# Developing a Regional Framework for Disaster Risk Reduction Based on Disaster-Related Data from Aceh, Indonesia

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**Abstract**

Aceh Province is highly vulnerable to various hazards, necessitating effective disaster risk reduction strategies. This study aims to develop an instrument to evaluate disaster risk reduction efforts in Aceh Province and to assess progress toward global disaster resilience targets. The data includes secondary disaster-related records from 2005 to 2024 and primary data from the instrument validation process, demonstrating excellent validity results based on the Content Validity Ratio (CVR) and Content Validity Index (CVI). The findings highlight significant improvements in key areas, including reductions in disaster mortality, affected populations, economic losses, damage to critical infrastructure, and strengthened early warning systems. However, challenges persist in implementing local disaster risk reduction strategies and enhancing international cooperation. This study offers practical insights for policymakers and contributes to strengthening disaster resilience and advancing disaster risk management research in sub-national contexts.

## 1. Introduction

Aceh Province, Indonesia, has long faced substantial challenges in managing disaster risks due to its exposure to various natural hazards, including earthquakes, tsunamis, floods, landslides, and extreme weather events [1]. The 2004 Indian Ocean tsunami remains a stark reminder of Aceh's vulnerability, with the Indonesian Government reporting approximately 130,000 fatalities, 40,000 missing persons, and over 500,000 displaced individuals [2]. This catastrophic event marked a turning point for regional disaster risk reduction strategies [3]. Beyond physical hazards, disaster risk in Aceh is also shaped by social, cultural, and economic factors. Strong communal ties and religious beliefs influence disaster response, yet risk perception can affect preparedness. Additionally, economic dependence on agriculture and fisheries makes the region highly vulnerable to climate-related hazards, while past conflicts have impacted infrastructure and governance, complicating disaster management. These factors reinforce the need for a localized Disaster Risk Reduction (DRR) framework that

integrates community resilience and institutional strengthening [4].

Despite post-tsunami recovery efforts, Aceh continues to experience significant disaster impacts. Indonesia's Disaster Data and Information (DIBI) publication recorded that between 2013 and 2019, Aceh faced seven types of disasters, including floods, landslides, extreme waves and coastal abrasion, tsunamis, extreme weather such as cyclones, forest and land fires, and earthquakes. These recurring disasters have continuously disrupted livelihoods and tested community resilience. Over the years, disaster frequency has fluctuated, with a persistent trend of high economic losses. In 2023 alone, the Aceh Disaster Management Agency (BPBA) reported 418 disaster events, leading to casualties, injuries, mass displacement, and significant financial losses [5]. While the frequency of disasters showed a slight decline compared to previous years, economic loss escalated sharply, increasing from IDR 335 billion in 2022 to IDR 430 billion in 2023. These trends emphasize the urgent need for proactive and localized DRR strategies. However, challenges such as inadequate risk assessments, limited resources, and insufficient coordination among stakeholders continue to hinder progress, particularly in rural and underserved areas [6, 7].

The Sendai Framework for Disaster Risk Reduction (SFDRR), adopted at the Third United Nations World Conference on Disaster Risk Reduction in March 2015, serves as the primary global policy framework for reducing disaster risks. SFDRR emphasizes four key priorities: improving understanding of disaster risk, strengthening risk governance, investing in DRR, and enhancing disaster preparedness for effective response and recovery. The framework is complemented by seven global targets, including significant reductions in mortality, affected populations, economic losses, and damage to critical infrastructure by 2030. It also promotes increased availability of disaster risk information, enhanced international cooperation, and expanded access to early warning systems [8].

However, DRR often remains concentrated at the national level, leaving significant gaps in local adaptation and assessment [9–12]. While national strategies provide a structured approach to disaster risk reduction, they often lack specificity in addressing sub-national regions' distinct vulnerabilities and capacities. Existing frameworks tend to generalize risk factors without considering localized variations in hazard exposure, institutional capacity, and resource availability. Moreover, the absence of standardized assessment tools

tailored for regional implementation limits the ability of local governments to evaluate their progress in achieving disaster resilience systematically. Local stakeholders, including government agencies, communities, and Non-Governmental Organizations (NGOs), also face difficulties in assessing DRR effectiveness due to inconsistent data, limited technical resources, and the lack of community-driven risk assessments. This disconnect hinders local governments and communities from addressing unique vulnerabilities and leveraging localized opportunities for resilience-building [13, 14].

The localized implementation of disaster frameworks is particularly critical in regions like Aceh Province, where local contexts deeply influence disaster risks and their impacts. While the Sendai Framework provides a global structure for DRR, its application at the sub-national level remains inconsistent due to gaps in localized risk assessments, resource limitations, and governance challenges. Many local governments struggle to translate broad DRR targets into actionable strategies, particularly in disaster-prone communities. In particular, NGOs also emphasize the need for more inclusive approaches that integrate community perspectives into disaster planning. Developing tools and methodologies tailored to the needs of sub-national regions can bridge the gap between global priorities and local realities. Such efforts would enhance the accuracy of disaster risk assessments and ensure that disaster risk reduction initiatives are more responsive, inclusive, and sustainable [15, 16].

This study aims to address this gap by developing and validating a tailored instrument to assess the progress toward global disaster resilience targets in Aceh Province. The research identifies contextually relevant indicators and evaluates progress using disaster data from 2005 to 2024. This study systematically examines disaster trends and assesses the effectiveness of DRR strategies by employing data-driven approaches, including statistical analysis and modeling techniques. By bridging the gap between global frameworks and local implementation, this study contributes to a deeper understanding of DRR at the sub-national level, offering practical insights for enhancing resilience in disaster-prone regions.

## 2. Materials and Methods

### 2.1. Research Approach

This study utilized a Research and Development (R&D) approach to create a localized instrument for assessing the implementation of SFDRR at the sub-national level. The R&D process followed four main stages: (1) Needs identification, where disaster resilience challenges were analyzed through literature review and stakeholder

**Table 1.** All experts for instrument validation.

| No. | Profession | Gender | Years of Experience |
|---|---|---|---|
| 1 | Stakeholder (BPBA) | Male | 27 |
| 2 | Stakeholder (BPBA) | Male | 26 |
| 3 | Faculty member (USK) | Male | 36 |
| 4 | Faculty member (USK) | Male | 36 |
| 5 | Faculty member (USK) | Male | 22 |
| 6 | Faculty member (USM) | Female | 10 |
| 7 | Practitioner | Female | 10 |

input; (2) Instrument design, involving the formulation of assessment indicators based on global DRR frameworks and Aceh's local disaster context; (3) Validation, where expert reviews and statistical techniques such as Content Validity Ratio (CVR) and Content Validity Index (CVI) were applied to assess relevance and reliability; and (4) Refinement and implementation, where feedback from validation was incorporated to improve the instrument before applying it to evaluate SFDRR targets [17].

## 2.2. Data Collection

Data collection was conducted through primary and secondary sources, targeting key stakeholders involved in DRR. Primary data were obtained through structured questionnaires and expert judgment assessments by selected experts from academia, government agencies, and practitioners. These experts provided their evaluations on the validity and relevance of the indicators through online surveys. The structured expert assessment ensured that perspectives from diverse professional backgrounds were incorporated in evaluating disaster resilience.

Secondary data were gathered from official reports, disaster-related databases, and policy documents spanning 2005-2024. This included historical disaster event records from BPBA and BNPB, published research and policy guidelines related to SFDRR implementation in Indonesia, and reports from international organizations on global DRR frameworks and their localized applications. The data collection process took place between August and December 2024 to ensure the most up-to-date information was included.

## 2.3. Content Validity

The validation process employed the Content Validity Ratio (CVR) and Content Validity Index (CVI) to ensure the indicators of the instrument were relevant and essential. Content validity measures the extent to which an instrument adequately represents all facets of the studied concept. CVR evaluates the essentiality of each item using expert ratings. CVR values range from -1 to +1, with positive values indicating consensus among experts

that the item is relevant [18]. The formula for CVR is given in Equation 1 [19]:

$$CVR = \frac{n_e - \frac{N}{2}}{\frac{N}{2}} \tag{1}$$

Where $n_e$ represents the number of experts rating the item as essential, and $N$ denotes the total number of experts.

In addition to CVR, CVI provides a comprehensive assessment of content validity at the item level (I-CVI) and scale level (S-CVI). I-CVI measures the proportion of experts rating an item as relevant, while S-CVI evaluates overall agreement across all items. The formulas for CVI are presented in Equations 2–4 [20]:

$$I_{CVI} = \frac{n_e}{N} \tag{2}$$

$$S_{CVI(AVE)} = \frac{\sum I_{CVI}}{n} \tag{3}$$

$$s_{CVI(UA)} = \frac{n_i}{n} \tag{4}$$

Where $S_{CVI(AVE)}$ represent the Scale Content Validity Index (Average), $s_{CVI(UA)}$ denotes the Scale Content Validity Index (Universal Agreement), $n_i$ is the number of items with unanimous agreement, and $n$ is the total number of items.

Seven experts were selected for validation: four faculty members, two experts from BPBA, and one additional practitioner (Table 1). The selection criteria were based on a minimum of 10 years of experience in disaster risk reduction, resilience planning, or disaster policy; presentation from academia, government agencies, and NGOs, ensuring diversity in expertise; and familiarity with SFDRR implementation at the local and national levels.

The sample size of seven experts was determined based on standard practices in qualitative research, particularly for CVR and CVI calculations, which typically involve 5-10 experts. Table 2 presents the commonly used minimum thresholds for validation [19]. This sample size balances practical feasibility and methodological rigor, as recommended in similar qualitative validation studies.

**Table 2.** Cut-off value for content validity test.

| Number of Experts | CVR Cut-off Value | S-CVI-AVE Cut-off Value | S-CVI-UA Cut-off Value |
|---|---|---|---|
| 5 | 0.99 | 0.9 | 0.8 |
| 6 | 0.99 | 0.9 | 0.8 |
| 7 | 0.75 | 0.9 | 0.8 |
| 8 | 0.78 | 0.9 | 0.8 |
| 9 | 0.62 | 0.9 | 0.8 |
| 10 | 0.59 | 0.9 | 0.8 |
| 11 | 0.56 | 0.9 | 0.8 |

**Table 3.** Instrument design for evaluating SFDRR targets in Aceh Province.

| SFDRR Targets | Assessment Index | Data Source | Reference |
|---|---|---|---|
| A | Reduction in the annual average number of deaths and missing persons during the 2016–2024 period compared to the previous period of 2005–2015 | [21] | [8] |
| B | Reduction in the annual average number of people affected by disasters during the 2016–2024 period compared to the previous period of 2005–2015 | [21] | [8] |
| C | Reduction in the trend of economic losses caused by disasters during the 2016–2024 period | [22] | [23, 24] |
| D | Reduction in the annual average number of damages to critical infrastructure caused by disasters during the 2016–2024 period compared to the previous period of 2005–2015 | [21] | [8] |
| E | Percentage of districts/cities in Aceh Province with more than 50% availability of Disaster Risk Assessment documents | [25] | [26] |
| F | Increase in budget allocation for disaster management programs regularly | [27, 28] | [16] |
| G | Increase in the number of people with access to early warning systems at the local level | [29] | [8] |

## 3. Results and Discussion

This section presents the development, validation, and assessment of the implementation of the SFDRR targets in Aceh Province, utilizing disaster-related data from 2005 to 2024. The analysis focuses on the alignment of global SFDRR targets with local realities, assessing how well Aceh's DRR efforts have been in achieving these targets. The study specifically examines the indicators identified during the research phase, which were used to evaluate the effectiveness of DRR strategies at the local level.

The results are structured around the global SFDRR priorities, including improvements in risk understanding, governance, investment in DRR, and preparedness for effective response and recovery. We assess the progress made in Aceh toward meeting these global targets, using descriptive statistical analysis to compare annual data on disaster frequency and economic losses over the last two decades. Additionally, we discuss the challenges faced in aligning these targets with Aceh's specific socio-economic, environmental, and governance contexts.

### 3.1. Instrument Design and Validation

The development and validation of the instrument were crucial in ensuring a robust and contextually appropriate assessment of the SFDRR targets in Aceh Province. The instrument was developed based on a comprehensive literature review to identify relevant indicators aligned with the global SFDRR priorities, while adapting them to the local disaster management context. These indicators address key aspects such as mortality reduction, reductions in disaster-affected populations, economic losses, and disaster risk management systems improvements.

Table 3 summarizes the developed indicators, along with their corresponding assessment indices, data sources, and references. All indicators outline the specific metrics used for each SFDRR global target (A–G), the organizations or institutions providing the required data, and the scholarly references that guided the development process. By linking global priorities with local implementation, this instrument offers a comprehensive and evidence-based framework for evaluating DRR efforts in Aceh Province.

This instrument is the foundation for a structured validation process involving expert judgment, ensuring its relevance and applicability to Aceh's disaster context. Seven experts, including four academics and three practitioners, participated in the validation process, selected based on their expertise in disaster risk management and familiarity with the SFDRR framework. Their professional experience ranged from less than 10 years to over 36 years, providing a diverse set of perspectives that strengthened the reliability and validity of the instrument.

The indicators listed in Table 3 were supplemented by additional operational indicators summarized in Table 4, which detail the specific metrics used to evaluate each SFDRR target. Together, these test results form a

**Table 4.** Indicators for assessing SFDRR global targets in Aceh Province.

| Indicator Code | Description | SFDRR Targets |
|---|---|---|
| A-1 (Combined) | Total number of deaths and missing persons due to disasters | Target A |
| A-2 | Total number of deaths caused by disasters | |
| A-3 | Total number of missing persons due to disasters | |
| B-1 (Combined) | Total number of people directly affected by disasters | Target B |
| B-2 | Total number of people injured due to disasters | |
| B-3 | Total number of people whose houses were damaged | |
| B-4 | Total number of people whose houses were destroyed | |
| B-5 | Total number of people who lost their livelihoods | |
| C-1 | Total economic losses caused by disasters | Target C |
| D-1 (Combined) | Total damage to critical infrastructure | Target D |
| D-2 | Total number of health facilities damaged or destroyed | |
| D-3 | Total number of educational facilities damaged or destroyed | |
| D-4 | Total number of other critical infrastructures damaged | |
| E-1 | Percentage of districts/cities in Aceh Province with availability of Disaster Risk Assessment documents | Target E |
| F-1 | Budget allocation for disaster management programs regularly | Target F |
| G-1 | Number of people with access to early warning systems at the local level | Target G |

**Table 5.** Content validity test results.

| Validation Category | Value | Interpretation |
|---|---|---|
| CVR | CVR = 1 for all indicator | All indicators are relevant |
| I-CVI | I-CVI = 0.857 for 3 indicators and I-CVI = 1 for 13 indicators | All indicators are relevant |
| S-CVI-AVE | 0.973 | Fit content validity |
| S-CVI-UA | 0.812 | Fit content validity |

comprehensive framework for assessing Aceh's DRR progress.

The validation process employed CVR and CVI methodologies to evaluate the essentiality and relevance of the indicators. The CVR measured the proportion of experts who deemed each indicator essential, while the CVI assessed both item-level and scale-level agreement. The validation process results are presented in Table 5, demonstrating that all indicators met or exceeded the minimum thresholds for content validity. Specifically, the CVR values for all indicators were 1, indicating unanimous agreement among the experts on their essentiality. Furthermore, the scale-level CVI-AVE and CVI-UA values were 0.973 and 0.812, respectively, reflecting fit overall content validity for the instrument.

With the validated instrument established, SFDRR global targets were assessed using disaster-related data from Aceh Province. The analysis aimed to measure the progress made in achieving each target, focusing on reductions in disaster impacts and improvements in DRR strategies at the local level. Each target is evaluated based on its associated indicators, utilizing quantitative data to provide insights into Aceh's achievements and challenges in disaster resilience. The following sections present a detailed evaluation of the achievements for each global target.

### 3.2. Target A: Reducing Disaster-Related Mortality

The evaluation of Target A under the SFDRR in Aceh Province highlights a significant achievement in reducing disaster-related mortality and missing persons. The trends during 2016-2024 reveal that comprehensive disaster management strategies, such as implementing early warning systems and evacuation protocols, have played a critical role in saving lives.

For instance, the reduction in deaths and missing persons is not merely a reflection of quantitative decline but also an indication of improved institutional readiness and public awareness. This success is largely attributed to localized disaster management plans that integrate community-based approaches with technological advancements. Despite these achievements, sustaining and enhancing these outcomes requires continuous investments in disaster education, early warning infrastructure, and inter-agency coordination to address emerging risks and ensure equitable access to resources. The findings of Target A are depicted in Figure 1, emphasizing the transformative impact of integrated disaster response systems on reducing mortality.

### 3.3. Target B: Minimizing the Impact on Disaster-Affected Populations

Target B illustrates the extensive efforts made to mitigate disasters' impact on Aceh Province communities. The period 2016-2024 saw a marked decline in the
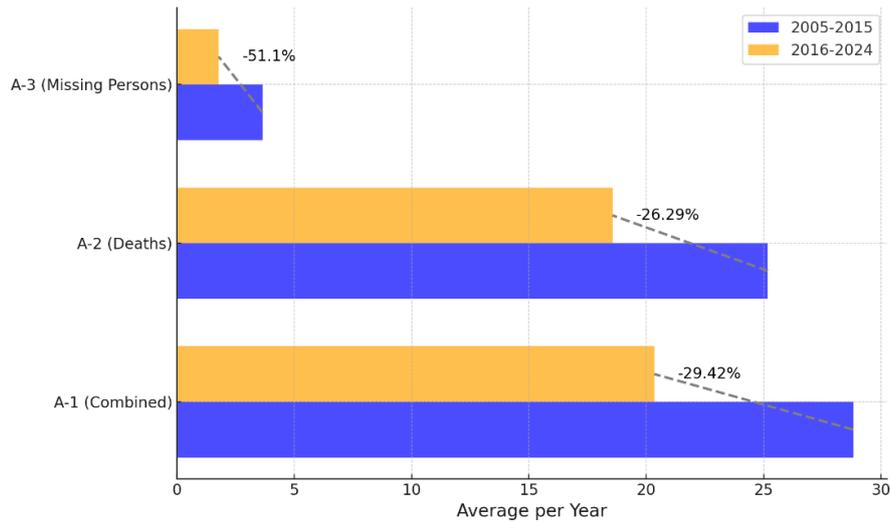
**Figure 1.** Graph of assessment results for SFDRR Target A in Aceh Province.
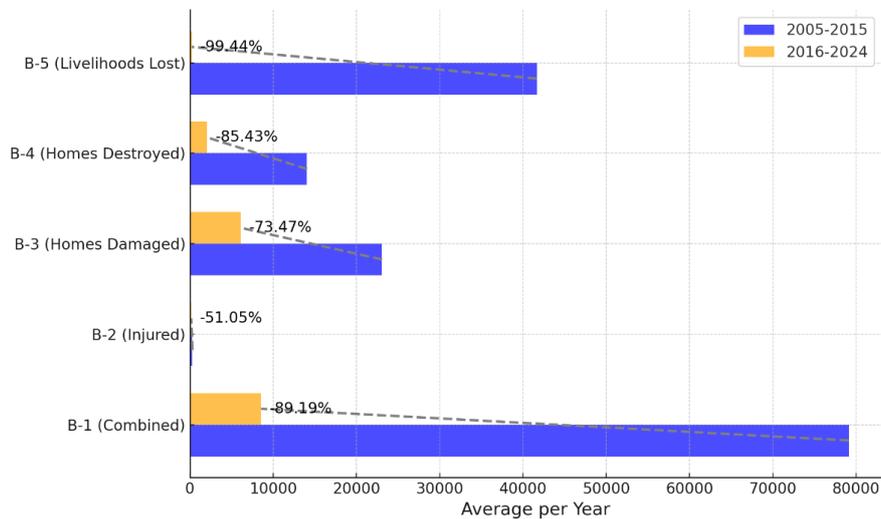


**Figure 2.** Graph of assessment results for SFDRR Target B in Aceh Province.

The number of people affected is a testament to the effectiveness of mitigation measures and social protection programs. Beyond the decline in numbers, this achievement reflects a fundamental shift in disaster preparedness, characterized by enhanced community resilience and risk reduction strategies.

The sharp decrease in injuries, damaged homes, and loss of livelihood underscores the role of proactive measures, such as hazard mapping, land-use planning, and community training programs. However, maintaining these gains requires addressing residual vulnerabilities, particularly in remote and marginalized areas. This includes fostering stronger community networks, ensuring resource allocation for recovery efforts, and integrating DRR into broader developmental goals. The outcomes of Target B are summarized in Figure 2, which underscores the role of collective action and targeted interventions in safeguarding vulnerable populations.

### 3.4. Target C: Economic Loss Reduction Due to Disasters

Target C's evaluation focuses on managing economic losses resulting from disasters in Aceh Province. The data available for this analysis spans from 2019 to 2024 due to limited availability of detailed disaster-related economic loss data before 2019. As depicted in Figure 3, the trend of economic losses exhibits considerable fluctuation rather than a consistent decline. While 2019 recorded the lowest economic loss at 160 billion Rupiah, there was a sharp increase of 125% in 2020, bringing the losses to 360 billion Rupiah. This was followed by a decline of 34.72% in 2021, but losses rebounded in 2022 with a 42.55% increase and further rose by 28.36% in 2023. However, in 2024, economic losses saw a significant drop of 71.40%, reaching 123 billion Rupiah, marking the lowest recorded loss in the observed period.
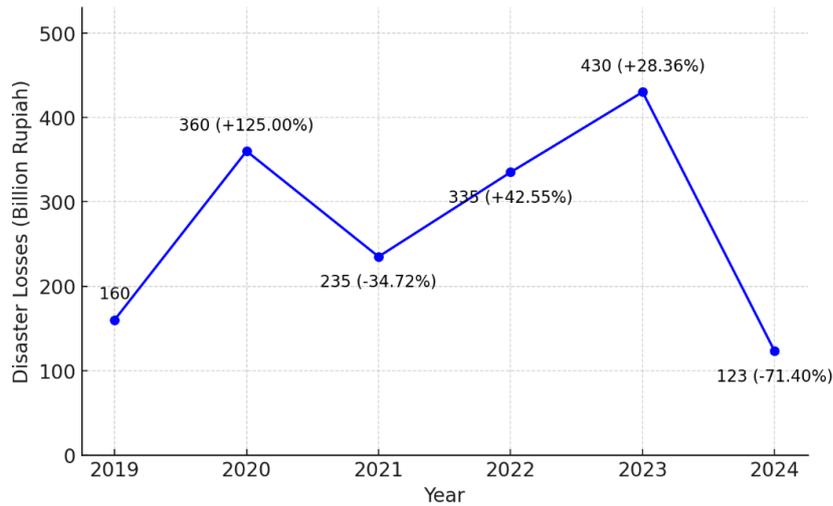
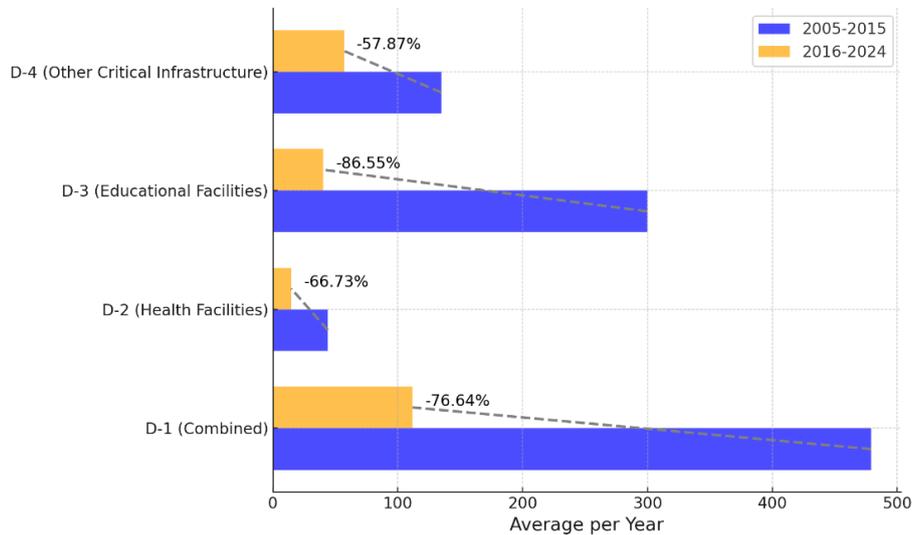**Figure 3.** Trend of disaster losses in Aceh Province.



**Figure 4.** Graph of assessment results for SFDRR Target D in Aceh Province.

These variations indicate that while some progress has been made in reducing economic losses, the trends remain inconsistent, suggesting that external factors influence disaster impacts and economic resilience. The substantial decrease in 2024 may reflect improved disaster risk reduction (DRR) strategies, better preparedness, or fewer severe disasters occurring that year. However, the sharp fluctuations in previous years highlight the necessity of strengthening disaster preparedness and economic planning to mitigate abrupt increases in losses.

### 3.5. Target D: Reducing Damage to Critical Infrastructure and Basic Services

Target D underscores the progress made in safeguarding critical infrastructure in Aceh Province, particularly health and educational facilities, against disaster-related damage. This target reflects a shift in focus from reactive recovery efforts to proactive resilience-building measures. The substantial decline in infrastructure damage during 2016-2024 is indicative of the effectiveness of disaster-resilient construction standards, retrofitting programs, and risk-informed urban planning.

The achievements in reducing damage to health and educational facilities highlight the role of strengthened institutional frameworks and targeted investments in ensuring the continuity of essential services during disasters. However, challenges remain in addressing the disparities in infrastructure resilience across urban and rural areas. Moving forward, there is a need to expand risk assessment methodologies, incorporate climate change projections, and prioritize infrastructure projects that serve high-risk communities. The key findings of Target D are illustrated in Figure 4, reflecting the critical role of resilient infrastructure in disaster risk management.
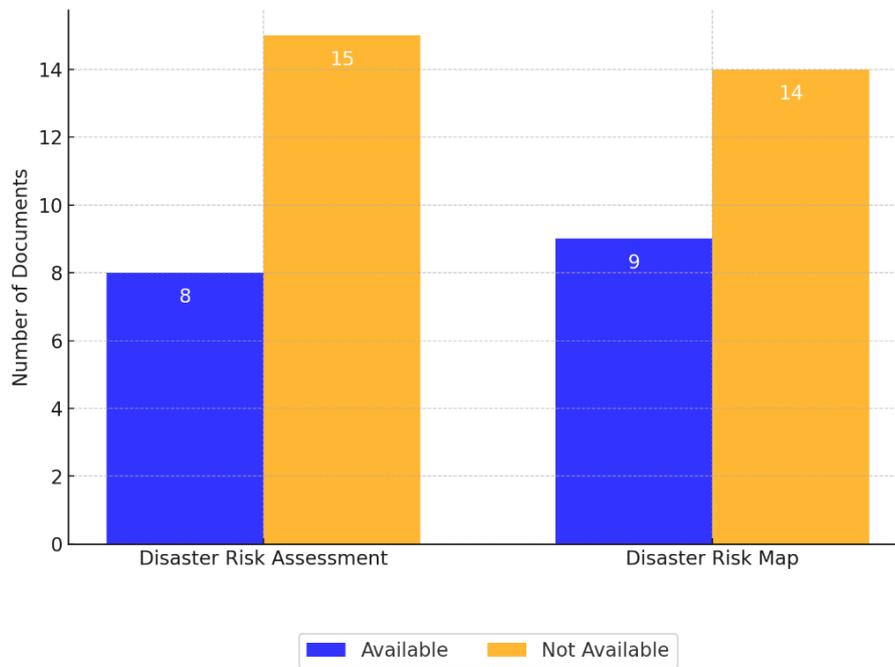
**Figure 5.** Graph of Disaster Risk Assessment and Risk Map availability.

### 3.6. Target E: Local Disaster Risk Reduction Strategies

Target E of the SFDRR emphasizes increasing the number of regions with DRR strategies at national and local levels. In Aceh Province, the evaluation of Target E focuses on the availability of Disaster Risk Assessments (KRB documents) and Disaster Risk Maps, which are essential for identifying risks, planning mitigation measures, and strengthening local resilience against disasters. As of 2024, only 8 out of 23 districts (34.78%) in Aceh have developed KRB documents, while the remaining 15 districts (65.22%) have yet to produce them. Similarly, 9 districts (39.13%) have published Disaster Risk Maps, whereas 14 districts (60.87%) still lack these critical documents.

The availability of these documents indicates some progress, but many of the existing documents require updating to remain relevant. Furthermore, the absence of documentation in several districts reflects deeper barriers, such as limited resources, lack of technical expertise, and coordination challenges among local government bodies and relevant stakeholders. The absence of KRB documents and Risk Maps in these districts highlights the need for collaborative efforts to develop and update these essential resources. These efforts are crucial to ensuring that disaster risk information is accessible to all regions and improving disaster preparedness. As shown in Figure 5, the disparities in document availability underscore the urgent need for targeted interventions to address the implementation gap. Strengthening collaboration between local governments, technical agencies, and other stakeholders is essential to bridging these gaps and improving regional resilience.

### 3.7. Target F: Strengthening International Cooperation for Disaster Risk Reduction

Target F under the SFDRR focuses on increasing international cooperation to support DRR in developing countries, including technology transfer, financial assistance, and local capacity building. In Aceh Province, the evaluation of Target F is aligned with the annual budget allocation for disaster management programs. As shown in Figure 6, the total disaster management budget increased from Rp98.76 billion in 2020 to Rp121.11 billion in 2023, with the highest annual growth rate of 10.33% recorded in 2021. This increase reflects a growing commitment to DRR initiatives; however, the allocated budget remains relatively small compared to the overall needs for comprehensive DRR programs.

The limited financial capacity of local governments highlights the crucial role of external assistance from international organizations, such as the National Disaster Management Agency and various NGOs. These entities have been instrumental in providing financial support, technical training, and technology transfer to enhance local disaster preparedness. Moving forward, sustained international collaboration and increased budgetary commitments are essential to address the gaps in disaster management funding and ensure the effective implementation of DRR strategies in Aceh Province.
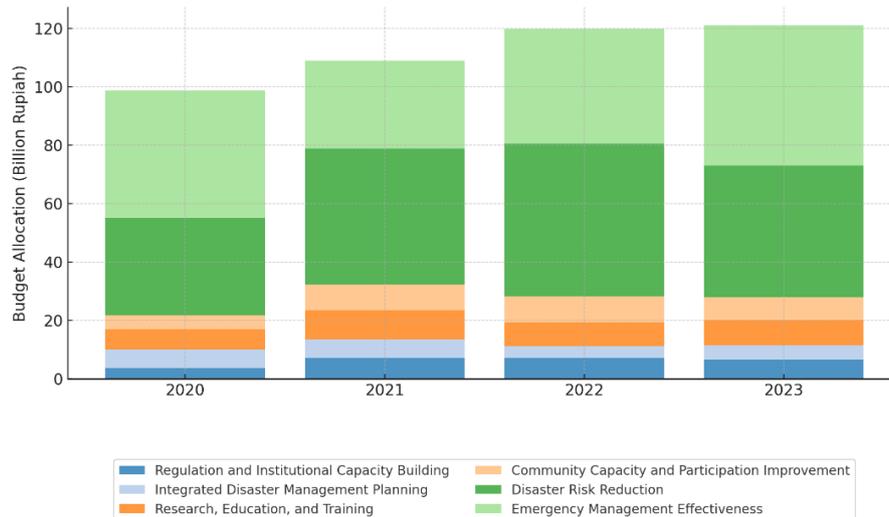
**Figure 6.** Graph of allocation of disaster management program funds in Aceh province.

### 3.6. Target G: Improving Access to Multi-Hazard Early Warning Systems

The assessment of progress toward Target G of the SFDRR in Aceh Province focuses on strengthening early warning systems, a key component of disaster preparedness. Aceh is currently equipped with eight tsunami sirens in Banda Aceh, Aceh Besar, and Aceh Barat, alongside 28 operational seismographs that enable real-time earthquake monitoring. These infrastructures are vital in delivering early warnings to communities in disaster-prone areas.

Additionally, the Government of Aceh, in collaboration with BMKG and the Ministry of Communication and Informatics (Kominfo), has enhanced early warning systems through technological innovations, such as the development of a digital television-based Early Warning System (EWS), which has been piloted since 2021. This system is designed to disseminate disaster-related information, including earthquakes, tsunamis, and extreme weather, on a broader scale, complementing existing communication channels such as social media, websites, and the Warning Receiver System New Generation (WRS NG).

However, while these systems are crucial, challenges remain in ensuring they reach all population segments, particularly in remote and rural areas. Many of these areas face limited accessibility to modern communication technologies, such as digital TV and the internet, which could hinder the timely receipt of early warnings. Moreover, vulnerable groups, such as the elderly, individuals with disabilities, and people in geographically isolated communities, may face difficulties in accessing or understanding these warnings. In this context, the effectiveness of the systems can be enhanced by focusing on improving coverage in underserved areas and ensuring that all segments of the population can access early warning messages in a user-friendly format.

Partnerships with international and national organizations are crucial to supporting the expansion of early warning infrastructure, providing technical training, and raising awareness among local governments and communities about the importance of early warning systems. These efforts are expected to enhance the effectiveness of early warning systems and ensure that more people are protectednumer from the impacts of future disasters.

This study provides a comprehensive overview of disaster dynamics in Aceh Province over the past two decades, offering insights into the risks and mitigation efforts undertaken. The validated instrument demonstrated high relevance to the global SFDRR targets, ensuring an evidence-based approach in evaluating key aspects such as reductions in mortality, affected populations, and economic losses. The use of robust validation methods, including the Content Validity Ratio (CVR) and Content Validity Index (CVI), confirms the reliability and accuracy of the indicators. This aligns with findings by Zamanzadeh et al. [18], who emphasized the critical role of standardized instruments in assessing the effectiveness of DRR policies.

The application of this instrument revealed significant progress in Aceh's achievement of SFDRR global targets, particularly in Targets A and B. Disaster mortality decreased by 26.29%, while the number of affected people declined by 89.19%, reflecting the impact of strengthened early warning systems and evacuation protocols. These findings are consistent with [30–31], who reported that innovations in early warning systems

have saved thousands of lives. Additionally, economic losses showed a stable downward trend, although the lack of detailed economic impact data poses challenges in fully capturing long-term disaster effects. Some publications also highlighted the importance of integrating long-term economic impact assessments to refine disaster risk planning, a recommendation that is pertinent to Aceh's context [32–34].

However, challenges persist in achieving Targets E and F. The availability of disaster risk assessment documents and risk maps remains limited, with 65.22% of districts lacking updated documentation. This finding underscores the urgent need for enhanced local capacity in disaster risk planning, as also noted by studies emphasizing the barriers posed by outdated risk data. Furthermore, budgetary limitations continue to impede the implementation of sustainable DRR programs. While international cooperation and financial allocations have improved, the resources remain insufficient to address Aceh's comprehensive DRR needs. Strategic interventions are essential to overcome these barriers and accelerate progress toward achieving all SFDRR targets by 2030.

Several limitations must be considered in interpreting the findings of this study. One of the main challenges is the inconsistency of disaster-related data across different time periods and sources, which may introduce biases in trend analysis. Some datasets lacked specific details on localized disaster impacts, particularly in rural areas, limiting the depth of assessment. Additionally, the framework developed in this study was tailored specifically to Aceh, meaning that its applicability to other regions may require further modifications. The study also relied heavily on expert validation rather than extensive field testing, which may limit the direct engagement of affected communities in evaluating disaster risk reduction efforts.

Future research should focus on broadening the study's geographic scope to encompass other disaster-prone regions, allowing for comparative analyses that can provide deeper insights into disaster risk management at various scales. In addition, employing more diverse data collection techniques, such as participatory community assessments and longitudinal field studies, could enhance the framework's robustness. Further advancements could also be made by integrating modern analytical tools, such as artificial intelligence and geospatial analysis, to improve disaster prediction and risk assessment. Finally, ongoing monitoring and periodic reassessment of the developed framework would be beneficial in ensuring that it remains relevant in the face of evolving disaster risks and climate change challenges.

## 4. Conclusions

This study successfully developed and validated an instrument to assess the achievement of global targets outlined in the Sendai Framework for Disaster Risk Reduction (SFDRR) within Aceh Province. The findings highlight progress in reducing disaster mortality, affected populations, economic losses, and damage to infrastructure, along with improving access to early warning systems. However, challenges remain in local DRR strategies and international cooperation, particularly gaps in risk documentation and limited funding. To address these challenges, updating risk assessments, increasing funding, and strengthening international partnerships are critical steps. Future research should focus on long-term impact studies, integrating climate change adaptation, and leveraging new technologies to enhance disaster preparedness and resilience. These efforts are essential to achieving SFDRR targets by 2030.

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