.

- **Credibility:** By involving many key public sector stakeholders (e.g., the regulator and other government departments), pool members can demonstrate higher credibility in supplying insurance.

- **Pricing stability:** Pools can involve a layer of capital to cover the first layer of losses, reducing the use of reinsurance and resulting in greater price stability.

- **Reinsurance:** Economies of scale facilitate the purchase of reinsurance at a more competitive price.

Preconditions

- **Reinsurance:** An agriculture or disaster insurance pool will have high covariate risks. It is imperative to have appropriate reinsurance arrangements to maintain the pool's solvency.
- **Regulatory framework:** Insurance pools involve many stakeholders and underwrite large, collective risks. To prevent conflict, it is necessary to have rules or regulations in place to demarcate the rights and duties of all the stakeholders.
- **Subject experts:** Managing a pool's risks and information-keeping requires subject specialists. Often, it requires engaging subject-matter specialists with a strong grasp of the specific risks being pooled and an in-depth understanding of the pool's reinsurance arrangements.
- **Medium- and long-term strategy:** As insurance pools are often created to address a market need in the medium term (3–5 years) and long term (5–10 years), a well-planned strategy is necessary to envisage future functioning. For example, a strategy may consider winding down a pool once certain performance thresholds are met.
- **Information systems:** Adequate information technology systems are needed to record data, settle distribution costs and claims, and demonstrate solvency.

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