Sumatra Journal of Disaster, Geography and Geography Education: December, 2023. Vol.7. No.2. pp. 1-7
Disaster, Geography, Geography Education http://sjdgge.ppj.unp.ac.id/index.php/Sjdgge
ISSN : 2580 - 4030 (Print) 2580 - 1775 (Online), Indonesia

EARTHQUAKE VULNERABILITY ASSESSMENT IN SANMA ISLAND, REPUBLIC OF VANUATU

Jafar

Department of Civil Engineering – Universitas Islam Indonesia, Indonesia
email: jafar@uii.ac.id

Corresponding Author, Received: Sept 11, 2023. Revised: Oct 11, 2023. Accepted: Dec 05, 2023

ABSTRACT: The purpose of this assessment is to identify which councils on Sanma Island are vulnerable to earthquake hazards. To measure vulnerability, it is necessary to identify certain contributing components, including exposure, sensitivity, and adaptive capacity. Exposure and sensitivity contribute to increasing the vulnerability, while adaptive capacity contributes to decreasing the vulnerability. Using this scheme, we identify specific variables for each component. These variables are called vulnerability variables. Next, we employ the Analytic Hierarchy Process (AHP) to obtain scores for each variable. Following the vulnerability assessment, five councils are categorized as areas with high vulnerability scores, including Canal-Fanafo, East Malo, East Santo, West Malo, and West Santo. This is because these areas are relatively close to the source of the threat (earthquake hazard). Moreover, these councils have a limited number of public facilities.

Keywords: Earthquake, Vulnerability Assessment, AHP, Vanuatu

1. INTRODUCTION

Hazards and disasters are a significant and growing concern [1]. Some of us, sometimes, are confused about these two words. We may perceive hazard and disaster as the same things, or we misunderstand the definition of these words. Hazard is “a process, phenomenon or human activity which may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation” [2]. When the hazard comes and brings impacts as mentioned above, then it becomes a disaster. If a hazard occurs but does not result in the mentioned impacts, it is not considered a disaster.

Natural disasters can be divided into two types: climate-induced disasters (CIDs) and non-climate-induced disasters (NCIDs) based on their causes. CIDs encompass various hydro-meteorological events, including floods, storm surges, coastal flooding, storms, typhoons, cyclones, heat waves, droughts, and wildfires. These events are either influenced by or related to climate change [2]. Meanwhile, NCIDs are geophysical disasters, including earthquakes, landslides, tsunamis, and volcanic eruptions [3]. Overall, the number of disasters, both CIDs and NCIDs, have steadily increased, particularly since the 1970s.

Earthquakes are a global issue, and they can be classified into four types based on their causes: explosion earthquake, volcanic earthquake, collapse earthquake, and tectonic earthquake [4]. The last type, tectonic earthquakes, are the most common and frequently occur. Tectonic earthquakes are strongly connected to the presence of the Ring of Fire (See Figure 1). Approximately 90% of the world's earthquakes occur near the Ring of Fire, also known as the Circum-Pacific Belt [5].

Earthquakes can be categorized into six classes based on their magnitude (see Table 1). Moderate to great earthquakes can result in loss of life or injury, property damage, social and economic disruption, or environmental degradation. Anyone can become a victim as long as they have vulnerabilities; in such cases, the risk is present. As long as they have vulnerability, then, the risk is there. Vulnerability is defined as 'the characteristics of a person or group and their situation that affect their ability to anticipate, cope with, resist, and recover from the impact of a natural hazard’ [6]

This research conducted an earthquake vulnerability assessment. The focus of this assessment is an island situated in the Pacific country of the Republic of Vanuatu, near the Ring of Fire (see Figure 2). More specifically, the study is centered on Sanma Island and its province. This island consists of ten councils. Over the past hundred years, it has experienced numerous earthquakes, including major ones. The objective of this assessment is to identify which councils on Sanma Island are vulnerable to earthquake hazards.

Sumatra Journal of Disaster, Geography and Geography Education: December, 2023. Vol.7. No.2. pp. 1-7
Disaster, Geography, Geography Education http://sjdgge.ppj.unp.ac.id/index.php/Sjdgge
ISSN : 2580 - 4030 (Print) 2580 - 1775 (Online), Indonesia

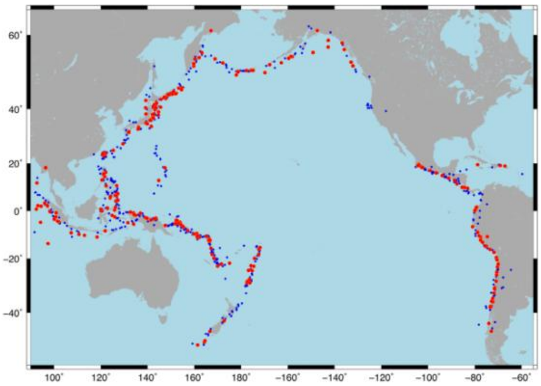
Figure 1. The Ring of Fire [7]

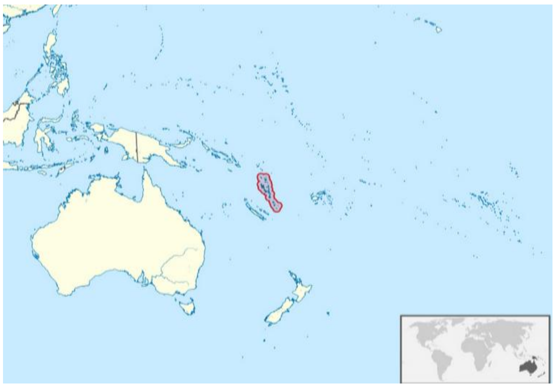
Figure 2. Republic of Vanuatu

Table 1. Earthquake Magnitude Classes

Class	Magnitude
Great	8 or more
Major	7 - 7.9
Strong	6 - 6.9
Moderate	5 - 5.9
Light	4 - 4.9
Minor	3 -3.9

2. METHOD

To measure vulnerability, it is necessary to identify certain contributing components, including exposure, sensitivity, and adaptive capacity. Exposure and sensitivity contribute to increasing the vulnerability, while adaptive capacity contributes to decreasing the vulnerability. In other words, if the exposure and sensitivity scores are high, then the vulnerability will be high. Vice versa, if the adaptive capacity scores are high, then the vulnerability will be low.

Using this scheme, we identify specific variables for each component. These variables are called vulnerability variables. Next, we employ the Analytic Hierarchy Process (AHP) to obtain scores for each variable. These scores, on a scale of 0-1, represent the importance of each variable. These scores will be used further in vulnerability analysis. Below, Figure 4 illustrates the methodology diagram.

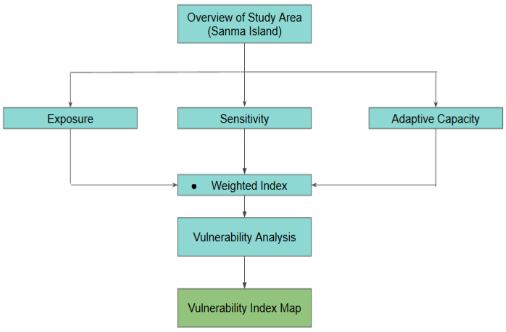

Figure 3. Methodology Diagram of The Study

3. RESULTS AND DISCUSSION

3.1 Exposure

Exposure can be defined as the situation of people, infrastructure, housing, production capacities, and other tangible human assets located in hazard-prone areas [8]. In this study, two variables of exposure were identified: Peak Ground Acceleration (PGA) and population density.

PGA can be defined as "amplitude of the largest peak acceleration recorded on an accelerogram at a site during a particular earthquake" [9]. When an earthquake occurs, it releases strong energy that spreads through the soils and reaches the surface where the buildings stand. Based on the Newton's Law II, Force (F) is the function of mass (m) and acceleration (a). This means that if the PGA affects the buildings, it will generate earthquake forces due to the buildings' mass.

Sanma Island experienced several major earthquakes in the past hundred years. Figure 3 displays recorded earthquakes that occurred in Vanuatu between 1900 and 2017. From those major earthquakes, an earthquake that occurred in 1965 with the magnitude of 7.7 were selected and then the PGA was obtained. The PGA is expressed in g (acceleration due to gravity) where 1g equals 9.81 m/sec^2. For analysis purposes, this unit is scaled into a score range of 0-1, where 1 represents the highest PGA (see Figure 5). Figure 4 illustrates that certain councils are highlighted in red, indicating they have higher PGA scores based on the previous earthquake event. The councils are Luganville, West Malo, East Malo, Canal Fanafo, and some part of East Santo.

The second component of exposure is population density related to the hazard. Each council has a different number of inhabitants. The higher the number of inhabitants exposed to the hazard, the greater the vulnerability. For population density, scores from 0-1 were assigned to each council. First, population density was categorized into 5 classes (see Table 2). Second, score for each council was decided (see Table 3). Table 3 shows that Luganville has the highest population density, with a score of 0.8.

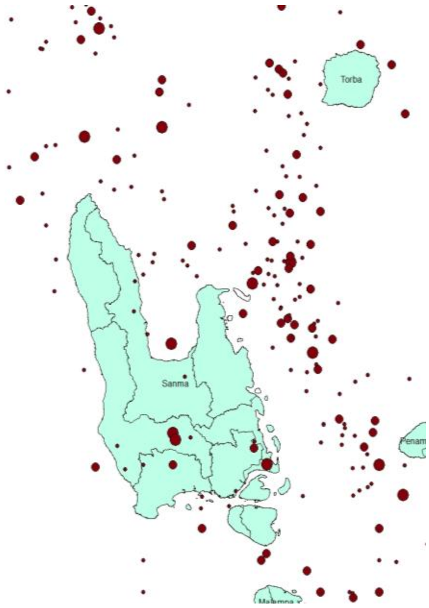

Figure 4. Recorded Earthquake in Sanma Island Vanuatu between 1900-2017 [10]

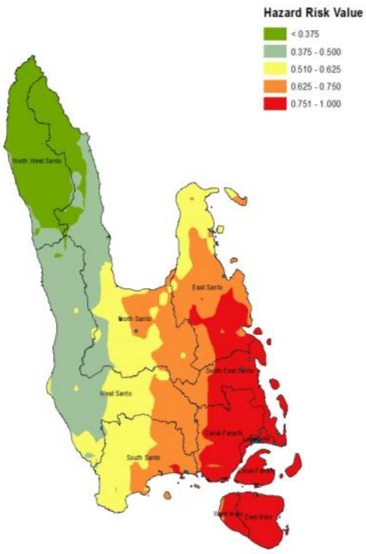

Figure 5. Earthquake Risk Value

Table 2. Population Density Classes

Population Density (inhabitants/km2)	**Classes**	**Score**
< 100	Very Low	0.2
100 - 250	Low	0.4
251 - 500	Moderate	0.6
501 - 1000	High	0.8
>1000	Very High	0.1

Table 3. The Population Density scores for each council

No.	Council	Population (Inhabitants)	Area (km^2)	Population Density (inh./ km^2)
1	Canal-Fanafo	4,916	360.5	13.64
2	East Malo	2,012	135.3	14.87
3	East Santo	4,685	607.2	7.72
4	Luganville	16,312	24.9	655.10
5	North Santo	4,747	1,023.5	4.64
6	North West Santo	1,697	457.5	3.71
7	South East Santo	5,956	257.2	23.16
8	South Santo	8,434	423.2	19.93
9	West Malo	2,353	47.8	49.23
10	West Santo	3,072	885.5	3.47

Source : Vanuatu National Statistics Office [11] with author edits

3.2 Sensitivity

Sensitivity refers to the extent to which various systems and population sectors are affected by hazards. In this study, children (0-14 years old) and elderly people (60+) were classified as the sensitive group. Children typically lack awareness of disasters, which often results in their lack of preparedness when disasters occur. Elderly people may have knowledge about disasters, but they often lose adaptability due to health issues like illness and disability. That is why elderly group becomes less capable of coping with disaster. The score for the sensitive group is based on its ratio. Councils with a higher percentage of the sensitive group receive higher scores (see
Table 4 and Table 5 below).

Table 4. The Score Range of Sensitive Group

No.	Ratio (%)	Score	No.	Ratio (%)	Score
1	< 10	0.1	6	51 - 60	0.6
2	10 - 20	0.2	7	61 - 70	0.7
3	21 - 30	0.3	8	71 - 80	0.8
4	31 - 40	0.4	9	81 - 90	0.9
5	41 - 50	0.5	10	91 - 100	1.0

Table 5. The Score of Sensitive Group for Each Council

Council	Age			Total	Kids & Elder P1eople	Ratio (%)	Score
	0-14	15-59	60+				
Canal-Fanafo	1,935	2,491	285	4,916	2,220	45.15	0.5
East Malo	789	988	140	2,012	929	46.17	0.5
East Santo	1,736	2,441	286	4,685	2,022	43.16	0.5
Luganville	5,671	9,397	797	16,312	6,468	39.65	0.4
North Santo	2,023	2,305	287	4,747	2,310	48.66	0.5
North West Santo	581	879	94	1,697	675	39.77	0.4
South East Santo	2,224	3,123	294	5,956	2,518	42.27	0.5
South Santo	3,567	4,076	477	8,434	4,044	47.95	0.5
West Malo	933	1,213	183	2,353	1,116	47.43	0.5
West Santo	1,306	1,460	164	3,072	1,470	47.85	0.5

Source: Vanuatu National Statistics Office [11] with author edits

3.3 Adaptive Capacity

According to Fussel and Klein [12], adaptive capacity is "the ability of a system to adjust to climate change (disaster) so as to moderate potential damage, take advantage of opportunities, or help cope with consequences". In other words, adaptive capacity is what enables the council to become less vulnerable. It can be what the councils have or what the government does to reduce the vulnerability.

For the adaptive capacities of Sanma Island, some crucial public services were included, namely, Hospitals, Police/Fire Stations, and Schools. Hospital is responsible for medical care during and after disaster occurs. Police/Fire Stations are crucial for search and rescue actions and evacuation. Lastly, School can be used as emergency shelters for internally displaced person (IDP).

After conducting observation, there is only one standard hospital in Sanma Island and it is located at Luganville Council. There are two Police Stations including Northern District Headquarter Figure 6) and there is one Fire Station which is located in Luganville Council as well Figure 7). There are 17 schools in Sanma Island and one college, Vanuatu Agriculture College. All public facilities of Sanma Island were displayed inFigure 8.

The areas within the island are scored based on the proximity to these public services. If a council has these components or at least these components are nearby, it will help to reduce the vulnerability. The areas within the radius of 0.0 - 0.5 miles from public services will be scored 1, the areas within the radius of 0.5 - 5.0 miles will be scored 0.5, and beyond the radius of 5 miles, the score will be 0.

Figure 6. Police Station of Luganville

Figure 7. Fire Station of Luganville

Sumatra Journal of Disaster, Geography and Geography Education: December, 2023. Vol.7. No.2. pp. 1-7
Disaster, Geography, Geography Education http://sjdgge.ppj.unp.ac.id/index.php/Sjdgge
ISSN : 2580 - 4030 (Print) 2580 - 1775 (Online), Indonesia

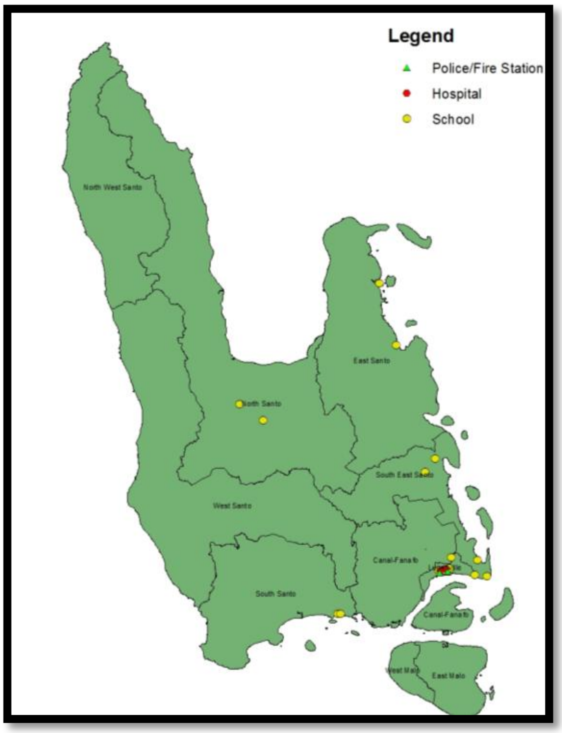

Figure 8. The Public Services in Sanma Island

3.4 Vulnerability

In the previous sections, the variables of exposure, sensitivity and adaptive capacity have been identified. The variables are 1) PGA; 2) Population Density; 3) Sensitive Group; 4) Hospital; 5) School; 6) Police/fire Station. In this section, we analyze these variables and calculate the vulnerability index. As described by Taylor [13], exposure and sensitivity increase vulnerability, while adaptive capacity reduces it. Therefore, we can express this definition using a simple formula.

$$V = (X + S) - AC \qquad (1)$$

Where:
X = Exposure
S = Sensitivity
AC = Adaptive Capacity

However, before analyzing the data, it is necessary to conduct AHP step to get the weighted index for each variable. The summary of AHP analysis is shown in Table 6 below.

By including the weighted index, the final formula of vulnerability index will be:

Vulnerability = ((0.4342*PGA) + (0.0615*Population Density) + (0.1195*Sensitive Group)) - ((0.2307*Hospital) + (0.1541*School) + (0.1225*Police/fire Station))

The vulnerability index map is shown in Figure 9. The average vulnerability value for each council is shown in Table 7 below.

Table 6. Analytic Hierarchy Process of Earthquake Vulnerability Assessment in Sanma Island

	Hazard Zone	Population Density	Vulnerable Group	Hospital	School	Police/fire Station	**Weighted Index**
Hazard Zone	1.00	5.00	3.00	3.00	4.00	3.00	**0.4342**
Population Density	0.20	1.00	0.25	0.33	0.50	0.50	**0.0615**
Vulnerable Group	0.33	4.00	1.00	0.50	0.50	0.50	**0.1195**
Hospital	0.33	3.00	2.00	1.00	2.00	3.00	**0.2307**
School	0.25	2.00	2.00	0.50	1.00	2.00	**0.1541**
Police/fire Station	0.33	2.00	2.00	0.33	0.50	1.00	**0.1225**

.Table 7.The Average Vulnerability Index for Each Council

No.	Council	Average Vulnerability Score	Vulnerability Index
1	Canal-Fanafo	0.7236	High
2	East Malo	0.7784	High
3	East Santo	0.7166	High
4	Luganville	0.4792	Low
5	North Santo	0.6877	Moderate
6	North West Santo	0.6332	Moderate
7	South East Santo	0.6913	Moderate
8	South Santo	0.6820	Moderate
9	West Malo	0.7175	High
10	West Santo	0.7132	High

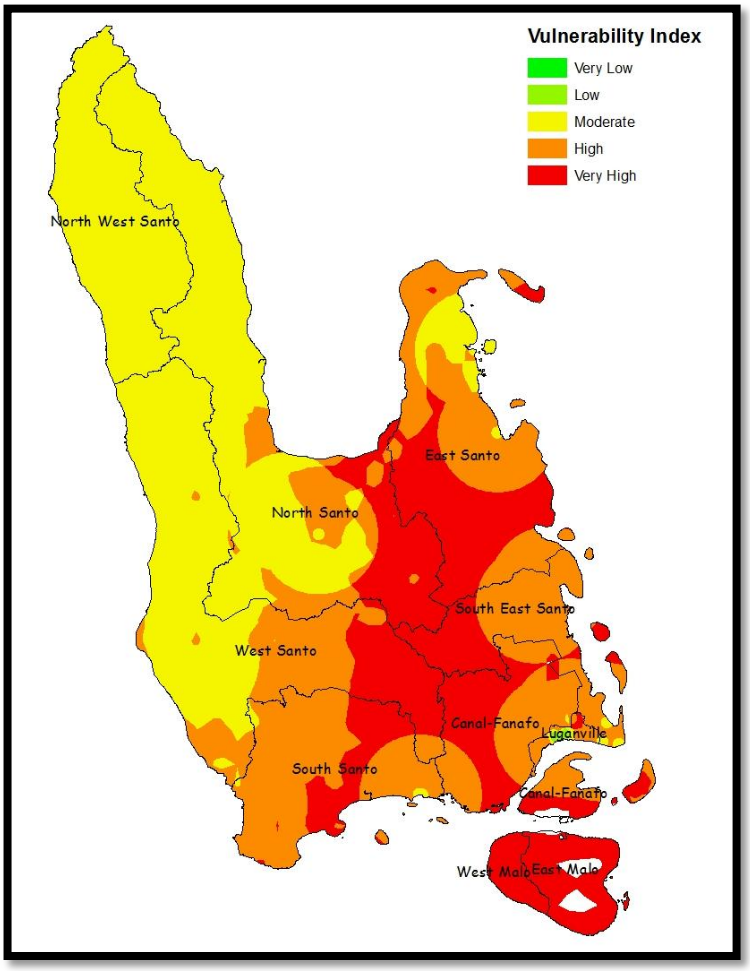

Figure 9. Vulnerability Index Map of Sanma Island

Following the vulnerability assessment, we obtained the vulnerability scores for the councils within Sanma Island. Five councils are categorized as areas with high vulnerability scores, including Canal-Fanafo, East Malo, East Santo, West Malo, and West Santo. This is because these areas are relatively close to the source of the threat (earthquake hazard). Moreover, these councils have a limited number of public facilities, hence their adaptive capacity is relatively low. Luganville, eventhough located near the threat and densely populated, has public facilities such as hospital, police stasion, schools, and fire station hence the vulnerability level is low. Based on these results, we can conclude that if the public facilities in the other councils are adequately provided or built, the vulnerability scores of these councils will decrease.

4. CONCLUSION

Based on the study, it can be concluded that:

1. There are 5 councils with a high level of vulnerability: Canal-Fanafo, East Malo, East Santo, West Malo, and West Santo.
2. Four councils have a moderate level of vulnerability: North Santo, North West Santo, South, and East Santo.
3. One council has Low level of vulnerability (Luganville).
4. Most of the councils with a high vulnerability level are located near the epicenter of the earthquake, except for Luganville.
5. Lastly, Luganville has a low level of vulnerability despite its proximity to the earthquake epicenter due to its strong adaptive capacity components.

5. FUTURE RESEARCH

This research includes only one sensitivity factor: the sensitive group (based on age). Future research should consider adding other factors, such as education level, infrastructure condition, and building categories, to yield more robust results. Education can influence the ability to understand and respond to information, thereby enhancing resilience and adaptive capacity. Infrastructure plays a role in reducing sensitivity and increasing adaptive capacity. Councils with better infrastructure are less sensitive. For example, if an earthquake hits a remote area with limited access, evacuating people from that area would be challenging. Delivering humanitarian assistance would also be hindered. The final component is buildings. Buildings are actually crucial components for earthquake vulnerability assessment, but we couldn't incorporate them due to a lack of data. Buildings should be the main issues since basically earthquakes do not kill people directly, the collapsed buildings due to earthquakes do. Non-earthquake-resistant buildings are more sensitive compared to earthquake-resistant ones. If we can locate and identify houses within the study area, we can measure vulnerability in more detail.

6. REFERENCES

[1] A. L. Peek and D. S. Mileti, "The History and Future of Disaster Research," in *Handbook of Environmental Psychology*, 2002, pp. 511–524.

[2] UNISDR, "Hazard," 2007. https://www.undrr.org/terminology/hazard (accessed Jul. 11, 2023).

[3] A. Wirtz and R. Below, "Disaster Category Classification and peril Terminology for Operational Purposes," *Context*, no. October, pp. 1–20, 2009, [Online]. Available: cred.be/sites/default/files/DisCatClass_264.pdf.

[4] Widodo, *Seismologi Teknik dan Rekayasa Kegempaan*. Yogyakarta: Pustaka Pelajar, 2012.

[5] T. Islam and J. Ryan, "Chapter 5 - Hazard Identification—Natural Hazards," T. Islam and J. B. T.-H. M. in E. M. Ryan, Eds. Butterworth-Heinemann, 2016, pp. 129–170.

[6] Y. Du, Y. Ding, Z. Li, and G. Cao, "The role of hazard vulnerability assessments in disaster preparedness and prevention in China," *Mil. Med. Res.*, vol. 2, no. 1, p. 27, 2015, doi: 10.1186/s40779-015-0059-9.

[7] P. Bountzis, G. Tsaklidis, and E. Papadimitriou, "Pseudo-prospective forecasting of large earthquakes full distribution in circum-Pacific belt incorporating non-stationary modeling," *Phys. A Stat. Mech. its Appl.*, vol. 604, p. 127945, 2022, doi: https://doi.org/10.1016/j.physa.2022.127945.

[8] UNISDR, "Exposure," 2009. https://www.undrr.org/terminology/exposure (accessed Jul. 11, 2023).

[9] J. Douglas, "Earthquake ground motion estimation using strong-motion records: a review of equations for the estimation of peak ground acceleration and response spectral ordinates," *Earth-Science Rev.*, vol. 61, no. 1, pp. 43–104, 2003, doi: https://doi.org/10.1016/S0012-8252(02)00112-5.

[10] USGS, "ANSS Comprehensive Earthquake Catalog." https://earthquake.usgs.gov/data/comcat/index.php#2.

[11] Vanuatu National Statistics Office, "2016 Post - TC PAM Mini Census Report. Port Vila," 2017. .

[12] H.-M. Füssel and R. J. T. Klein, "Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking," *Clim. Change*, vol. 75, no. 3, pp. 301–329, 2006, doi: 10.1007/s10584-006-0329-3.

[13] J. Taylor, D. Fatimah, S. Dougherty, R. Hidayani, and A. Rifai, *Climate Change Vulnerability Assessment Kupang City. Solo: United Nations Development Programme- Safer Communities Through Risk Reduction (UNDP-SCDRR) and Yayasan Kota Kita*. 2015.