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Reformulation disaster risk index assessment in Palu City, Indonesia

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The complexity of its tectonic plate influences Indonesia. Archipelagic countries pose a catastrophic threat of disaster. The subduction line surrounding Indonesia contributes to the enormous potential for tectonic earthquakes. Geographical conditions and natural disaster susceptibility in Indonesia led to a catastrophic earthquake in Palu City on 28 September 2018, one of the most catastrophic disasters in Indonesia. Response to disaster risk requires a transformation from adaptive capacity to resilience. Adaptive capacity cannot respond to catastrophic events and unpredictable disasters. Resilience can be a component in the disaster risk index because it reduces the level of risk and is also necessary as a learning process for rebuilding a system after a catastrophic disaster. This research formulates a disaster risk index by refining the standard calculation method. The capacity component in the formula will be replaced with the resilience component. The calculation of the disaster risk index, considering the resilience component, will be tested in Palu City. The disaster risk index of Palu City will be reduced if the resilience component is applied. A system can use the resilience component to reach a new equilibrium after a catastrophic disaster, even if it happens repeatedly. That way, a system bounces back better and develops its ability to face disasters, forming a new balance that reduces disaster risk.

Contribution: This study aims to reformulate the Disaster Risk Index, thereby improving disaster risk calculations. The system can remain resilient to disasters and transform into a new system after a disaster, even when disasters occur repeatedly.

Keywords: resilience; sensitivity; exposure; catastrophic; disaster; risk.

Introduction

Adaptation and coping capacity efforts in response to disasters are often carried out, but these efforts are not always effective in dealing with catastrophic disasters. Disaster mitigation efforts after catastrophic disasters are also reactive and temporary (Yu et al. 2023). These responses cannot cope with the weather, pressure and shocks that will occur due to disasters. Areas that have experienced catastrophic disasters require a robust and resilient system to mitigate future catastrophic disasters. After a catastrophic disaster, the system must transform to reach a new state of balance. That way, the system can survive and not collapse in the event of another catastrophic disaster.

Resilience theory is particularly suitable for implementation in areas that have experienced catastrophic disasters such as those caused by tsunamis and volcanic eruptions in Indonesia. Resilience systems can enhance a system's capacity to withstand shocks and pressures (Hodbod & Eakin 2015). Areas that have experienced catastrophic disasters require disaster risk reduction efforts that are not only focused on the recovery stage but also prepare the area to face future disasters. The area needs to build resilience to face future disasters.

This research aims to reformulate the Disaster Risk Index by improving its calculation. This formulation is intended for catastrophic disaster recovery phases because resilience is demonstrated when a system experiences disruptions and shocks caused by catastrophic disasters. The calculation of the Disaster Risk Index, considering the resilience component, will be tested in Palu City. The Disaster Risk Index of Palu City will be reduced if the resilience component is applied. Using the resilience component, a system can reach a new equilibrium point after a catastrophic disaster occurs, even if it happens repeatedly. That way, a system bounces back better and develops its ability to face disasters, forming a new balance that reduces disaster risk.

Resilience theory in Disaster Risk Index assessment

The calculation of the Disaster Risk Index considers resilience theory developed from the Disaster Resilience of Place (DROP) model, as shown in Figure 1. The position of vulnerability, adaptive capacity and resilience is depicted in the Venn diagram introduced by Cutter (2021). If a system only has a coping capacity, the disaster risk will not be reduced. Therefore, there needs to be absorptive capacity, which is the ability to recognise, understand and respond to a disaster event. If there is absorptive capacity, then the initial stage of resilience has been achieved; the next step is improvisation and social learning, allowing the system to become resilient to disasters. DROP diagram serves as a reference for reformulating the concept of disaster risk reduction, illustrating the link between adaptive capacity, vulnerability and resilience.

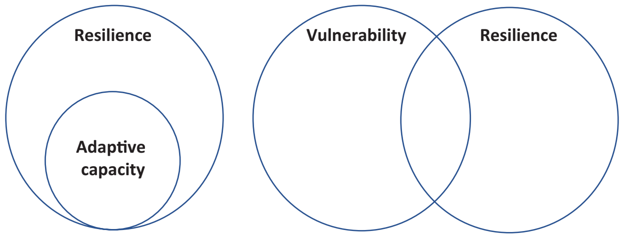
Cutter's theory was developed in response to subsequent theories that linked resilience theory and disaster risk reduction. For example, the Australian Natural Disaster, in the article by Parsons et al.' (2016), also coping capacity and adaptive capacity as the basis for developing a resilience index (Figure 2). According to Liu (2015) and Mohamed, Hailu and Tebarek (2020), coping capacity refers to a system's ability to coping resources, skills and opportunities in response to disturbances caused by disasters. Meanwhile, adaptive capacity is a process that requires post-disaster adjustments.

Based on the risk calculation described in points 1 and 2, the researcher aims to reformulate the concept of disaster risk calculation that can be applied to disaster-prone areas in Indonesia that have experienced catastrophic disaster events. This reformulation represents resilience as an accumulation of adaptive capacity, coping capacity, spatial planning and governance. Resilience is the ability to improvise and transform a system to be better prepared for disasters, encompassing preparedness, emergency response and disaster management efforts following a disaster. Figure 3 shows the basic disaster risk formula in the context of climate change. The risk formula is influenced by hazard, vulnerability and adaptive capacity.

Replication of resilience theory and disaster risk index

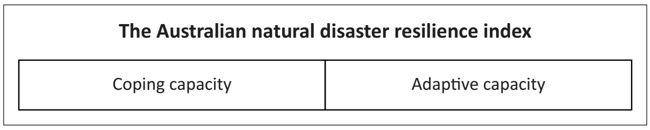
Referring to the initial disaster risk formula, the concept of adaptive capacity, based on DROP, and the resilience framework of the Australian Natural Disaster was developed to reformulate disaster risk reduction, which includes hazard, exposure, sensitivity and resilience.

Coping and adaptive capacities have not been able to reduce disaster risk significantly; researchers aim to reformulate the concept of disaster risk reduction, making it implementable and applicable to disaster-prone areas in



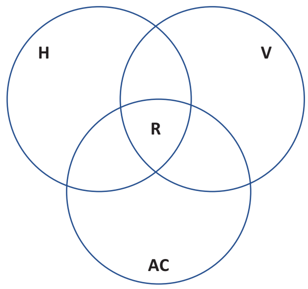
Source: Cutter, S.L., 2021, *Urban risk and resilience*, The International Society for Urban Informatics

FIGURE 1: Disaster Resilience of Place Theory as the basis for reformulation of Disaster Risk Index calculation.



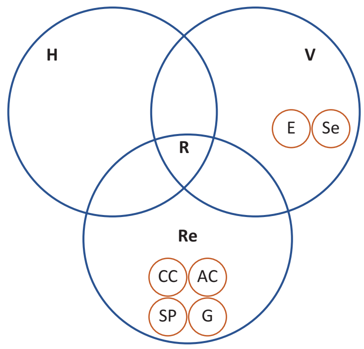
Source: Parsons, M., Glavac, S., Hastings, P., Marshall, G., McGregor, J., McNeill, J. et al., 2016, 'Top-down assessment of disaster resilience: A conceptual framework using coping and adaptive capacities', *International Journal of Disaster Risk Reduction* 19, 1–11. https://doi.org/10.1016/j.ijdrr.2016.07.005

FIGURE 2: The Natural Disaster Resilience Index as the basis for reformulating the Disaster Risk Reduction concept.



H, Hazard; R, Risk; V, Vulnerability; AC, Adaptive Capacity.

FIGURE 3: Disaster Risk Index Calculation in the context of climate change as the basis for reformulating the disaster risk reduction concept.



R = H ∩ *V* ∩ *Re*
R = H ∩ (*E*//Se) ∩ (CCUACUSPUG)
V = *E* // Se
CCUACUSPUG = Re

H, Hazard; CC, Coping Capacity; R, Risk; V, Vulnerability; AC, Adaptive Capacity; Re, Resilience; Se, Sensitivity; G, Governance; E, Exposure; SP, Spatial Planning.

FIGURE 4: Replication of resilience theory and calculation of the Disaster Risk Index based on resilience.

Indonesia that have experienced catastrophic disaster events. This reformulation represents resilience as an accumulation of adaptive and coping capacities (Figure 4 and Figure 5). Resilience is the ability to improvise and transform a system to be better prepared for disasters, encompassing preparedness, emergency response and disaster management efforts following a disaster.

This disaster risk reduction reformulation replaces the vulnerability variable with exposure and sensitivity variables. Exposure variables are used to determine the spatial unit of the sensitivity variable precisely. Meanwhile, the sensitivity variable represents the system's responsiveness to the impact of a disaster. This component is dynamic and continually changes over time. This component also cannot be separated from exposure related to how a system responds to disturbances (Monte et al. 2021). So, vulnerability can be reformulated into components of exposure and sensitivity.

According to Cutter and Parsons' Theory, coping and adaptive capacities are integral to resilience. Likewise, in Indonesia, before a catastrophic disaster, efforts were made to enhance coping and adaptation capacities. It is just that neither of these efforts could address catastrophic disasters and a new type of disaster emerged, namely, liquefaction. Therefore, a resilience component is necessary to cope with intense disasters and emerging types of disasters (Lindblom 2015; Yu et al. 2023):

$$R = \int \{H, V, AC\} \rightarrow R = \int \{H, E, Se, Res\} \quad \text{[Eqn 1]}$$

$$R = \frac{H \times V}{C} \rightarrow R = \frac{H \times E \times Se}{Res} \quad \text{[Eqn 2]}$$

Resilience is the accumulation of all aspects of livelihood that contribute to reducing the value of disaster risk (Rockefeller Foundation, 2015). The resilience variable will be developed from the resilience framework and previous research. The components of resilience have been obtained, namely, adaptive capacity (AC), coping capacity (CC), spatial planning (SP) and governance (*G*), where total resilience is the sum of all the four components:

$$Res_{Total} = AC + CC + SP + G \quad \text{[Eqn 3]}$$

So that the final equation is obtained from the reformulation of the Disaster Risk Index calculation:

$$R = \frac{H \times E \times \mathrm{Se}}{\mathrm{ResTotal}} \quad \text{[Eqn 4]}$$

Disaster Risk Index assessment through application of resilience theory

Hazard components

The hazard component uses data from the Ministry of Energy and Mineral Resources. This hazard is identified as a natural process that can cause disasters such as earthquakes, volcanic eruptions, floods, droughts and landslides. Thus, natural hazards are natural events arising from specific geophysical (Liu 2015).

As a natural event, the essential characteristics of hazards consist of space, time and magnitude (Rockefeller Foundation 2015; Ruggerio 2021; Ruiter & Loon, 2022). The spatial attribute identifies the location of the geophysical disaster and the extent of the affected area. The time scale also consists of two attributes: the time of occurrence and the duration of the event. Magnitude indicates the strength of the hazard event, including intensity, frequency and speed. The conclusion of the compilation of hazard components in this study is as follows:

- Focus on hazards caused by geological and hydrometeorological factors.
- Assessment of vulnerability levels using Geographic Information System (GIS) scoring and analysis (superimposed) for each type of hazard.

The hazards considered in the risk calculation of Palu City comprise five types: liquefaction, tsunami, active fault, landslide and flood. Additionally, there are five disaster exposure classifications: very low, low, medium, high and very high (Figure 6).

The horizontal and longitudinal fault movement in the southern part of Kulawi, which crosses Palu City, caused a tsunami anomaly on 28 September 2018. The horizontal fault movement caused a tsunami wave that hit Palu City, resulting in a tsunami height of 6 m. The distribution of the tsunami flow depth varies. At the bottom of Palu Bay, along Talise Beach and the coastal tourist area of Palu City, the tsunami height ranges from 1.67 m to 5.55 m (Geological Agency 2018).

It impacted economic activity in Palu City because the dominant activities on Palu City's coast were commercial, both formal and informal (Palu City Government, 2022). In addition, social facilities were also affected by the tsunami disaster. In addition, social facilities were also affected by the tsunami disaster.

Tectonic evolution on Sulawesi Island has resulted in a complex geological structure characterised by faults, folds and fractures at both sea and land levels. The Palu–Koro Fault is one of the geological structure patterns on land. The Palu–Koro Fault is divided into five segments from north to south: the Palu Segment, Gumbassa Segment, Saluki Segment, Moa Segment, and Meloi Graben Segment.

Liquefaction disasters are triggered by earthquakes, especially in areas such as the vicinity of the Purba River, which has a high potential for liquefaction (Geological Agency 2018). In 2018, massive liquefaction occurred in the Balaroa and Petobo areas, resulting in the emergence of an underground waterway.

Exposure components

Dhungana et al. (2025) stated that exposure is part of disaster risk. *Exposure* can be defined as the number, type and value of properties, infrastructure, environment, economy or population at risk under a hazardous event's threat (Gill et al. 2022; Ortwin Renn et al. 2019). According to the UN Office for Disaster Risk Reduction (UNDRR 2017), exposure is a risk element that consists of individuals, groups of people or elements located in the vicinity of where the hazard event occurs (Jones & Tanner, 2015; Lindstädter et al. 2016; Otsuki, Jasaw & Lolig 2017). Castro et al. (2016) utilise elements such as population, buildings, infrastructure and economic centres to assess the level of exposure. In this study, population and building elements will be used to assess the level of exposure. This exposure component can be assessed based on the building plots exposed to the disaster, which are also used to determine the sample in this study. This exposure analysis is crucial for understanding the regional units or populations that are exposed to damage and both material and non-material losses.

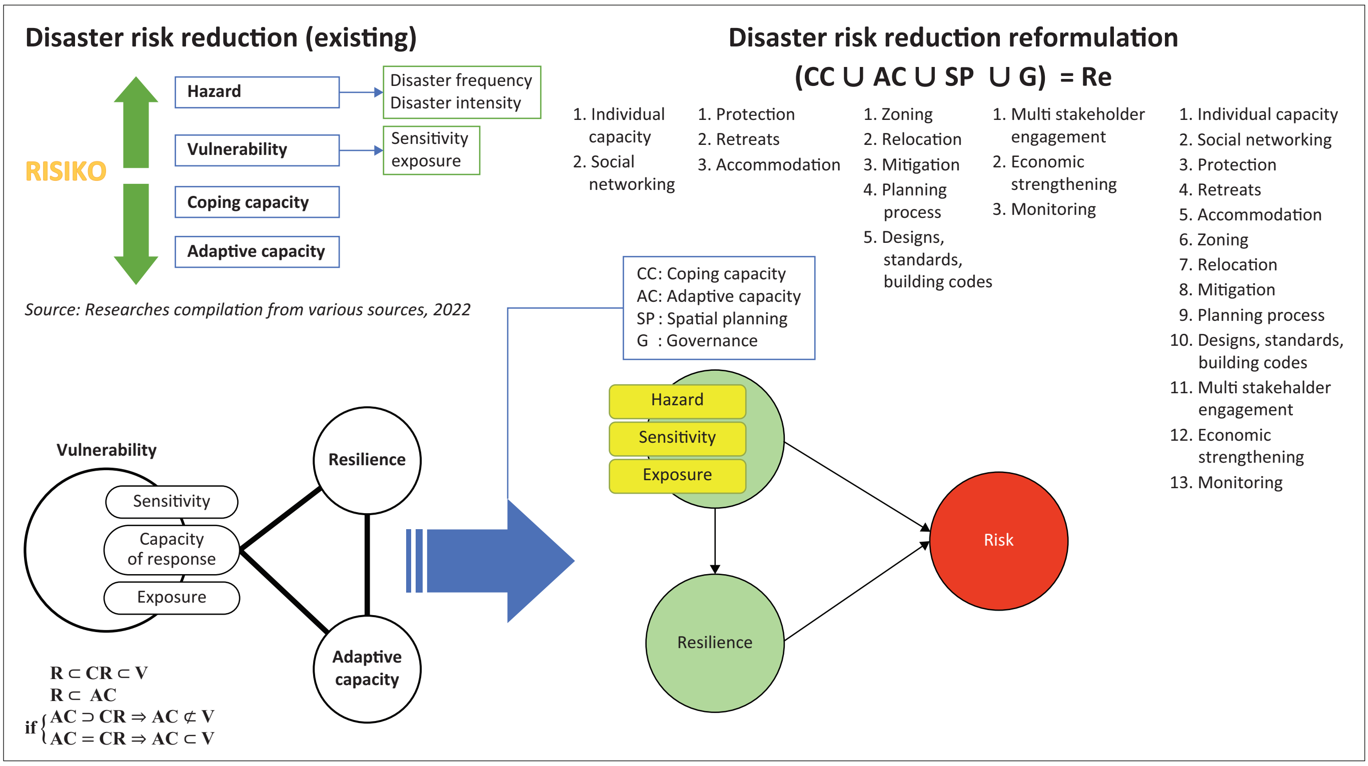
The conclusion of the development and justification of the exposure components in this study is:

- The Palu City building plot serves as a unit of analysis, assuming the community constitutes a disaster-exposure group. Identification of exposed residents through the building plot.
- The function of the building plot needs to be reclassified into: settlement buildings, economic activity buildings (trade and services, hotels, industry), office buildings, public facility buildings and social facilities, non-built-up area.

Figure 7 shows the delineation of exposure to settlement plots, public and social facility plots, economic activity plots, office plots and non-built-up areas. Thus, the level and type of exposure on each plot will differ and further differences will also be found in the sensitivity component. Other community groups also experience each exposure. For example, exposure to settlement plots is experienced by individual actors or households. At the same time, investor actors experience exposure to economic activity plots.

The exposure component utilises 30-m resolution Landsat imagery map data, building distribution maps and 1:5000-scale topography maps. From the 30-m resolution Landsat map, built-up and non-built-up areas can be identified. The building distribution map provides information on buildings in Palu City, including their functions. On the topography map, land use in Palu City can be identified. Based on the interpretation of the three data sets, land use synchronisation in Palu City can be implemented, supported by both secondary data and primary surveys. Land use reclassification in Palu City was conducted based on the results of field interpretation and observations. Then, the score of the reclassification results will be determined based on interviews with key stakeholders.

The exposure components are classified into five. The highest score indicates a high level of exposure. Likewise, the lowest score indicates a low level of exposure.



CC, Coping Capacity; G, Governance; AC, Adaptive Capacity; Re, Resilience; SP, Spatial Planning.

FIGURE 5: Disaster risk reduction reformulation.

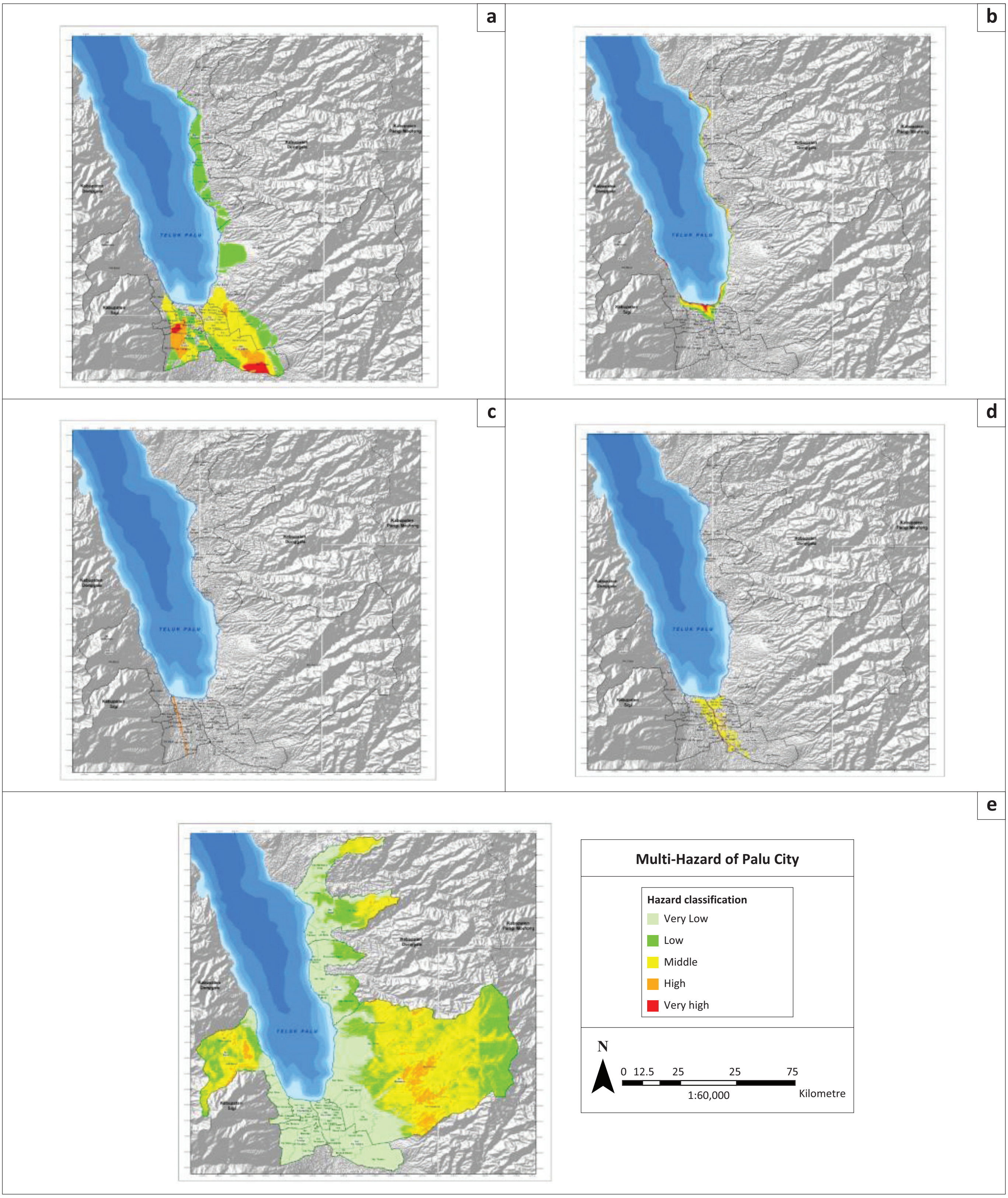


FIGURE 6: Multi-Hazard of Palu City: (a) liquefaction, (b) tsunami, (c) active fault, (d) flood and (e) landslide.

This study determines the highest score, namely settlement, with a score of five. This determination is due to the dominance of land use in Palu City, which is primarily characterised by settlement. Additionally, the 2018 disaster had the most significant impact on settlement areas. The lowest value is one in non-built areas. This determination is based on the fact that there are only a few settlements in non-built-up areas. So, it can be concluded that no one is exposed to disasters in non-built areas.

Sensitivity components

Sensitivity analysis applies to five types of disasters: liquefaction, tsunami, active fault, landslide and flood. The scoring and processing of spatial data on sensitivity components are based on the results of questionnaires distributed to the community, stakeholders and economic actors. The results of spatial data processing are in scoring reclassification into four reclassification (Figure 8).

The level of sensitivity can be identified from the characteristics inherent in each individual and society. These characteristics can be observed in various sectors, including economic, social, environmental, demographic and others. Sensitivity can be crucial in forming resilience, but it can also increase the risk of disasters. If individuals or communities lack the necessary character or resources to face disasters, then their sensitivity to disasters is likely to be higher. In other words, the risk experienced will be higher. However, if individuals and communities have the character or capital to face disasters, then their sensitivity will be lower. In other words, the risk experienced will be lower.

Figure 8 proves that the sensitivity of Palu City is high. Individuals and communities were not ready to face the catastrophic disasters. Even the community needed to recognise or understand the threat of catastrophic disasters in Palu City. They have yet to be informed about the disaster's vulnerability in Palu City. So, they were unable to survive or recover quickly from the 2018 disaster. The Palu City area was also paralysed for several days after the disaster. The infrastructure is also not redundant, and there is no alternative. That is what caused the life of Palu City to come to a standstill after the disaster.

The highest sensitivity is in settlements' land use, with an area of 6699.16 Ha. This classification is the widest, encompassing economic activities, public and social facilities and offices. This is because the number of exposed residents in settlements' land use is greater than in other land uses. Settlements are also not ready to face the catastrophic disasters. As evidence of the 2018 catastrophic disaster, the worst damage was in the settlement areas.

Resilience components

Sensitivity analysis applies to five types of disasters: liquefaction, tsunami, active fault, landslide and flood. The level of resilience can be identified through the disaster risk reduction programme, specifically in the form of disaster mitigation. The Palu City resilience programme is based on the disaster risk assessment document, the Palu City spatial plan, the Palu City medium-term development plan and other relevant documents related to disaster mitigation in Palu City.

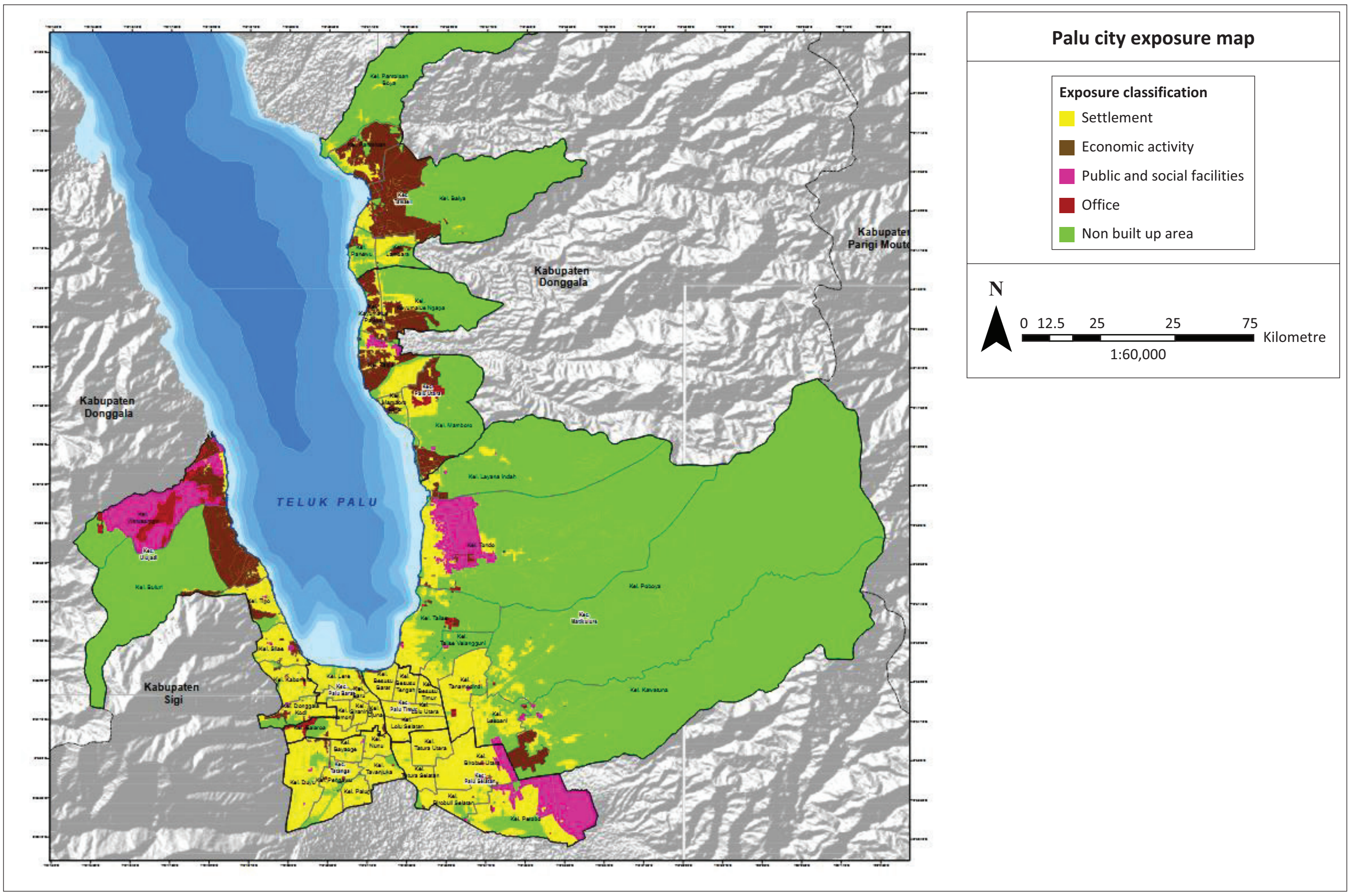
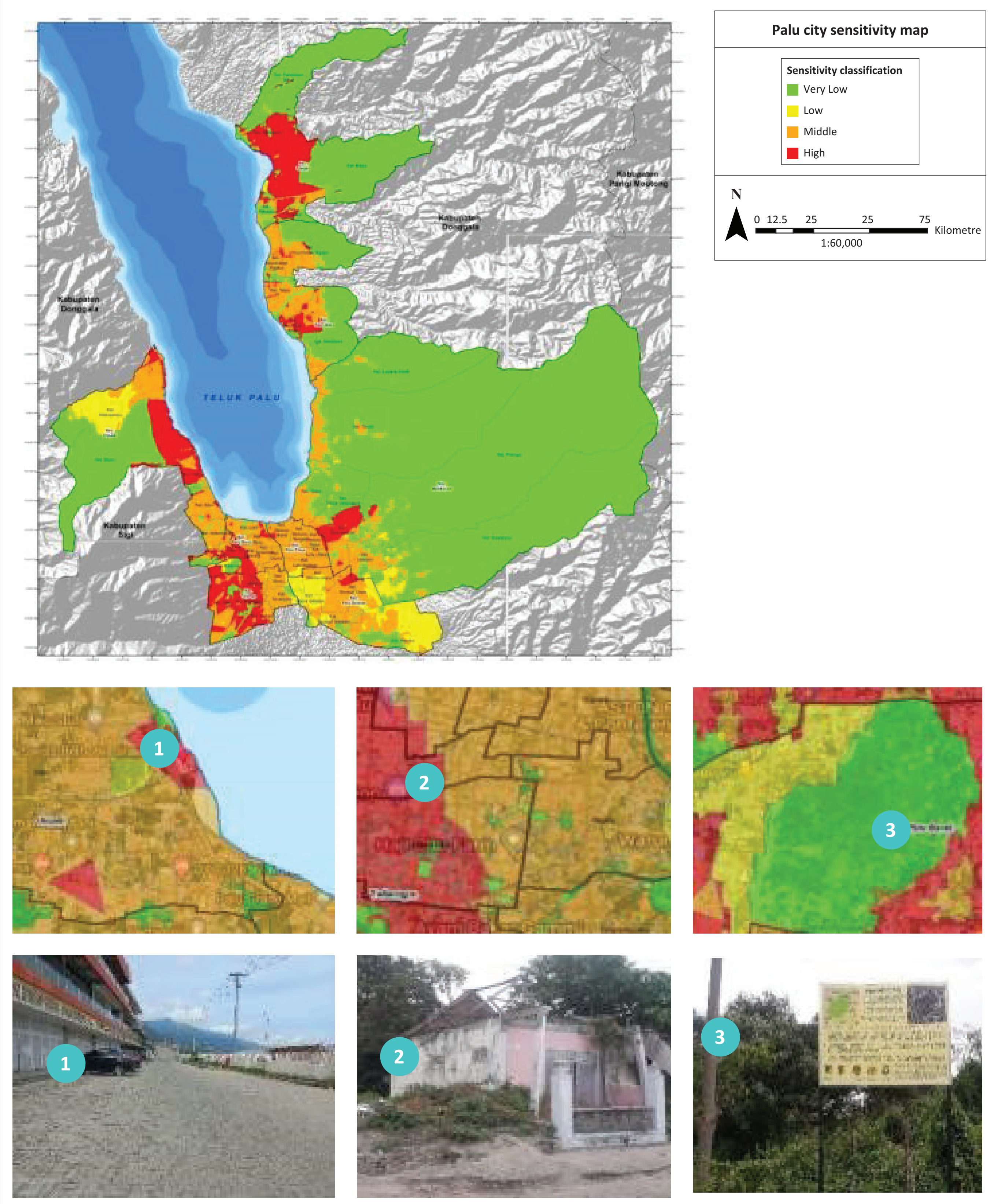


FIGURE 7: Palu City exposure map.



Note: Images marked with (1) describe sensitivity in coastal areas. Coastal communities need safe evacuation sites to avoid tsunamis. Images marked with (2) describe sensitivity in liquefaction-prone areas. These houses were severely damaged during liquefaction. Images marked with (3) describe sensitivity in liquefaction-prone areas. The ground swallowed up these houses due to liquefaction. Currently, no construction is permitted in these areas.

FIGURE 8: Palu City sensitivity map.

Researchers examine the resilience programmes to categorise them into resilience components: coping capacity, adaptive capacity, spatial planning and governance. The level of resilience is measured based on the plan and its implementation. If there is only a plan, the score is one; however, if there is both a plan and its implementation, the score is two. Seventy-six programmes have been grouped into resilience components. There are still programmes that need to be implemented, resulting in a low level of resilience. This affects the resilience score.

The classification of coping capacity, adaptive capacity, spatial planning and governance is based on several literatures. Coping capacity is an inherent characteristic or resource possessed by a system to deal with shocks resulting from disasters (Parsons et al. 2016). Adaptive capacity refers to the ability of a system formed through a learning process to withstand shocks because of disasters (Mentges et al. 2023). Spatial planning and governance are supported by policies and stakeholders to implement disaster risk reduction.

The following are some programmes as an effort towards resilience:

- Disaster mitigation, rehabilitation and reconstruction programme after a catastrophic disaster: One of the priorities for the development of Palu City is a safe, comfortable and disaster-resilient environment. This priority can be realised through resilient infrastructure.
- Development of resilience-based tourism activities: Tourism activities are centred in the coastal area of Palu Bay, which, in its development, requires integration into the overall arrangement of the Palu Bay area. Developing coastal tourism also requires security guarantees from disasters, so it involves disaster mitigation.
  The area affected by the active fault and liquefaction disaster will be made into a tourist attraction, mainly known as the Palu City Disaster History Triangle (Palu Bay–Nalodo Balaroa Area–Nalodo Petobo Area). However, the programme has not been seen in development until 2024. The area affected by the active fault and liquefaction remains undeveloped, and no tourism activities are currently present.
- Development of permanent dwelling: There are five permanent dwellings in Palu City that were built for people affected by the 2018 disaster, namely Duyu permanent dwelling, Petobo permanent dwelling, Talise permanent dwelling, Tondo permanent dwelling and Lere permanent dwelling.

These five permanent dwellings are further discussed in the following section:

1. Duyu permanent dwelling: Duyu permanent dwelling is included in the landslide disaster risk. Duyu permanent dwelling is included in the successful construction of permanent dwellings because it is equipped with public facilities and infrastructure. Ownership of this permanent dwelling is in the process of legalisation. Three hundred twenty-two units of housing have certificates. Duyu permanent dwelling is located outside the liquefaction disaster prone area at a distance of 190 m from the liquefaction disaster prone area (the outermost side is the high disaster prone area).
2. Petobo permanent dwelling: Petobo permanent dwelling is included in the low-liquefaction disaster risk and low-landslide disaster risk. Petobo permanent housing is located outside the liquefaction disaster prone area at a distance of 115 m from the liquefaction disaster prone area (the outermost side is the low disaster prone area). Ownership of this permanent dwelling is in the process of legalisation. Six hundred fifty-five units of housing have certificates.
3. Talise permanent dwelling: Talise permanent dwelling is included in the very low landslide disaster risk.
4. Tondo permanent dwelling: Tondo permanent dwelling is included in the very low landslide disaster risk. Tondo permanent dwelling includes very low liquefaction disaster risk and very low landslide disaster risk. Tondo permanent dwelling is equipped with public infrastructure.
5. Lere permanent dwelling: Lere permanent dwelling is located in an area with high tsunami, liquefaction and flood disaster risk. The area of Lere permanent dwelling is 0.5 hectares with 35 housing units.

Figure 9 proves that Palu City's resilience remains in the low classification. Disaster mitigation efforts aimed at achieving resilience are still limited and have yet to encompass the entire urban system.

Resilience with a high classification is associated with land use for economic activity. This is because the land use of economic activity has the funding to develop disaster mitigation infrastructure. In contrast, the ability of each individual to use settlement still needs to be higher.

Disaster Risk Index

Tabular and spatial data processing on hazard, exposure, sensitivity and resilience components are inputs for the Palu City Disaster Risk Index Analysis. The overlay is performed on the four components to produce disaster risk. The mathematical formula has been described. Figure 10 is a process assessment of the Palu City Disaster Risk Index.

As explained in point three, this Disaster Risk Index Calculation has different components from the initial calculation. The following are the differences.

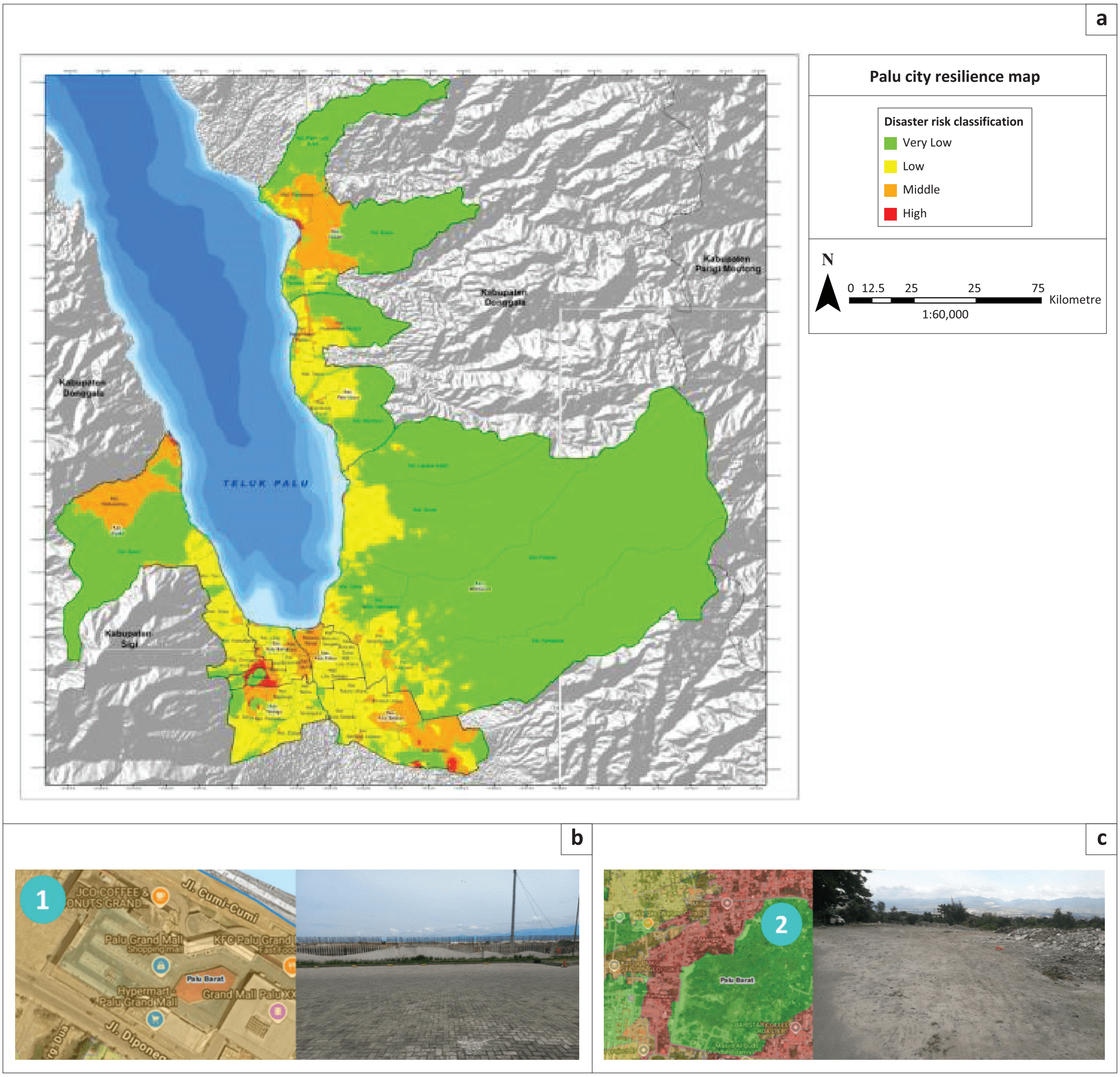


FIGURE 9: (a) Palu City resilience map, (b) Construction of a tsunami retaining wall on Cumi-Cumi Street along 2.36 kilometres in 2024 and (c) In the area affected by liquefaction, it is no longer functional. However, the surrounding area, including the high-disaster-prone area, remains densely populated, yet its resilience is very low.

Table 1 illustrates that the resilience-based Disaster Risk Index calculation is more detailed and accurate than the initial Disaster Risk Index calculation.

Disaster risk analysis goes through the stages of aggregation analysis and overlay of hazard, exposure, sensitivity and resilience components, as illustrated in Figure 10. High-classified risks are found in settlement land use and economic activities, the percentage of which is < 1% of the area. The Disaster Risk Index considering the resilience component is smaller than the Disaster Risk Index considering the capacity component, especially in coastal areas and city centres. The sensitivity level is included in the medium classification. This is because the government, the private sector and non-governmental organisations (NGOs) have initiated resilience programmes.

Figure 11 shows areas with high risk, such as: (1) industrial activities, containers and public facilities; (2) areas that are included in high-risk zones are open areas that function as tourist attractions, rather than settlement areas. The use of space with this design is developed by developers who have paid attention to disaster mitigation and (3) areas with multiple risks because there is more than one type of hazard in these areas with high sensitivity values, but low resilience values. The assessment of the multi-risk disaster index is also found in areas with multiple risks. This is due to the overlap of more than one type of hazard, for

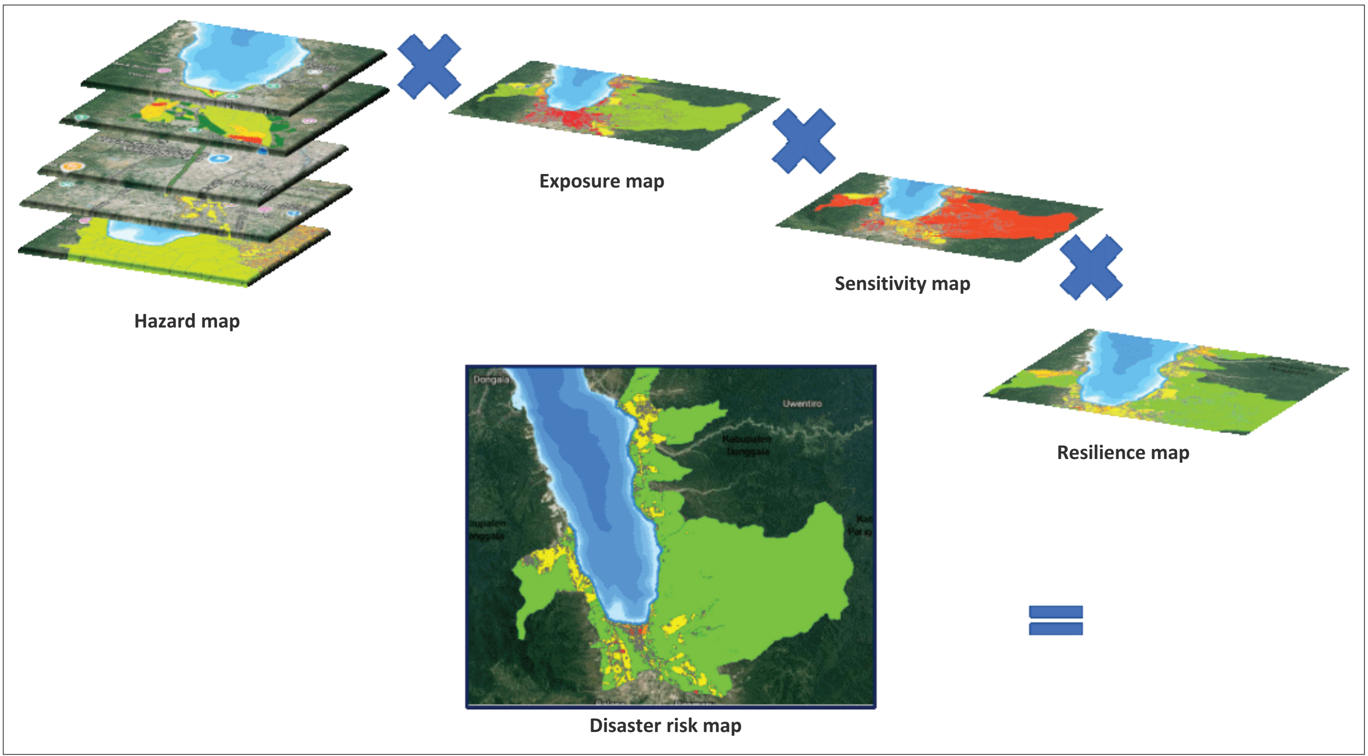


FIGURE 10: Spatial analysis process of Disaster Risk Index Assessment.

TABLE 1: Differences between initial and Resilience-Based Disaster Risk Index formulas.

Analysis components	Initial Disaster Risk Index formula	Resilience-based Disaster Risk Index formula	Explanations
Scale	Using Indonesian Disaster Risk Index data from the National Disaster Management Agency, with a scale of 1:25 000–1:100 000	Data sourced from the Palu City spatial plan and the Palu City detailed spatial plan with a scale of 1:5000–1:10 000	Data sources for calculating the Resilience-based Disaster Risk Index are more detailed.
Unit of analysis	Administrative unit	Plots	The unit of analysis for calculating the Resilience-based Disaster Risk Index is more detailed.
Formula	$R = \frac{H \times V}{C}$	$R = \frac{H \times E \times Se}{Res}$	• The vulnerability component (V) in the initial Disaster Risk Index calculation can be biased if it is not differentiated according to the exposed community. Each community or urban activity has different vulnerabilities. This can be explained by the exposure (E) and sensitivity (S) components in calculating the Resilience-Based Disaster Risk Index. • In the initial calculation of the Disaster Risk Index, the risk value reduction is through coping capacity (C). This cannot be applied to calculating the post-catastrophic disaster risk. In the context of post-catastrophic disasters, resilience components are employed. The resilience component variables include coping capacity, adaptive capacity, spatial planning and governance.

example, areas prone to liquefaction disasters overlap with areas prone to tsunami disasters and areas prone to active fault disasters.

Conclusion

The intensity and frequency of occurrences of disasters are increasing and becoming more unpredictable, making adaptation capacity inadequate for reducing disaster risk. This is because adaptation capacity only returns a system to its original equilibrium. Meanwhile, resilience can create a new equilibrium, allowing a system to transform and become resilient in the face of repeated disasters. This resilience aims to build back better after a catastrophic disaster. That way, disaster risk can be reduced significantly.

Resilience can reduce the Disaster Risk Index if disaster resilience components are implemented gradually and sustainably. In the Palu City case study, it is demonstrated that a high resilience component value reduces the Disaster Risk Index. The Disaster Risk Index (with reformulation calculations) will be lower than the value of the disaster vulnerability level if resilience efforts have been implemented. Resilience efforts can reduce the exposure and sensitivity value. Conversely, if there are no resilience efforts, the Disaster Risk Index will be higher. Initiation of resilience efforts has been seen in Palu City. High-risk classification is found in settlement land use and economic activities, the percentage of which is <1% of the area. The community's resilience is still minimal. Most resilience programmes originate from the government.

Calculating disaster risk based on resilience will have a broad impact, significantly enriching the science of disaster risk studies. In the long term, calculating the Disaster Risk Index considers adaptation and coping capacity in reducing it and strengthening the system through resilience. That way, the system can recover quickly and remain resilient in the event of another disaster.

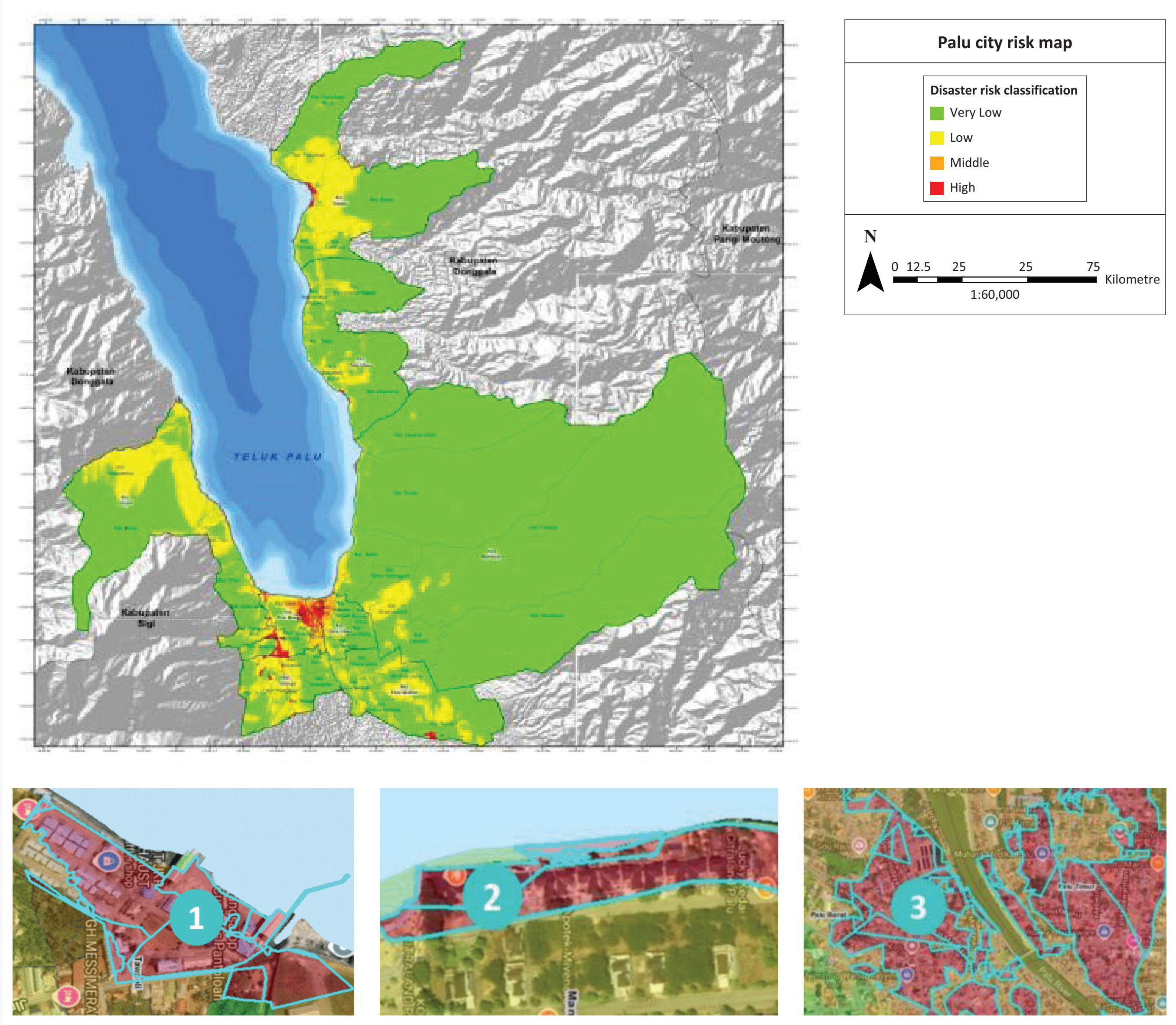


FIGURE 11: Palu City disaster risk map.

Acknowledgements

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

R.K.Y. investigated and wrote the original draft. D.S.A.S., H.P.R. and S.A.S. were the supervisors. All authors, R.K.Y., D.S.A.S., H.P.R. and S.A.S. reviewed the manuscript.

Ethical considerations

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Data availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Disclaimer

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