

**The Role of Climate Finance in Early Warning Systems for Rural and Coastal Populations: A Comparative Analysis of India, Rwanda, and Trinidad and Tobago.**

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## **Abstract**

Climate change has intensified the frequency and severity of extreme weather events, disproportionately affecting rural and coastal populations in developing countries. Early Warning Systems (EWS) have emerged as critical tools for reducing disaster risks; however, their effectiveness is closely tied to the availability and allocation of climate finance. This paper examines the role of climate finance in strengthening EWS, with a primary focus on India and comparative insights from Trinidad and Tobago and Rwanda. Using a qualitative research approach based on secondary data, the study explores how financial mechanisms such as the Green Climate Fund and Systematic Observations Financing Facility support EWS development. Findings indicate that while India has made significant progress in integrating EWS into national disaster management frameworks, gaps remain in financing distribution, local capacity, and last-mile communication. Rwanda demonstrates effective utilization of targeted climate finance for infrastructure upgrades, while Trinidad and Tobago highlights challenges which are typical of Small Island Developing States, including funding gaps and institutional fragmentation. The study concludes that sustained, equitable, and locally targeted climate finance is essential for enhancing resilience and protecting vulnerable populations.

## **Keywords**

Climate finance; Early warning systems; India; Rwanda; Trinidad and Tobago; Rural vulnerability; Coastal resilience; Disaster risk reduction

## 1. Introduction

Extreme weather events are becoming more severe, and unfortunately, developing countries are bearing the brunt of the impact. Just looking at the basic data, disasters like floods and storms have caused over \$87 billion in damages in highly vulnerable places such as India (World Meteorological Organisation [WMO], 2020). There's a broad consensus among the international community that Early Warning Systems (EWS) is the smartest way to adapt; they save lives and offer an impressive return on investment, sometimes as high as 10 to 1 (Asian Development Bank [ADB], 2024). But there's a caveat: even though our forecasting technology is better than before, the destruction in rural and coastal areas hasn't decreased as much as we'd expect. This is what we term the "Early Warning Paradox."

Emerging economies and small island nations now have world-class upstream forecasting. They know a storm is coming. But that information gets stuck. Downstream communication and alerting the vulnerable of an actual warning in time for them to evacuate, is all but immobilised. This breakdown is referred to as the Valley of Death in the warning chain (ADB, 2024). The science is sound, but the administration fails in execution.

Our research suggests that the issue with these "last mile" warning systems isn't really a problem with technology: It's a systemic problem related to money. International adaptation finance just isn't materialising, despite all the international pledges. Much of the pledged finances are in the form of debt-increasing loans, rather than usable grants (Oxfam, 2025). As a result, (United Nations Environment Programme [UNEP], 2025) estimates that developing countries now require 12 to 14 times the current funding just to survive these climate impacts.

In response to the research problem the research asks:

1. How does the structure and allocation of climate finance influence the effectiveness of Early Warning Systems in rural and coastal populations?

2. To what extent do institutional arrangements and governance mechanisms mediate the relationship between climate finance and last-mile delivery of early warnings?
3. Why do countries with varying levels of financial resources (such as India, Rwanda, and Trinidad and Tobago) experience different outcomes in EWS performance?
4. What financing models or approaches are most effective in ensuring that early warning systems reach vulnerable populations at the local level?

By examining and providing examples from India, Rwanda and Trinidad and Tobago, this paper illustrates how these financial barriers are leaving local governments out in the cold. Even when the technological blueprints exist, money becomes mired in bureaucracy. It is evident from the huge delays in disbursement, that 60% of global climate funds remain unspent (UNFCCC, 2025), and even more so in localities like India, where Rs. 8,392 crore (88%) of the National Disaster Mitigation Fund remains fully dormant (World Bank, 2025).

To truly close the early warning gap, we need a different approach to financing adaptation. Instead of keeping funds stuck in central ministries or in foreign avenues, we must prime the engines of capital for movement to localised grassroots institutions that are indeed mitigating the last mile gap (GNDR, 2025).

## **2. Literature Review**

### **2.1 Climate finance and the adaptation gap**

Climate finance is central to climate adaptation and disaster risk reduction because it supports institutional capacity, protective infrastructure, and resilience-building measures. However, existing literature shows that although overall climate finance flows have increased, they remain insufficient and unevenly distributed relative to adaptation needs (Oxfam, 2025; UNEP, 2025). UNEP (2025) estimates that developing countries require between \$310 billion and \$387 billion annually for adaptation, while current flows remain around \$26 billion. Oxfam (2025) further argues that reported climate finance is often overstated and frequently delivered through non-concessional loans, increasing debt burdens in vulnerable economies. This indicates that the challenge is not only the volume of finance, but also in its accessibility, equity, and design.

### **2.2 Early Warning Systems and the last-mile problem**

Within an adaptation policy, Early Warning Systems (EWS) are widely recognised as a cost-effective intervention, with benefit–cost ratios of at least 10:1 (Asian Development Bank [ADB], 2024). The World Meteorological Organization (WMO, 2022) describes EWS as generating a “triple dividend” by saving lives, protecting livelihoods, and supporting long-term development. Yet the literature also shows that investment in EWS does not automatically improve outcomes for vulnerable populations (United Nations Office for Disaster Risk Reduction [UNDRR], 2022). A major reason is the persistent “last-mile” gap between forecasting and community-level action. ADB (2024) describes this as a “Valley of Death” in the warning chain, where upstream investments in monitoring and prediction are not matched by downstream investment in dissemination, communication, and preparedness. UNEP (2025), Oxfam (2025), and UNFCCC (2025) show that climate finance is often centralised, delayed, or undisbursed, limiting local implementation. The effectiveness of

last-mile delivery also depends on communication infrastructure such as mobile networks and internet access (International Telecommunication Union [ITU], 2023). ADB (2024) notes that national investments in meteorological systems are often not matched by funding for communication networks, while Wadhawan (2023) highlights that national indicators can mask local disparities in digital access.

### **2.3 Governance, equity, and local delivery**

The literature also shows that EWS effectiveness depends on governance, equity, and the ability to adapt warning systems to local conditions. UNDRR (2022) emphasises that weak institutional coordination and poor integration of local knowledge can undermine warning dissemination. Beyond physical infrastructure, warnings must also be socially and culturally accessible. The International Federation of Red Cross and Red Crescent Societies (IFRC, 2023) notes that warnings may fail if they are not communicated through trusted and locally understood channels. However, climate finance often prioritises technical and infrastructure-based solutions over inclusive communication strategies such as local languages, community organisations, and context-specific dissemination (United Nations Development Programme [UNDP], 2025). Equity concerns are equally significant. The Intergovernmental Panel on Climate Change (IPCC, 2022) warns that poorly designed adaptation measures can reinforce existing inequalities, while Oxfam (2025) argues that loan-based finance can further constrain developing countries' ability to invest in local resilience. Centralised allocation may also favour visible, large-scale projects over community-based interventions, leaving rural and coastal populations underserved. In response, there is a need for climate finance subsidiaries, where resources and decision-making are devolved to lower levels of governance to better align finance with local needs (Steinbach et al., 2022).

### **3. Research Gap**

Although climate finance and Early Warning Systems have both received growing scholarly attention, they are often studied separately. Research examining how financial structures, allocation mechanisms, and governance arrangements influence the ability of EWS to reach vulnerable populations across different geographic and institutional contexts remains limited. This gap is particularly important because last-mile failures are not only technical, but also financial and institutional. This study addresses that gap through a comparative analysis of India, Rwanda, and Trinidad and Tobago, examining how climate finance is mobilised, allocated, and operationalised in shaping EWS effectiveness.

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## **4. Methodology**

This study uses a qualitative comparative case study design to examine how the structure, allocation, and governance of climate finance influence the effectiveness of Early Warning Systems (EWS) in different development contexts. A qualitative approach is appropriate because the study focuses on institutional processes, policy dynamics, and financial governance rather than only measurable outputs.

### **4.1 Research Design and Analytical Framework.**

The analysis is guided by a comparative political economy perspective, which treats climate finance as a governance system shaped by institutional arrangements and decision-making processes. To examine how finance translates into EWS outcomes, the study applies the following analytical framework:

Climate finance mobilization → allocation mechanisms → institutional coordination → local-level implementation → EWS effectiveness, with particular attention to the last mile.

This framework serves as the primary analytical lens for examining how financial flows are mediated through institutions and governance, enabling the study to identify where and why resources fail to translate into effective early warning outcomes.

### **4.2 Selection and Justification of Cases.**

Three case studies were selected using a most-different systems design: India, Rwanda, and Trinidad and Tobago. These cases represent different economic and institutional contexts but share exposure to climate-related risks. India is a large emerging economy with significant climate finance flows and advanced forecasting systems, yet persistent in last-mile gaps. Rwanda is a least developed country relying on targeted external financing, offering insights into coordinated and gap-specific interventions. Trinidad and Tobago is a Small Island Developing State (SIDS) with limited access to concessional finance, highlighting structural inequalities in the climate finance system.

By creating this comparative design, the research can isolate the role that variations in financing models and institutional arrangements play in determining the results of EWS in different environments.

### **4.3 Data Collection**

The study relies on secondary data, including peer-reviewed literature, reports from international organisations, climate finance project documents, policy reports, and country-specific grey literature.

### **4.4 Data Analysis**

The data was analysed through thematic coding based on key categories: sources of climate finance, allocation processes, institutional coordination, technological capacity, and last-mile communication. A within-case analysis was followed by cross-case comparison to identify shared patterns and differences in how financial governance shapes EWS performance.

### **4.5 Limitations**

This study has some limitations. Reliance on secondary data may introduce reporting bias and gaps in local-level evidence. The three-case design also limits broader generalisation, and the absence of primary field data restricts insight into community-level experiences. Despite these constraints, the methodology provides a focused framework for comparing the relationship between climate finance and EWS effectiveness.

## 5. Analysis and Findings

### India

#### Early Warning Systems (EWS) Spatial Data

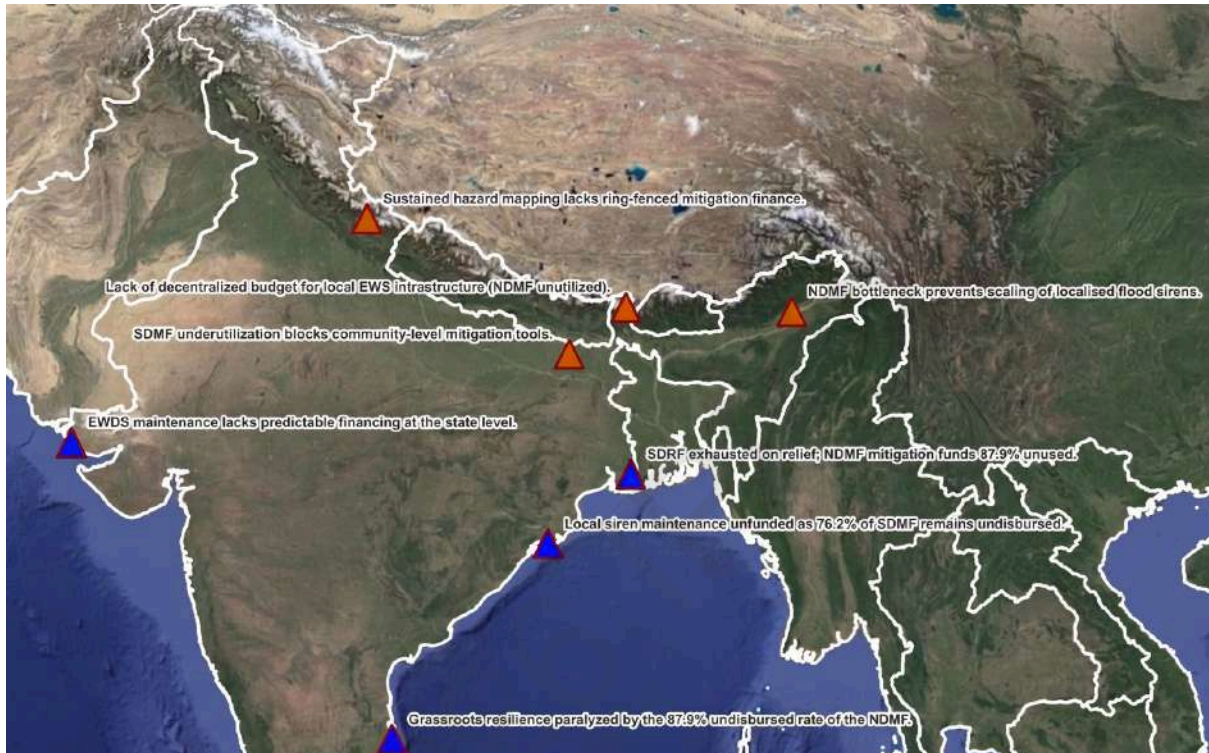


Figure 5.1 Showing Spatial Data for EWS Risk Locations

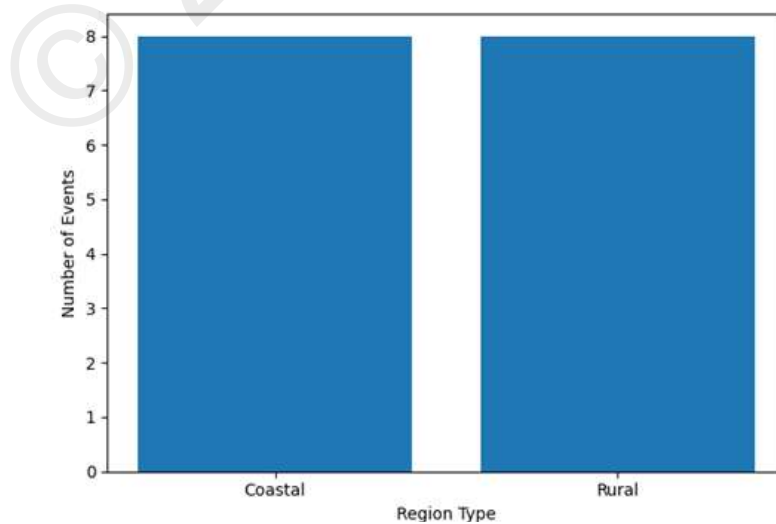
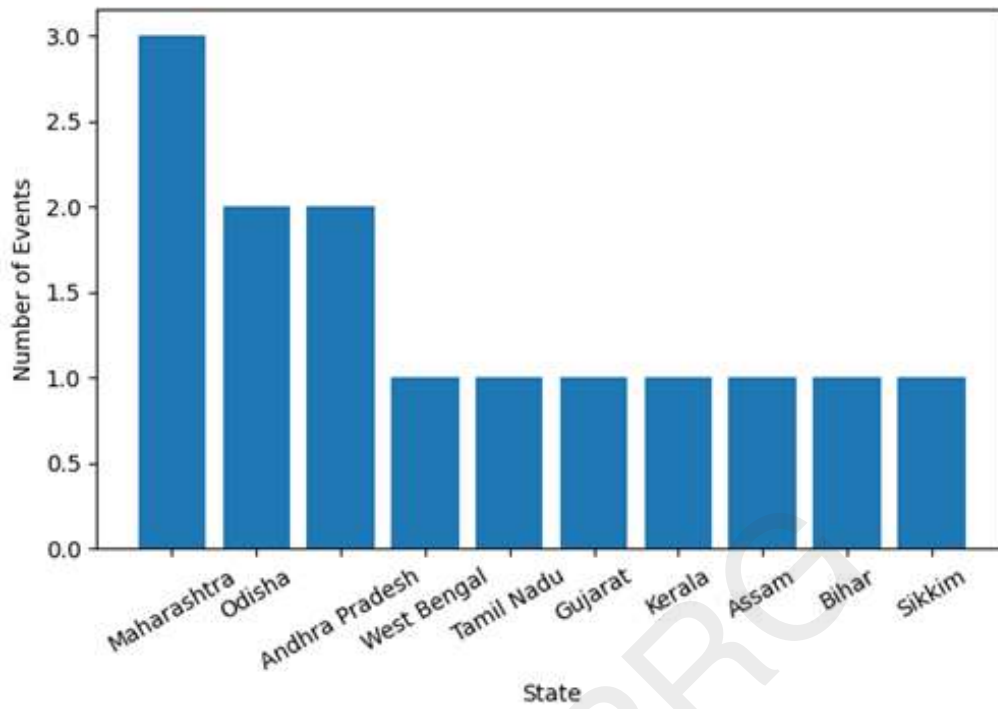


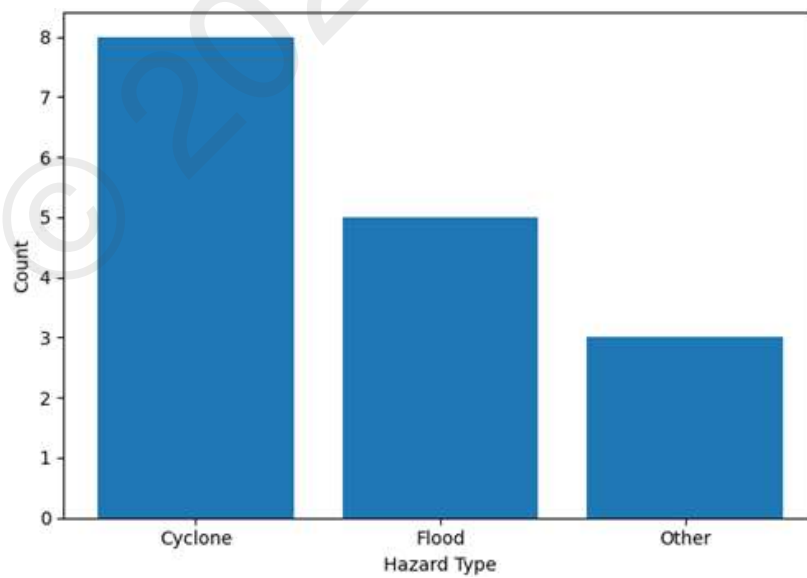
Figure 5.2: Showing Distribution of EWS Risk Events by Region



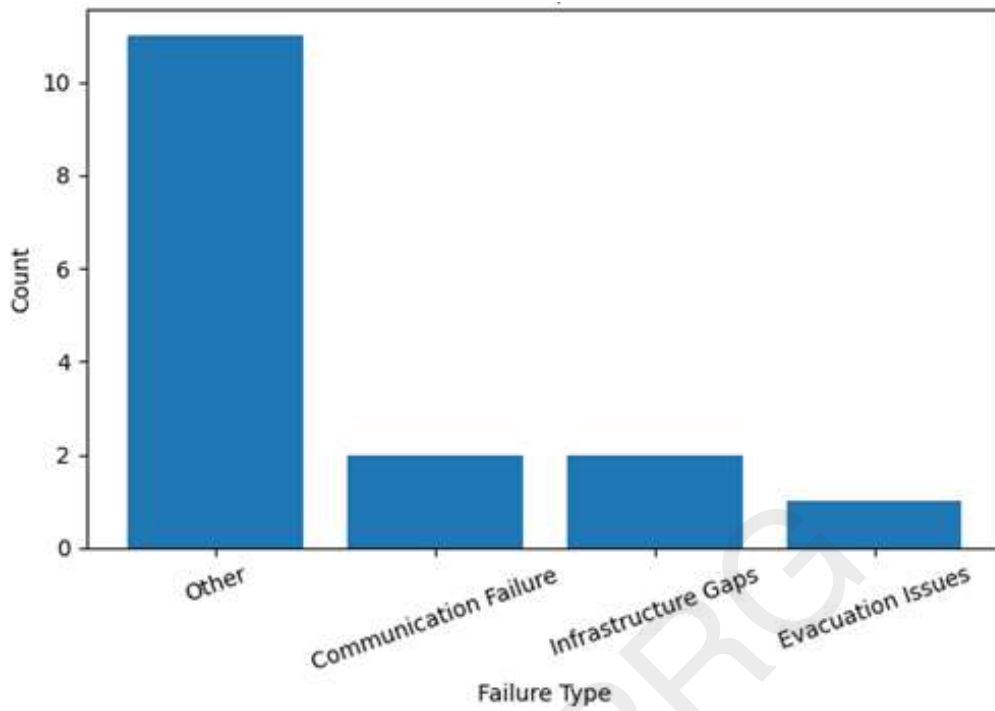
**Figure 5.3: Showing Total Number of EWS Risk Per Location**

### India

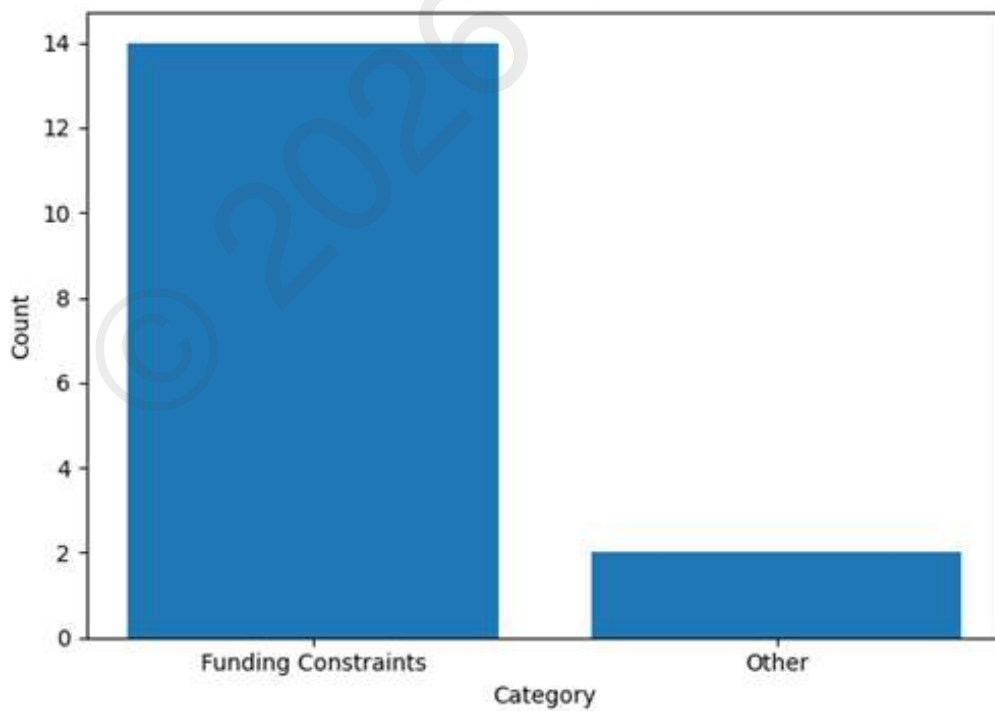
#### Early Warning Systems (EWS) Non-Spatial Data



**Figure 5.4: Showing Distribution of EWS Hazard Events**



**Figure 5.5: Showing Distribution of EWS Failure Gap**



**Figure 5.6: Showing Distribution of Financial Bottlenecks**

## **Interpretation**

Figures 5.1–5.6 show that India’s EWS risk is distributed across both coastal and rural areas, with cyclones and floods forming the dominant hazard profile. However, the main constraint is not exposure alone but the conversion of finance into local preparedness: funding constraints outweigh other bottlenecks, indicating that advanced forecasting capacity is not consistently translated into local warning infrastructure.

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## Rwanda

### Early Warning Systems (EWS) Spatial Data

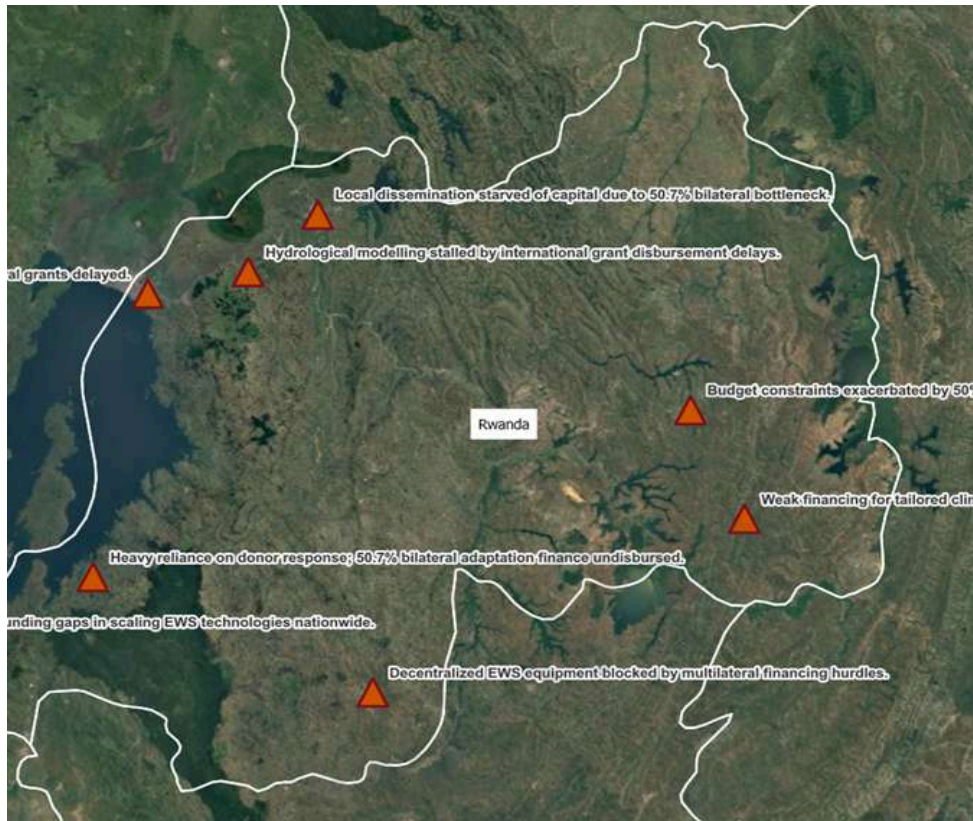
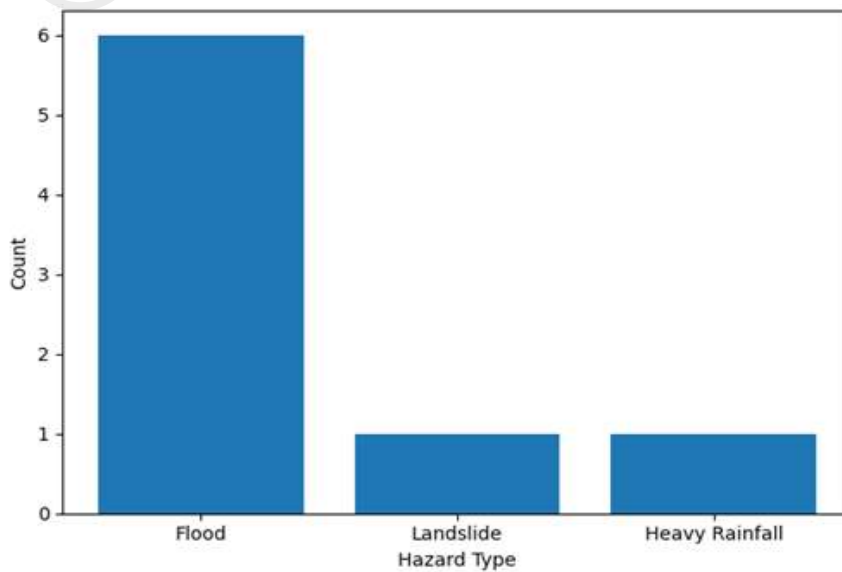


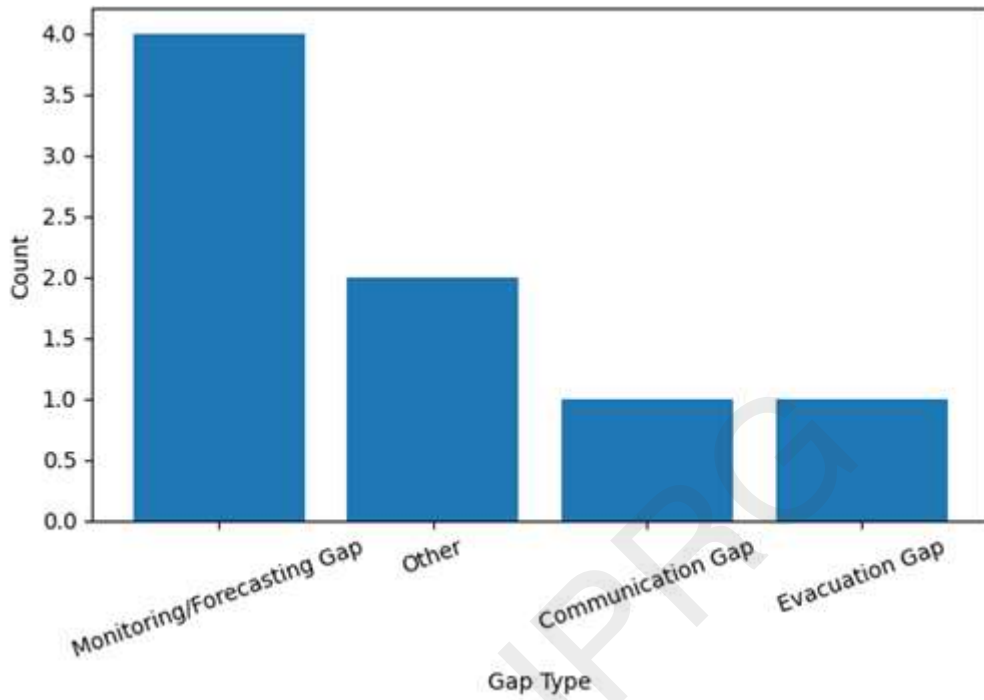
Figure 5.7 Showing Spatial Data for EWS Risk Locations (8 Rural)

## Rwanda

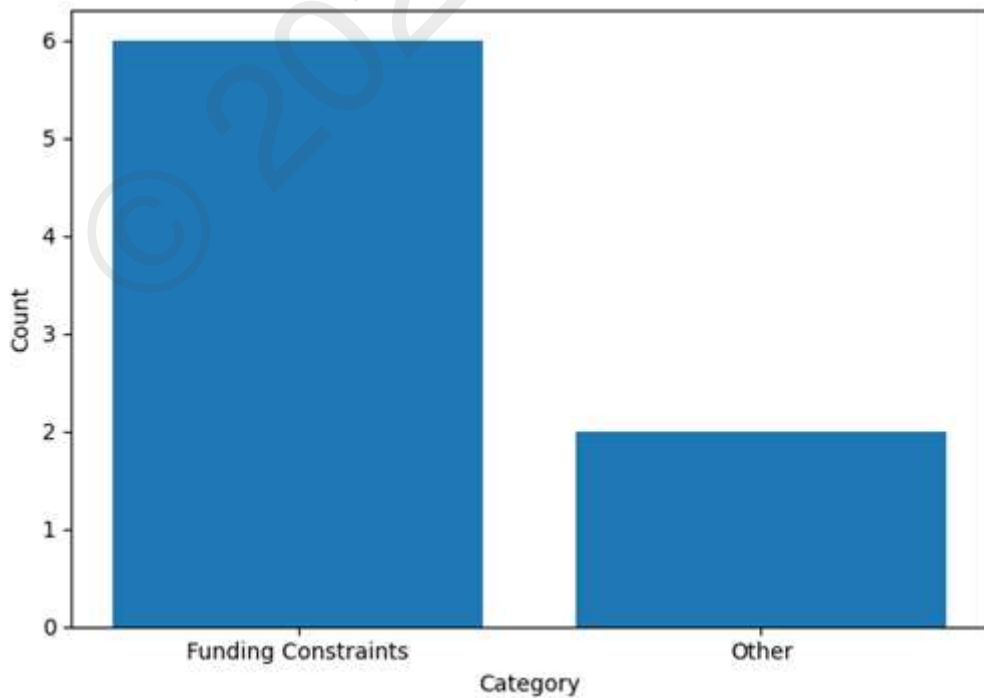
### Early Warning Systems (EWS) Non-Spatial Data



**Figure 5.8: Showing Distribution of EWS Hazard Events**



**Figure 5.9: Showing Distribution of EWS Failure Gap**



**Figure 5.10: Showing Distribution of Financial Bottlenecks**

## **Interpretation**

Figures 5.7–5.10 present Rwanda as a mainly rural, flood-led case, where the number of hazard categories is narrower, but monitoring, forecasting, and funding gaps remain central. This supports the view that targeted finance can improve EWS efficiency, although long-term maintenance still depends on predictable disbursement.

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## Trinidad and Tobago

### Early Warning Systems (EWS) Spatial Data

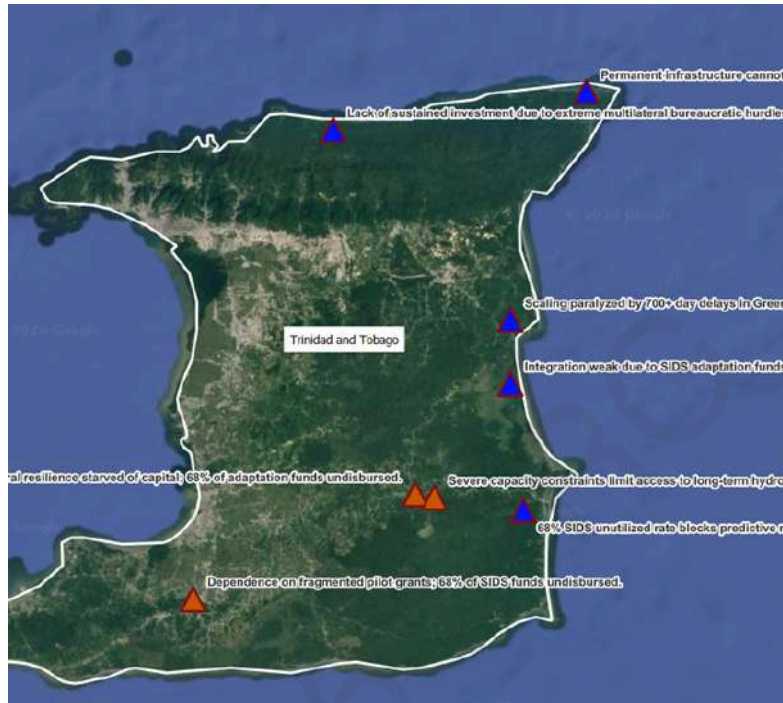


Figure 5.11: Showing Spatial Data for EWS Risk Locations (5 Coastal and 3 Rural)

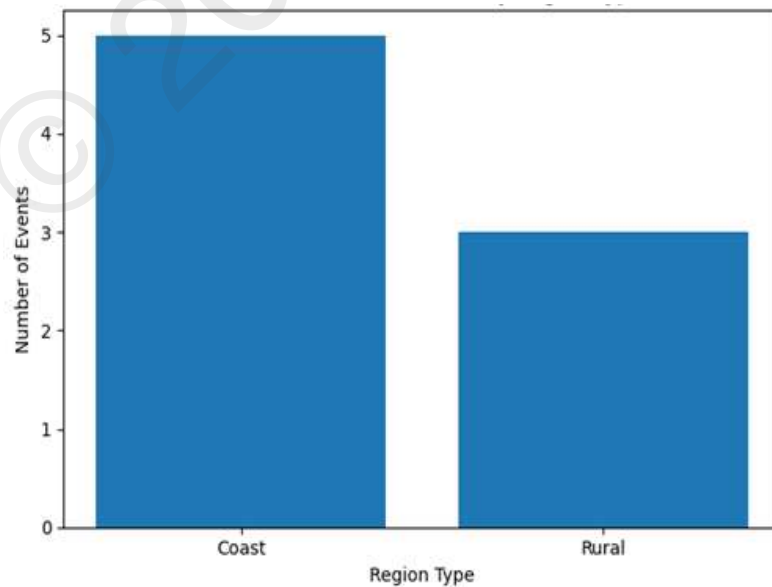


Figure 5.12: Showing Distribution of EWS Risk Events by Region

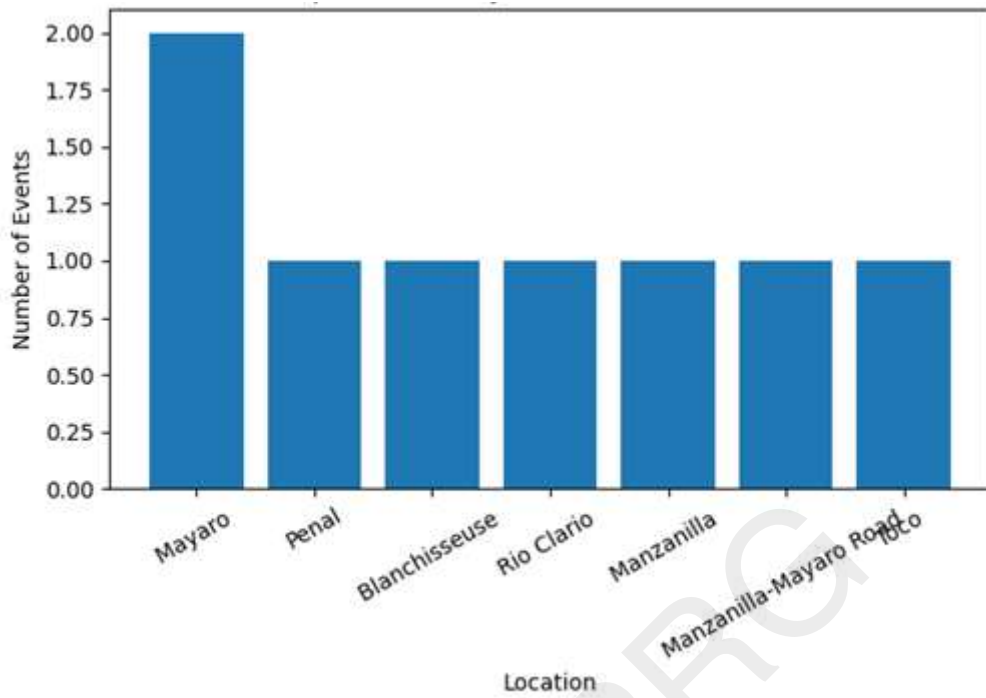


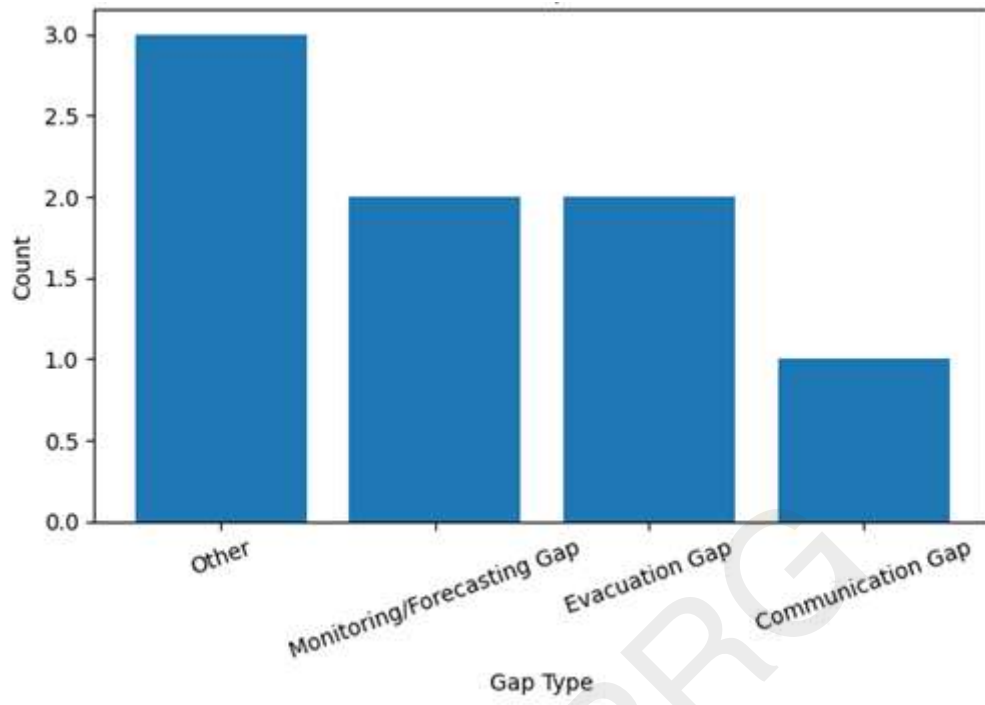
Figure 5.13: Showing Total Number of EWS Risk Per Location

### Trinidad and Tobago

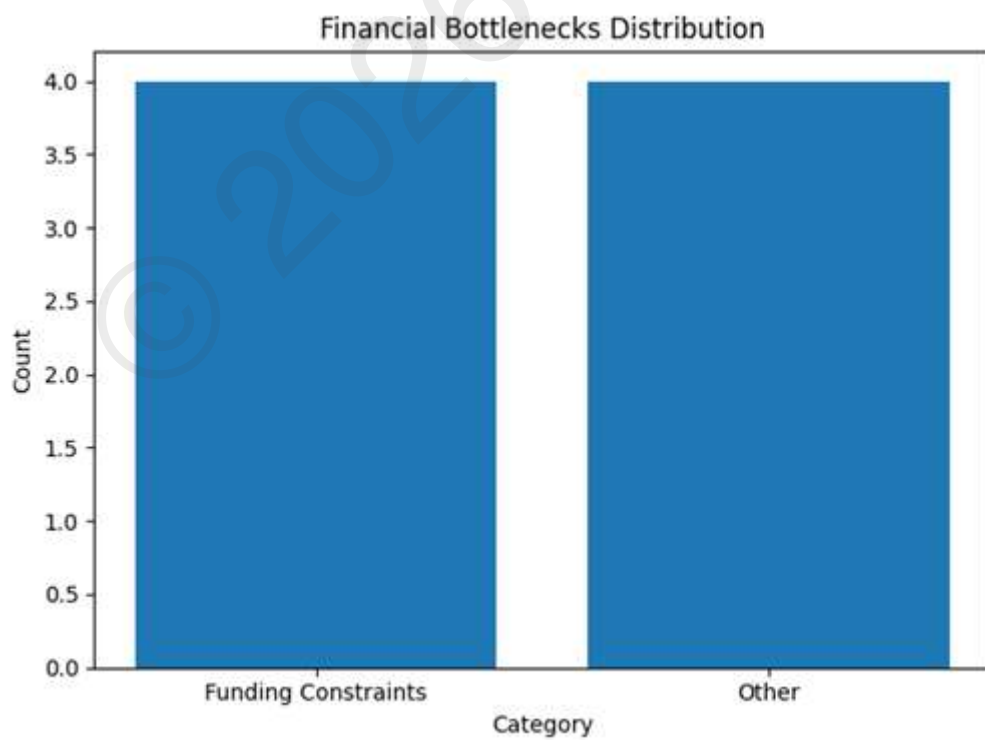
#### Early Warning Systems (EWS) Non-Spatial Data



Figure 5.14: Showing Distribution of EWS Hazard Events



**Figure 5.15: Showing Distribution of EWS Failure Gap**

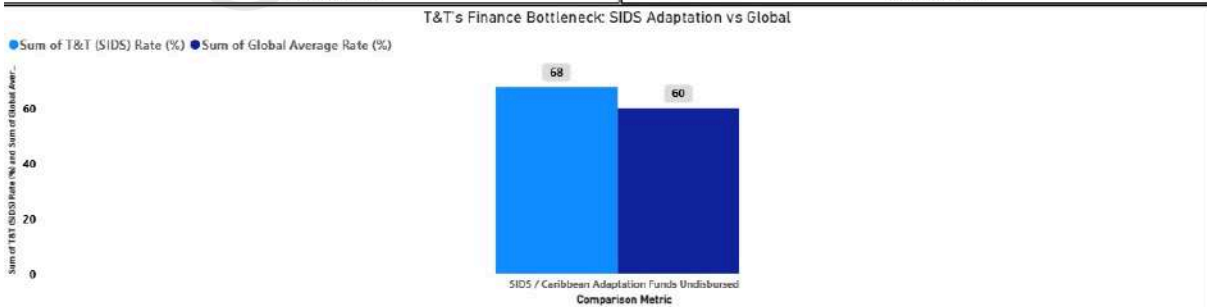
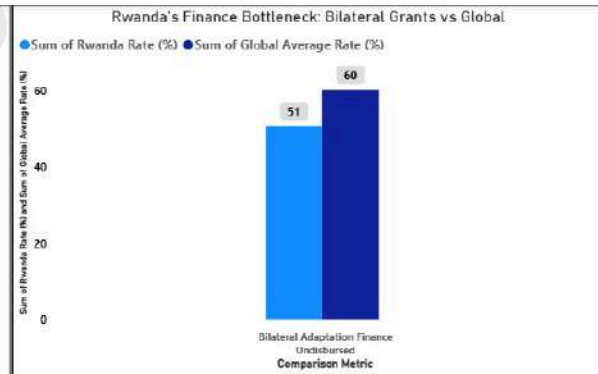
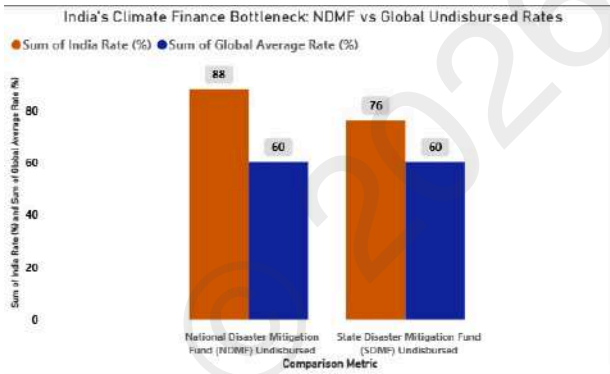
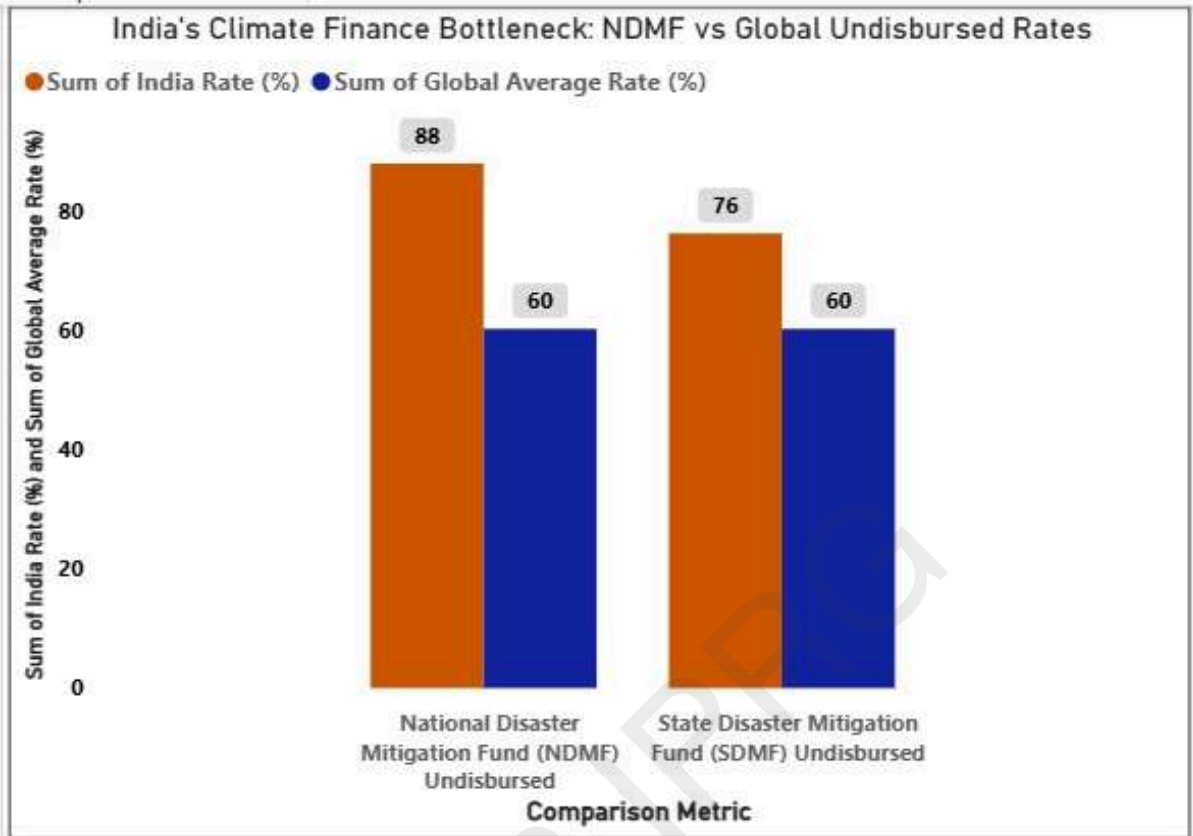


**Figure 5.16: Showing Distribution of Financial Bottlenecks**

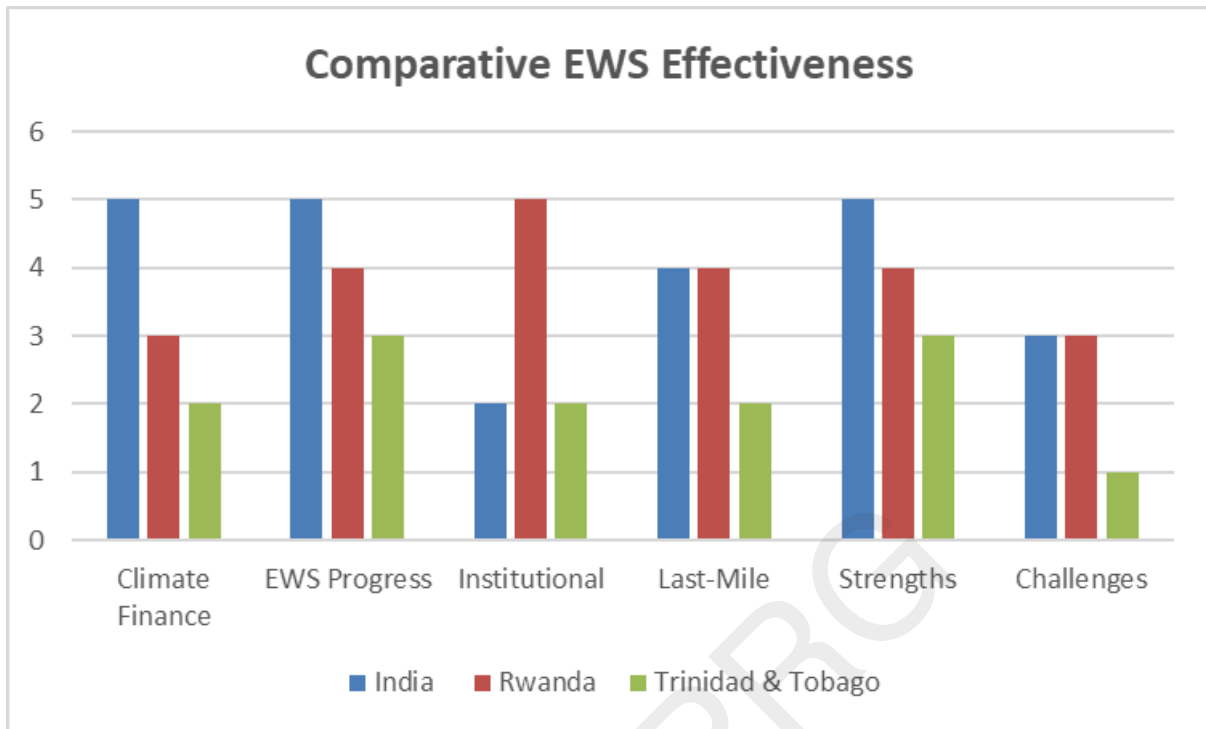
## **Interpretation**

Figures 5.11–5.16 show that Trinidad and Tobago’s risks are concentrated around flood-prone coastal and rural locations, while financing constraints, monitoring gaps, and fragmented implementation weaken last-mile delivery.

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**Figure 5.17. Comparative Analysis of utilization vs. underutilization rates of climate mitigation funding within India, Trinidad & Tobago and Rwanda.**



**Figure 5.18: Showing Comparative Analysis of Climate Finance and Early Warning Systems in India, Rwanda, and Trinidad and Tobago (based on UNDP (2025), WMO (2020; 2022), CDB (2023), and UNDRR (2022)).**

**Ranking:** 1 - Very Weak, 2 - Weak, 3 - Moderate, 4 - Strong, 5 - Very Strong

### Interpretation

Comparative Figures 5.17 and 5.18 show that the three countries differ not only in the amount of finance available, but in how effectively finance is converted into EWS outcomes.

- India represents a high input but uneven model: large-scale finance and advanced forecasting have improved national capacity, but local implementation remains constrained by uneven distribution and dormant funds.
- Rwanda represents a moderate input but efficient model, where targeted finance and stronger institutional coordination allow limited resources to produce comparatively stronger EWS outcomes.

- Trinidad and Tobago represents a structurally constrained SIDS model, where weaker access to concessional finance, institutional fragmentation, and last-mile communication gaps reduce EWS effectiveness. Overall, the comparison shows that financial structure and institutional coordination matter more than financial scale alone.

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## 6. Discussion

The findings show that climate finance shapes Early Warning System (EWS) effectiveness not simply through the volume of funding, but through the way finance is allocated, governed, and converted into local action (UNEP, 2024; UNDP, 2025). Across the three cases, a clear finance-to-impact gap emerges, where financial commitments do not consistently translate into community-level risk reduction.

Figure 5.17 reinforces this pattern by showing high undisbursed rates across all three countries: 87.9% in India's National Disaster Mitigation Fund (NDMF), 50.7% in Rwanda, and 68% in Trinidad and Tobago's adaptation funds. These bottlenecks indicate that the key challenge is not only the mobilisation of climate finance, but also its disbursement and implementation through effective institutional pathways.

The comparison further shows that financial scale alone does not guarantee stronger EWS outcomes. India demonstrates that large domestic and international climate finance can strengthen national forecasting systems and preparedness, yet persistent last-mile disparities reveal that higher financial input does not automatically produce equitable protection (WMO, 2024; UNDRR, 2022). This supports the argument that national-level indicators of progress can conceal subnational inequalities in delivery and absorptive capacity (Hallegatte et al., 2019; World Bank, 2022).

Rwanda presents a contrasting case, where more limited but targeted finance, combined with institutional coordination and capacity building, has supported more effective translation of resources into EWS performance (World Bank, 2022; WMO, 2022; UNDP, 2025). At the same time, Rwanda's 50.7% undisbursed rate suggests that even relatively successful models remain vulnerable to delays linked to donor dependence and external financing cycles (Oxfam, 2025; UNEP, 2024).

Trinidad and Tobago illustrates a different but related constraint: as a middle-income Small Island Developing State, it faces restricted access to concessional finance despite high climate vulnerability, while institutional fragmentation further limits the effective use of available resources (Caribbean Development Bank, 2023; UNEP, 2024; Oxfam, 2025; UNDRR, 2022; CDB, 2023).

These findings suggest that climate finance should be assessed not only by the amount pledged, but by how effectively it is distributed, disbursed, and aligned with local implementation needs. The persistence of last-mile communication gaps across all three cases indicates that EWS failure is often rooted in financial design and institutional prioritisation rather than in technology alone (UNDRR, 2022).

Although major investments often support forecasting models and upstream infrastructure, downstream elements such as communication networks, community preparedness, and local dissemination remain underfunded (ADB, 2024; ITU, 2023; UNEP, 2024). This reflects wider inequalities in climate finance systems, where centralised decision-making can marginalise local actors and reproduce vulnerability at both global and domestic levels (UNDP, 2025; IPCC, 2022).

Overall, the discussion points lead to the need for climate finance models that prioritises equitable distribution, stronger subsidiarity, and long-term support for local delivery systems, if EWS are to provide effective protection for rural and coastal populations (UNEP, 2024; UNDP, 2025; WMO, 2022).

## 7. Conclusion

This study shows that the “Valley of Death” in Early Warning Systems is less of a failure of forecasting technology than a failure of climate finance governance. Across the three cases, the central issue is not the amount of finance pledged, but whether resources are disbursed, coordinated, and translated into local protection. The findings demonstrate that blocked allocation pathways, institutional delays, and limited last-mile investment continue to weaken the effectiveness of EWS for vulnerable rural and coastal populations.

Closing the gap between macro-level forecasting and local protection requires a shift in global climate finance from centralised pooling to decentralised, flexible disbursement. In line with this, we recommend the following structural interventions:

- **Bypass Subnational Bottlenecks (India Model):** Redesign domestic disaster risk management frameworks to require direct fiscal transfers to district and panchayat-level authorities, reducing bureaucratic delays and preventing the accumulation of dormant funds at state and national levels.
- **Streamline SIDS Multilateral Access (Trinidad and Tobago Model):** International funds such as the Green Climate Fund (GCF) should create rapid-access, grant-based financing windows for Small Island Developing States, explicitly designed to bypass current approval delays of more than 700 days.
- **Ring-Fence Last-Mile Infrastructure:** Require that at least 30% of all approved EWS adaptation finance be legally reserved for downstream components, including local siren networks, informal communication channels, and community-based evacuation training.
- **Shift from Projects to Systems (Rwanda Model):** Move vulnerable, least developed countries away from fragmented, short-term project funding toward sustained,

direct-access institutional financing to support long-term continuity and reliability of EWS.

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