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Assessing Natural Disaster Vulnerability in Indonesia Using a Weighted Index Method

Faradiba Faradiba[1†], St. Fatimah Azzahra[2], Taat Guswantoro[1], Lodewik Zet[3] and Nathasya Grisella Manullang[1]

[1]Physics Education Study Program, Universitas Kristen, Indonesia
[2]Chemistry Education Study Program, Universitas Kristen, Indonesia
[3]BPS-Statistics Indonesia, Indonesia
†Corresponding author: Faradiba Faradiba; faradiba@uki.ac.id

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ABSTRACT

Natural disasters are natural activities that can disrupt various aspects. Natural disasters cannot be avoided, but the impact of natural disasters can be minimized through mitigation. This can be known through event history to determine an area's vulnerability to natural disasters. This research aims to determine regional natural disaster vulnerability by calculating the natural disaster index. The data used in this research refers to data from the 2021 PODES data collection, which contains the intensity of natural disasters and casualties according to the type of natural disaster in Indonesia in 2020. The method used for the calculation is the weighted index method. The results of this research produced 5 clusters based on the level of natural disaster vulnerability according to sub-district/village. The top five provinces in Indonesia that have the highest natural disaster-prone areas are Aceh, North Sumatra, West Java, East Java, and Central Sulawesi. Research shows that sub-districts/villages in Indonesia are known according to their level of vulnerability to natural disasters. These results can be used as a reference for the government to carry out mitigation so that accelerated development in the local area can continue.

INTRODUCTION

Natural disasters are a phenomenon that often haunts Indonesia. As an archipelagic country located on the Pacific Ring of Fire, Indonesia is vulnerable to various types of natural disasters, ranging from earthquakes, volcanic eruptions, floods, and landslides to tsunamis (Hakim & Lee 2020, Malawani et al. 2021, Teh & Khan 2021). The existence of this natural disaster is no stranger to the Indonesian population. Most of them have even experienced it directly. Every year, news about natural disasters graces the mass media, painting a distressing picture of the loss and suffering caused by natural forces.

Not only do they cause material losses, but natural disasters also often cause loss of life. The ever-increasing loss of life is a reflection of how devastating the impact of natural disasters can be. Behind Indonesia's natural fragility, there are factors such as global warming, deforestation, and environmental pollution, which are increasingly making the situation worse. This high level of vulnerability requires alertness and cooperation between the government, society, and humanitarian organizations to reduce the impacts caused by natural disasters.

Apart from geographical factors, human factors also contribute to the frequent occurrence of natural disasters in Indonesia. Rapid population growth causes pressure on natural resources and the environment to increase. Practices such as deforestation, unsustainable agriculture, and irregular development can exacerbate the risk of natural disasters (Azare et al. 2020, Chirwa & Adeyemi 2020, Kumar et al. 2022). Deviations in environmental management and land use can also

increase the impact of natural disasters, such as flooding due to river flows being blocked by rubbish or development on river banks.

Apart from geographical and human factors, climate change is also an increasingly significant cause of increasing the risk of natural disasters in Indonesia (Celik 2020, Ebi & Hess 2020, Faradiba et al. 2024, Merrey et al. 2018, Prarikeslan et al. 2023). Climate change causes unstable weather patterns, increasing the frequency and intensity of extreme rainfall, drought, and tropical storms (Faradiba 2021). This has a direct impact on the occurrence of floods, landslides, and other disasters that damage infrastructure, disrupt livelihoods, and threaten the safety of residents (Faradiba & Zet 2020).

The impact of natural disasters can be very destructive and detrimental to society at large. One of the main impacts is material loss, where infrastructure such as houses, roads, bridges, and other public facilities can be damaged or destroyed due to earthquakes, floods, or volcanic eruptions. These losses not only affect the daily lives of residents but also cause economic activities, such as agricultural production, trade, and industry, to be hampered.

Apart from material losses, natural disasters can also cause human losses, both in terms of fatalities and physical and mental injuries. When a disaster occurs, people are vulnerable to various risks, such as being buried in the ground, drowning in floods, or being injured by building debris. Additionally, the psychological impact of losing a home, possessions, or even family members can cause lasting trauma and stress.

Apart from material and human losses, natural disasters can also cause social losses. Disasters often divide communities, sever social relationships, and result in forced migration. In addition, disasters can also exacerbate social disparities, where those who already live in conditions of economic or social vulnerability become more vulnerable to the impacts of disasters than those who are better off.

A region's vulnerability to natural disasters becomes clear when we look at the intensity and impacts they cause. The high intensity of natural disasters, such as earthquakes, volcanic eruptions, floods, or tsunamis, is a strong indicator of the region's vulnerability. Apart from that, the number of fatalities caused by natural disasters also provides a very important picture in evaluating the vulnerability of an area.

Regions that often experience natural disasters with high intensity and cause a significant number of fatalities show a serious level of vulnerability. For example, areas that are in the path of active earthquakes or close to active volcanoes tend to have a high vulnerability to earthquakes and volcanic eruptions. Likewise, areas are often affected by floods or tsunamis due to their geographical location in lowland or coastal areas.

Apart from geographical factors, social, economic, and infrastructure factors also play a role in determining the level of vulnerability of an area to natural disasters. Areas with high levels of poverty or weak infrastructure tend to be more vulnerable to the impacts of natural disasters due to a lack of access to health facilities, evacuation, and post-disaster assistance.

Natural disasters are a threat that is difficult to avoid because their strength depends on natural factors, which often cannot be predicted with certainty. However, although they cannot be completely avoided, the impacts caused by natural disasters can be minimized through various mitigation efforts. Disaster mitigation is a series of proactive actions aimed at reducing the risk and vulnerability of society to natural disasters.

One important aspect of disaster mitigation is a better understanding of the types of natural disasters that may occur in an area, as well as the factors that influence them. With a deep understanding of potential threats, the government and society can take appropriate preventive steps, such as preparing emergency response plans, developing disaster-resistant infrastructure, and preparedness training.

Apart from that, disaster mitigation also involves efforts to increase public awareness about disaster risks and safe ways to act when a disaster occurs. Education about evacuation, first aid, and the use of technology to monitor and predict disaster threats are also important parts of disaster mitigation. The higher the level of community awareness and preparedness, the more effective the disaster mitigation efforts will be.

In managing natural disaster risks, it is important to have a clear understanding of a region's vulnerability to various types of disasters. To do this, an index that can be used to measure the level of vulnerability to natural disasters in each region is needed. This index serves as a tool to compare levels of vulnerability between regions in Indonesia, thereby enabling stakeholders, including the government, humanitarian organizations, and the general public, to identify the most vulnerable areas and prioritize mitigation efforts.

By using the natural disaster vulnerability index, the government, and other stakeholders can identify areas that require special attention in terms of disaster mitigation (Fig. 1). Steps such as improving disaster-resistant infrastructure, educating the public about disaster risks, and developing effective emergency response plans can help reduce vulnerability and increase regional resilience

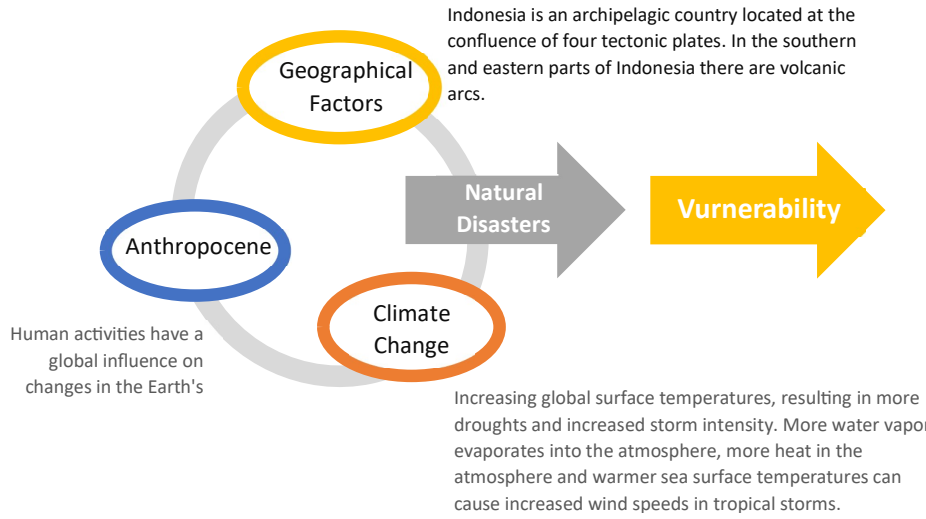

Fig. 1: Research conceptual framework.

to natural disasters. Thus, the use of a natural disaster vulnerability index can be a very valuable tool in efforts to reduce the impact of disasters and protect people's lives and property. Several previous studies related to natural disaster indices have been carried out using several methods, namely the Buffer-From-Cluster Approach (BFCA), index based on mortality, and others (Peduzzi et al. 2009, Pulvirenti et al. 2020, Wannewitz et al. 2016).

There have been many studies analyzing the impact of natural disasters in various regions (Kaniasty 2020, Pramono et al. 2020, Rosselló et al. 2020).

However, there are still only a few that calculate the natural disaster index in the smallest administrative areas. Therefore, this research aims to calculate the natural disaster index in sub-district and rural areas. The results of the research will produce an index for each region, which will be divided according to vulnerability clusters.

MATERIALS AND METHODS

This research uses data from the results of the 2021 Village Potential Data Collection (PODES), which includes information about the intensity of natural disasters and the number of fatalities due to various types of natural disasters in Indonesia during 2020. PODES is a government program that aims to collect data related to the condition of villages. Villages throughout Indonesia, including data related to natural disasters. This data is a rich and comprehensive source of information for analyzing the vulnerability and impact of natural disasters in various regions in Indonesia.

The method used in this research is the weighted index method, which is a statistical approach that is commonly used to combine several indicators or variables into one single index (Sun et al. 2021, Zhu et al. 2020). In this context, a weighted index is used to calculate the level of vulnerability to natural disasters in various regions in Indonesia. This approach allows researchers to assign appropriate weights to each variable under consideration, such as the intensity of natural disasters and the number of fatalities, thereby providing a more accurate picture of the level of vulnerability.

Weighted index is an average calculation method where each value in a data set has a certain weight that influences its contribution to the overall average value. The general formula for calculating the weighted index is as follows:

$$\text{Weighted Index} = \frac{\sum_{i=1}^{n} W_i \, x \, X_i}{\sum_{i=1}^{n} W_i}$$

Notes:

$7_{©}$ is the weight assigned to each value in the data set.

$8_{©}$ is value of each element in the data set.

$Ø$ is the number of elements in the data set.

By using the weighted index method, this research aims to provide a deeper understanding of the level of vulnerability to natural disasters in Indonesia. It is hoped that the results of this analysis can provide valuable input for decision-makers, including governments and humanitarian organizations, in designing effective and targeted disaster mitigation policies and programs. With a better understanding of vulnerability to natural disasters, it is hoped that mitigation efforts can be more targeted and have a significant impact in protecting communities and their assets from the threat of natural disasters.

RESULTS AND DISCUSSION

Based on Table 1, it is found that flood disasters are the type of natural disaster that occurs most frequently in Indonesia. This is not surprising considering Indonesia's geographic and climate characteristics, which are prone to high rainfall and topography, which tends to be swampy and hilly. Various factors, including heavy rain, river overflows, sea tides, and overflowing lakes or dams, can trigger floods. This condition causes flooding to become a constant threat to Indonesian people, especially to those who live in lowland areas or close to large rivers.

The impact of flooding on Indonesian society is very large, both in terms of material losses and casualties. Floods often cause damage to infrastructure, such as houses, roads, bridges, and other public facilities. Apart from that, floods can also disrupt economic activities, such as agriculture, trade, and industry. It is not uncommon for floods to result in loss of life, especially if there is no effective early warning system or adequate emergency response infrastructure.

To overcome the threat of flooding, various mitigation efforts need to be carried out, including building flood-resistant infrastructure, good river and drainage management, and increasing community capacity to face flood risks. Apart from that, it is also important to take adaptation steps to climate change, which could increase the intensity and duration of floods in the future. With coordinated and directed efforts, it is hoped that the level of vulnerability to flood disasters in Indonesia can be reduced so that people can live more safely and prosperously amidst inevitable natural threats.

Based on Table 2, as the intensity of flood disasters increases in Indonesia, the number of fatalities due to flood disasters occupies the top position compared to other types of natural disasters. This phenomenon shows how serious the impact of flooding is on the lives and safety of Indonesian people. Floods can cause huge losses not only in terms of material damage but also threaten human lives.

Flood disasters can cause casualties due to various factors, such as drowning, being swept away by flood currents, being buried by building rubble, or contracting infectious diseases after the flood recedes. Especially in areas that are prone to flooding and have high levels of population density, the risk of loss of life due to flooding is increasingly high. In addition, sometimes, a lack of access to safe evacuation facilities and effective early warning systems also contributes to high death tolls.

The increase in the number of fatalities due to floods highlights the importance of more effective flood mitigation and management efforts. Steps such as improving flood-resistant infrastructure, improving drainage systems, providing adequate evacuation facilities, and increasing

Table 1: Intensity of natural disaster events in 2020 by types.

Natural Disaster	Total	Std. Err.	[95% Cof. Interval]	
Landslide	10.518	174,89	10.175,20	10.860,80
Flood	26.889	278,30	26.343,51	27.434,49
Flash floods	1.054	46,78	962,30	1.145,69
Earthquake	20.881	335,56	20.223,30	21.538,70
Tsunami	19	10,14	-0,89	38,89
Tidal Waves	3.370	112,58	3.149,33	3.590,66
Whirlwind/ Tornado/Typhoon	3.726	75,83	3.577,36	3.874,63
Erupting volcano	321	28,20	265,70	376,29
Forest and Land Fires	1.856	68,44	1.721,84	1.990,15
Drought (Land)	2.750	61,90	2.628,66	2.871,33
Abrasion	1.614	66,35	1.483,94	1.744,05

Table 2: Number of death victims from natural disasters in 2020 by types.

Natural Disaster	Total	Std. Error	[95% Cof. Interval]	
Landslide	526	162,95	206,61	845,38
Flood	13.625	2.360,47	8.998,49	18.251,50
Flash floods	1.019	623,77	-203,59	2241,59
Earthquake	184	31,04	123,15	244,84
Tsunami	0			
Tidal Waves	831	417,81	12,09	1.649,90
Whirlwind/ Tornado/Typhoon	514	141,88	235,90	792,09
Erupting volcano	2	1,41	-0.77	4,77
Forest and Land Fires	667	637,10	-581,72	1.915,73
Drought (Land)	5.228	1.581,06	2.129,12	8.326,87
Abrasion	196	52,74	92,62	299,37

Table 3: Weight of natural disaster intensity in 2020 by types.

Natural Disaster	Weight
Landslide	0,04754842598427350
Flood	0,12155634400942500
Flash floods	0,00476478807638565
Earthquake	0,09439614783966680
Tsunami	0,00008589276418532
Tidal Waves	0,01523466396339630
Whirlwind/Tornado/Typhoon	0,01684402312392120
Erupting volcano	0,00145113564755199
Forest and Land Fires	0,00839036685936601
Drought (Land)	0,01243184744787530
Abrasion	0,00729636428395299

Table 4: Weight of casualties from natural disasters in 2020 by types.

Natural Disaster	Weight
Landslide	0,0154624429624430
Flood	0,4005243067743070
Flash floods	0,0299548087048087
Earthquake	0,0054089154089154
Tsunami	-
Tidal Waves	0,0244283081783082
Whirlwind/Tornado/Typhoon	0,0151096876096876
Erupting volcano	0,0000587925587926
Forest and Land Fires	0,0196073183573184
Drought (Land)	0,1536837486837490
Abrasion	0,0057616707616708

public awareness about the dangers of flooding are key to reducing the risk of loss of life due to flood disasters. With coordinated and integrated efforts between the government, society, and various related parties, it is hoped that the number of fatalities due to flooding can be reduced so that Indonesia can become more resilient in facing the inevitable threat of natural disasters.

In Table 3 and Table 4, weight data is used to calculate the natural disaster index. The method used in this calculation is the weighted method, which considers various factors in determining the severity of a natural disaster. In this context, the depth of calculation of the natural disaster index is influenced by two main factors, namely the number of natural disaster events and the number of victims affected.

These factors are then given a certain weight according to the level of impact on society and the environment. This weight is reflected in the Tables mentioned previously, where each natural disaster is given a weight based on an analysis of the risks and impacts it has. For example, natural disasters with a high number of fatalities will have greater weight than other natural disasters that have a more limited impact.

Table 5: 2020 natural disaster index range by cluster.

Cluster	Range Index
1	0.00
2	0.01-0.0941268
3	0.0941269-0.1286526
4	0.1286527-0.2824877
5	> 0.2824877

The results of calculating the natural disaster index are grouped into 5 clusters, as listed in Table 5. The higher the index value, the higher the vulnerability to natural disasters in that area. A value of zero in cluster 1 indicates that the region did not experience natural disasters during the research reference. Based on Fig. 2, if added up for each cluster, most regions in Indonesia do not have natural disasters.

From the data listed in Table 6, it can be seen that the provinces of Aceh, North Sumatra, West Java, East Java, and Central Sulawesi stand out as the regions with the number of villages or sub-districts most vulnerable to natural disasters. This information is presented based on clustering analysis, with a focus on cluster 6, which shows the highest natural disaster vulnerability index. The results of this study are in line with previous research (Ardiansyah et al. 2021, Capah, 2022, Ismana et al. 2022, Kharimah et al. 2022, Samad et al. 2020).

This focus on cluster 6 provides a clear picture of areas where the potential for natural disasters is a very important issue and needs special attention. This highlights the importance of grouping regions based on their level of

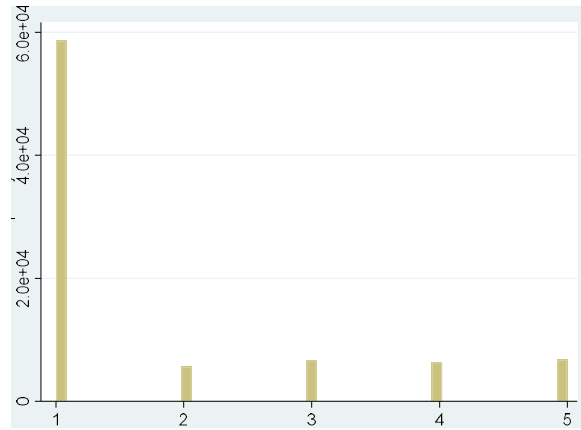

Fig. 2: Number of subdistricts/villages according to natural disaster index clusters in 2020 by cluster.

Table 6: Number of subdistricts/villages according to natural disaster index distribution Clusters and Provinces in 2020.

Province Code	Province	Cluster					Total
		1	2	3	4	5	
11	Aceh	4.550	238	633	466	627	6.514
12	Sumatera Utara	4.136	407	333	317	939	6.132
13	Sumatera Barat	622	98	114	145	308	1.287
14	Riau	1.342	92	186	160	96	1.876
15	Jambi	1.033	40	198	147	144	1.562
16	Sumatera Selatan	2.767	119	200	128	78	3.292
17	Bengkulu	1.227	57	64	79	87	1.514
18	Lampung	2.162	127	142	128	95	2.654
19	Kepulauan Bangka Belitung	285	52	17	21	18	393
21	Kepulauan Riau	300	85	11	16	16	428
31	DKI Jakarta	154	4	58	26	25	267
32	Jawa Barat	3.383	715	610	718	531	5.957
33	Jawa Tengah	6.100	851	711	579	321	8.562
34	DI Yogyakarta	255	79	30	44	30	438
35	Jawa Timur	6.277	473	653	535	558	8.496
36	Banten	956	92	203	147	154	1.552
51	Bali	518	69	45	48	36	716
52	Nusa Tenggara Barat	811	102	59	77	102	1.151
53	Nusa Tenggara Timur	2.368	648	157	189	88	3.450
61	Kalimantan Barat	1.248	68	224	324	284	2.148
62	Kalimantan Tengah	815	36	173	258	294	1.576
63	Kalimantan Selatan	1.379	87	274	165	102	2.007
64	Kalimantan Timur	699	43	100	104	100	1.046
65	Kalimantan Utara	324	15	67	46	30	482
71	Sulawesi Utara	1.183	121	127	136	273	1.840
72	Sulawesi Tengah	1.087	79	209	263	382	2.020
73	Sulawesi Selatan	2.056	243	301	272	179	3.051
74	Sulawesi Tenggara	1.942	118	148	71	30	2.309
75	Gorontalo	372	63	66	102	131	734
76	Sulawesi Barat	266	44	95	108	137	650
81	Maluku	845	154	101	79	69	1.248
82	Maluku Utara	477	58	120	207	341	1.203
91	Papua Barat	1.537	38	135	176	100	1.986
94	Papua	5.182	109	111	83	70	5.555
Indonesia		58.658	5.624	6.675	6.364	6.775	84.096

vulnerability to natural disasters to help central and regional governments plan more effective mitigation strategies.

The intensity of natural disasters can be reduced significantly by involving active participation from the local level, namely sub-districts and villages, in disaster mitigation efforts. This means giving regions a more important role in preparing for and responding to the threat of natural disasters. The data listed in Fig. 2 highlights the important role of Central Java Province in terms of early warning systems for natural disasters.

Central Java Province, with the largest number of sub-districts or villages in the natural disaster early warning system, shows high commitment and awareness in terms of disaster mitigation. This reflects investments made in early

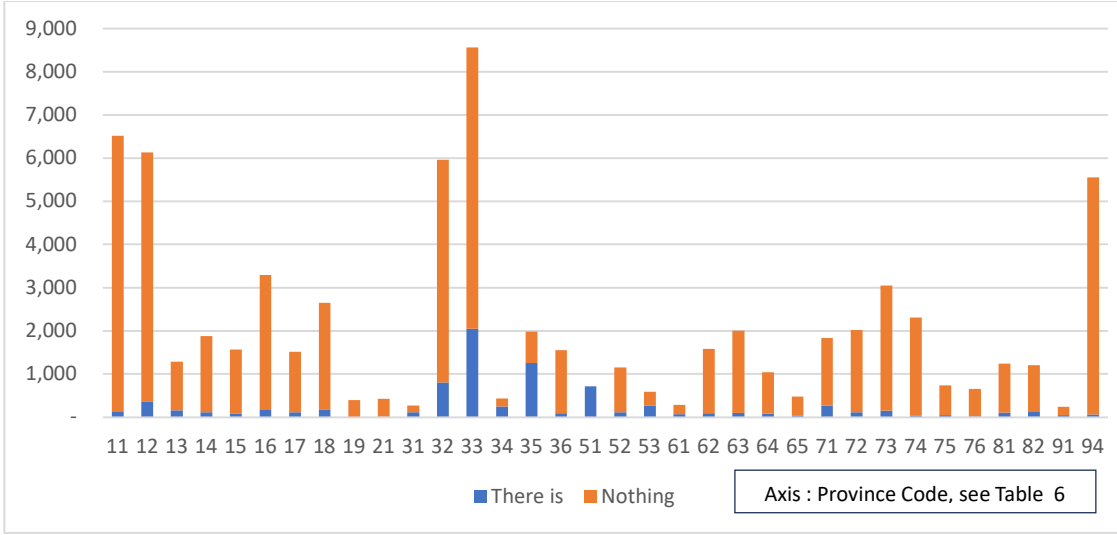

Fig. 2: Number of subdistricts/villages according to the 2020 natural disaster early warning system by Province.

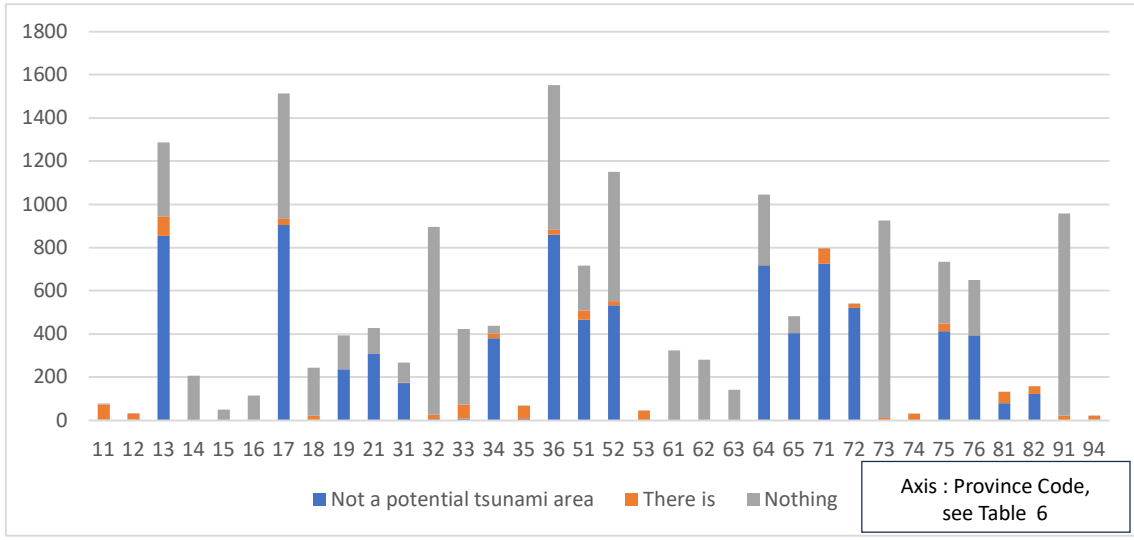

Fig. 3: Number of Subdistricts/Villages According to the 2020 Special Tsunami Early Warning System by Province.

warning infrastructure and the knowledge and skills of local communities in dealing with the threat of natural disasters.

The data depicted in Fig. 3 reveals that Aceh Province stands out as the province that has the largest number of sub-districts or villages integrated into a special tsunami early warning system. The presence of this early warning system reflects high awareness of the risk of tsunami disasters in the region, especially considering the tragic history of the large tsunami in 2004 that hit Aceh and most of the surrounding area.

The bitter experience of the disaster has prompted serious efforts to improve preparedness and mitigation in Aceh, with a particular focus on tsunami early warning. The availability of a widespread early warning system in sub-districts and villages in Aceh shows the commitment of the government and local communities to anticipating and responding to the threat of disaster quickly and effectively.

Aceh Province has a topography that is prone to earthquakes and tsunamis because of its position on the Pacific Ring of Fire. Therefore, investment in early warning infrastructure and community outreach is key in efforts to maintain safety and minimize losses due to the tsunami disaster. The existence of an extensive early warning system in Aceh not only reflects progress in disaster mitigation but also provides an example for other areas potentially exposed to similar threats to improve their preparedness.

The data depicted in Fig. 4 and Fig. 5 confirms that Central Java Province stands out as the province with the largest number of sub-districts or villages equipped with safety equipment and disaster evacuation signs/routes to increase preparedness for natural disasters. The existence of this safety equipment is a concrete step in preparing ourselves to face various potential natural disasters that could occur in the area.

Central Java Province, which is geographically located in the center of Java Island, has a fairly high risk of natural disasters such as earthquakes, floods, landslides, and volcanic eruptions. Therefore, awareness of the importance of disaster preparedness has encouraged serious efforts to provide safety equipment in every sub-district or village.

The data depicted in Fig. 6 shows that South Sumatra Province stands out as the province with the largest number of sub-districts or villages that are actively involved in the construction, maintenance, or normalization of water channels. This indicates a high commitment from the government and local communities to managing water infrastructure to reduce the risk of disasters related to flooding and waterlogging.

Based on Fig. 6, South Sumatra Province, with its geographical characteristics dominated by lowlands and large river flows, is often vulnerable to floods and other water-related problems. Therefore, activities to create, maintain, and normalize water channels are very important to reduce disaster risks and increase community resilience to these threats.

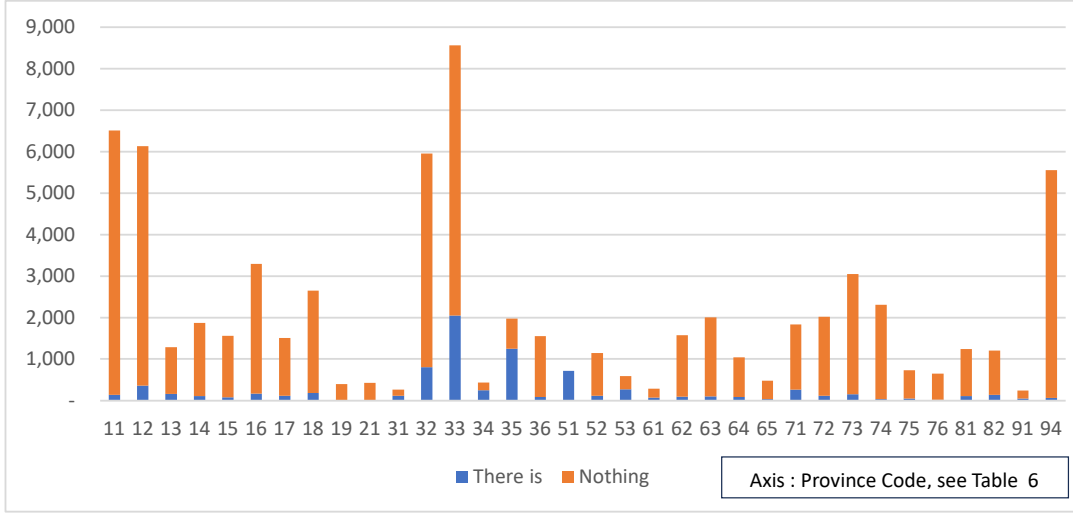

Fig. 4: Number of subdistricts/villages according to safety equipment in 2020 by Province.

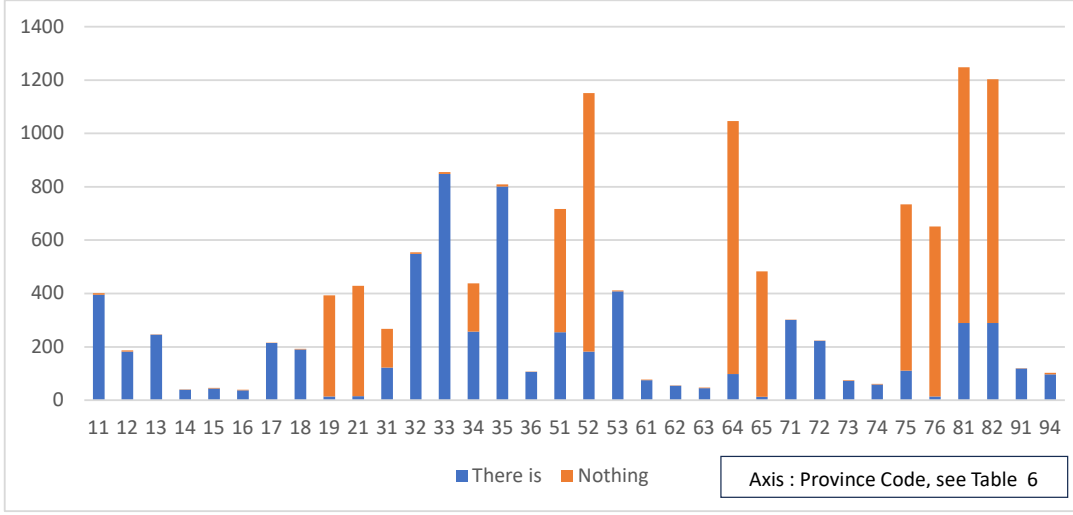

Fig. 5: Number of subdistricts/villages according to signs and disaster evacuation routes in 2020 by Province.

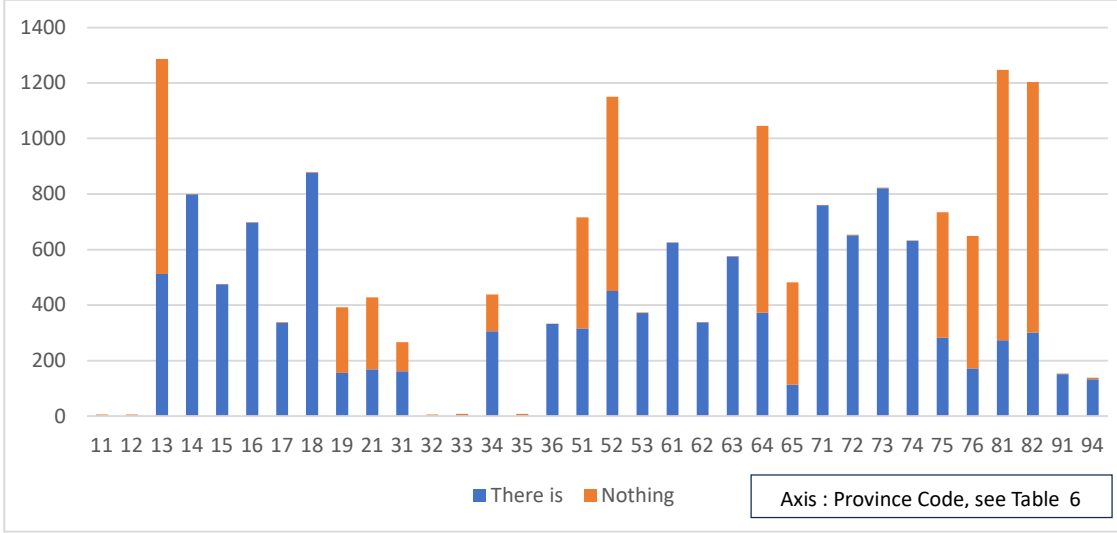

Fig. 6: Number of subdistricts/villages according to construction, maintenance, or normalization of water channels in 2020 by Province.

The active participation of sub-districts and villages in this effort shows the importance of the local role in managing water infrastructure. Local communities have extensive knowledge of local environmental conditions and can make valuable contributions in planning and implementing effective waterway maintenance activities.

Natural disaster mitigation is a crucial effort in anticipating and reducing the negative impacts caused by natural disasters. The main goal of disaster mitigation is to protect human lives, property, and vital infrastructure from damage or loss caused by natural disasters. The importance of disaster mitigation lies in the principle of prevention, which is more effective than handling it after a disaster occurs, thereby minimizing human and material losses.

Natural disaster mitigation is a shared responsibility that various parties must carry out. This includes government, civil society, non-governmental organizations, educational institutions, and the private sector. Each party has a different but interrelated role in achieving optimal disaster mitigation goals.

Through the index that has been calculated in this research, it is hoped that it can help the government in mitigating disaster-prone areas and evacuating areas that have been affected by disasters. The government's role is very important to minimize losses due to natural disasters. Apart from that, the government's role is also needed to repair areas that have been affected by natural disasters so that regional development acceleration can be achieved well.

The government has a central role in coordinating natural disaster mitigation efforts, starting from planning policy implementation to resource allocation. Civil society also has an important role in increasing preparedness and awareness of potential disasters, as well as actively participating in mitigation activities such as evacuation training and risk management. Non-governmental organizations often provide direct assistance to disaster victims and play a role in counseling and advocacy related to disaster mitigation. Meanwhile, the private sector can contribute in the form of technical support, financial resources, and infrastructure that can be used for disaster mitigation.

By actively involving various parties and coordinating natural disasters, mitigation efforts can become more effective and sustainable. Collaboration between government, communities, non-governmental organizations, and the private sector is key in building community resilience to the threat of natural disasters.

CONCLUSIONS

As an archipelagic country located on the Pacific Ring of Fire, Indonesia is vulnerable to various types of natural disasters, ranging from earthquakes, volcanic eruptions, floods, and landslides to tsunamis. Natural disasters are sometimes difficult to avoid, but the negative impacts of natural disasters can be minimized, especially in locations that are indicated to be prone to natural disasters. This research produces regional categorization based on the level of vulnerability to natural disasters. These results can be used as a reference in mitigating natural disasters, especially in areas that have the highest natural disaster index. Synergy is needed from various parties to minimize the negative impact of natural disasters. Through good mitigation, the

development of areas affected by natural disasters can be more alert in facing natural disasters.

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