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SOCIAL VULNERABILITY OF MULTI-HAZARD DISASTER-PRONE AREAS IN PALU CITY, CENTRAL SULAWESI

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ABSTRACT

Palu City, Indonesia, is highly vulnerable to multi-hazard disasters (earthquakes, tsunamis, liquefaction, and fault lines), exacerbated by socioeconomic disparities and inadequate preparedness. Despite extensive hazard data, gaps persist in understanding social vulnerability dynamics in high-risk areas. This study assesses multi-hazard social vulnerability in Palu City to inform targeted DRR strategies. A mixed-methods approach integrates GIS-based hazard mapping (BNPB, 2023 data) with quantitative social vulnerability analysis (population density, gender, age, disability, education, and disaster preparedness groups) across East and West Palu. Results reveal homogeneous social vulnerability distribution, with coastal urban areas (e.g., Balaroa, Lere) facing the highest risk due to dense populations and limited resources. Disaster preparedness groups marginally mitigate vulnerability, but systemic gaps persist. The study underscores the need for inclusive, multi-hazard DRR policies prioritizing vulnerable groups and leveraging community-based interventions. Findings offer a replicable framework for other disaster-prone regions in Indonesia and globally.

KEYWORDS *Disaster, Multi-Hazard, Social Vulnerability, and Disaster Risk*

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INTRODUCTION

The development of urban areas is always getting wider and more complex, which raises new challenges related to efforts to understand various forms of urban vulnerability. In recent decades, there have been natural disasters that show that the level of vulnerability of people to damage is increasing, especially due to earthquakes (Ganapathy, 2011). The existence of risks to natural disasters includes the presence or possibility of danger to natural disasters, exposure that includes elements and humans exposed to disaster hazards, and vulnerability refers to the inability of elements and humans to overcome or survive the impact of existing disasters (Thywissen, 2006). Hazards can be measured in a given magnitude and frequency, and the existence of knowledge related to the spatial analysis of human settlements in affected areas can help understand the population's exposure to risk. The existence of vulnerability factors, especially human beings related to social conditions such as poverty, the elderly, people with disabilities, and others, can cause a greater impact on disasters in community groups like this. Although the level of danger and exposure is similar, it causes varying impacts due to differences in survival ability (Raduszynski T., 2023).

Earthquakes, one of the world's most significant natural disasters, can spread to other disasters, such as liquefaction and tsunami that occurred in Indonesia, in Palu City on September 28, 2018 (Directorate General of Spatial Planning, 2018). Historically, structural damage caused by earthquakes is a melting of the soil that has historically been observed in moderate and strong earthquake disasters, also known as liquefaction (Ambraseys, 1988). Meanwhile, the tsunami phenomenon is a series of waves that cross the ocean, which, when they hit the coast, inundate low-lying areas caused by earthquakes (Gandhi K., 2021).

Earthquakes cause changes in the Earth's surface as well as landscapes, causing many casualties and property (Gandhi K., 2021). Worldwide, the phenomenon of earthquakes is the main cause of death, injury, and disruption (Petal, 2011). Factors contributing to the high death and injury rate include rapid population growth, high poverty rates, low construction standards, and the potential for additional hazards such as landslides, tsunamis, or other disasters due to earthquakes, individual demographic characteristics, community behavior at the time of an earthquake, and the effectiveness of emergency response (Petal, 2011). Rapid and uncontrolled population growth signals an increased exposure to risks that ultimately magnify social vulnerability by taking over the built environment and the interaction between communities and the region (Manoharan S. G., 2023).

Palu City is a city with a relatively high rate of natural disasters with a variety of natural disasters, which at its peak on September 28, 2018 there was an earthquake of 7.5 on the Richter Scale due to the activity of the Palu Koro fault which caused a series of landslides, soil movements, liquefaction and also tsunamis that claimed more than 4,000 lives, 200,00 people were displaced, with economic losses estimated at US$911 million, making it the deadliest disaster to exist in 2018 (Mason H. B., 2021). This incident made Palu a city that received relatively high attention from the Indonesian government and the international community. This can be seen from the many studies related to the Palu City disaster and the

establishment of ZRB (Disaster Prone Zone) by the central government, as well as directly in the preparation of the Palu City RTRW in Palu City Regional Regulation No. 21, 2021, one of the goals of which is disaster resilience. In disaster risk reduction efforts, it is important to understand and measure vulnerability effectively so that a clear picture of possible impacts can be obtained and targets can be set for disaster-resilient urban development (Manoharan S. G., 2023). An important factor in the vulnerability to earthquakes is the development of urban landscapes due to the rapid and uncontrolled expansion of urban areas, seismological activities, and geological and environmental conditions that trigger social and economic damage (Pinto, 2000).

The phenomenon of regional development that is increasingly wide and complex as well as natural disasters that affect the level of vulnerability of urban areas and also communities, so it is necessary to see the extent to which natural disasters affect regional development and also the level of community/social vulnerability to natural disasters, especially for the Palu city area which every year experiences earthquakes and has felt the impact of liquefaction and tsunamis due to the 2018 earthquake a 7.4 Richter Scale shock (Directorate General of Spatial Planning, 2018). The International Strategy for Disaster Reduction/ISDR (2004) The definition of vulnerability is a condition caused by physical, social, economic, and environmental factors or processes that increase communities' vulnerability to the impact of hazards.

Vulnerability is generally divided into two, namely physical and social vulnerability (Rucińska D., 2023), but in several studies, the concept of vulnerability is discussed in a multidimensional manner involving physical, social, economic, environmental, and institutional vulnerabilities (ADRRN., 2010; BNPB., 2019; ISDR., 2004; PB., 2007; Pompella, 2010; Ramli M. W. A., 2023; Rucińska D., 2023). According to Raduszynski & Numada, (2023)Social vulnerability is a series of characteristics of a group or individual in terms of the capacity to anticipate, overcome, fight, and recover from the impact of natural disasters. Therefore, it is very necessary to understand that the impact of natural disasters is not only determined by the characteristics of danger and exposure to human settlements but also related to the characteristics of the exposed population.

Palu City as a disaster-prone area that has received attention from the central government and the world, already has a lot of data related to disasters, there is a map of disaster-prone zones (ZRB), there is data related to estimates and levels of existing disasters, but there is no discussion about the population or community groups that are exposed and the population of socially vulnerable people. Therefore, it is necessary to conduct a study related to social vulnerability in Palu City to areas prone to earthquakes, tsunamis, fault boundaries, and liquefaction in Palu City based on existing disaster data, which then determines the value of social vulnerability using variables that are used as the basis for determining the value of social vulnerability obtained from synthesizing variables based on literature and theory developed by experts and looking at the characteristics of the research area so that It was produced to identify the relevant social vulnerability variables in the context of this study (Signature., 2023).

This study examines the social vulnerability level to multi-hazard disaster-prone areas in Palu City. This results in a better understanding of social vulnerability to multi-hazards (earthquakes, tsunamis, fault boundaries, and liquefaction) and their effects on disaster risk reduction. The current research advances existing studies by specifically analyzing **multi-hazard social vulnerability** in Palu City through an integrated GIS-based approach, combining disaster risk mapping (earthquakes, tsunamis, liquefaction, and fault lines) with granular social vulnerability indicators (e.g., gender, disability, age, education, and disaster preparedness groups). Unlike prior works focusing on single hazards (Manoharan S. G., 2023; Mason H. B., 2021) or generic vulnerability assessments (Birkmann J., 2013; Cutter, 2017), this study uniquely quantifies the **cumulative impact of concurrent hazards** on socially vulnerable populations, identifying East and West Palu as high-risk zones due to homogeneous vulnerability distribution. It also introduces **localized policy gaps** by revealing the absence of targeted strategies for multi-hazard resilience despite existing ZRB (Disaster Prone Zone) frameworks (Tengah., 2019), thereby contributing to context-specific disaster risk reduction (DRR) literature.

RESEARCH METHOD

The research approach used is quantitative research in studying, assessing, analyzing, and describing the actual conditions in the field regarding social vulnerability. Quantitative research was chosen because it consisted of the preparation of research hypotheses, reliability, and validation of results, for the conduct of surveys and experimental research (including modeling research) (Buchori, 2022). This research involves theories, hypotheses, observations, empirical generalizations, and acceptance or rejection of hypotheses that depend on the existence of populations and sampling techniques as the main basis, until the depiction of real conditions in the field related to social vulnerability to multi-hazard aspects using geographic information system tools.

RESULT AND DISCUSSION

Disaster Conditions in Palu City

Palu City has a diverse history of disaster events, some of which have caused impacts in the form of casualties, physical losses, and significant land damage. The history of disaster events in Palu City is documented based on the Indonesia Disaster Data and Information (DIBI) issued by BNPB (2023). According to DIBI, in the period 1815-2015, there were 6 (six) types of disasters that often hit Palu City, including floods, flash floods, extreme waves and abrasion, earthquakes, epidemics and disease outbreaks, and landslides. The impact of the disaster is very significant for Palu City (Directorate General of Spatial Planning, 2018). In addition, the major disaster in the city of Palu that occurred on September 28 provides a new understanding that not only the 6 disasters mentioned by DIBI need attention, but there are boundaries of the Palu Koro Fault, liquefaction, Tsunami,

and also earthquakes whose disasters are interrelated caused by the activity of the Palu Koro Fault itself.

Disaster-Prone Space Zone in Palu City

As a result of the major disaster on September 28, 2018 in Palu City, the local government conducted various studies conducted by various related OPDs and assisted by existing researchers in providing input related to the direction of the use of disaster-prone space zones in Palu City, which resulted in the Governor of Central Sulawesi Regulation Number 10 of 2019 concerning Post-Disaster Rehabilitation and Reconstruction. The government issued a Disaster Prone Zone (ZRB) Directive. Disaster-prone zoning is divided into four zones, and land use guidelines are given for each zone.

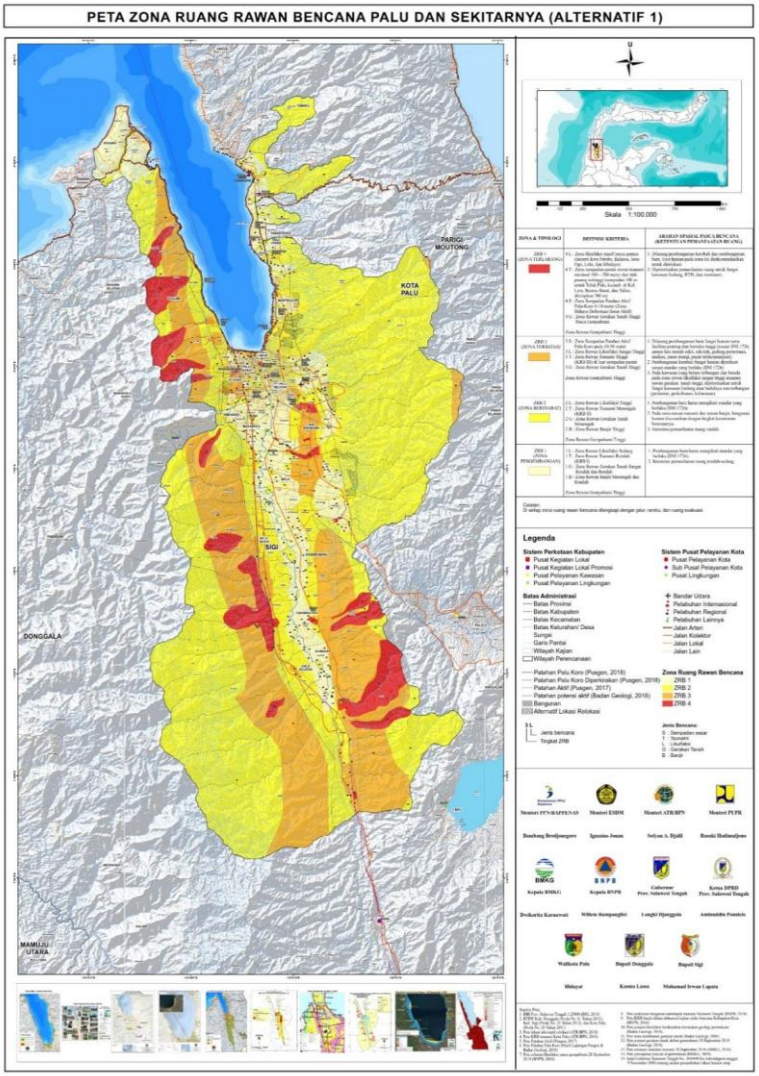

Figure 1. Map of Pasigala disaster-prone space zones (Palu, Sigi, and Donggala)

Disaster Danger Areas of Palu City

Palu City, Central Sulawesi, is known as one of Indonesia's regions with a high risk of various natural disasters. The analysis of natural disasters in Palu City covers various aspects. However, this discussion is condensed into the multi-hazard aspect. These disasters can cause other disasters, such as a significant earthquake in Palu City on September 28, 2018, where the activity of the Palu-Koro fault caused an earthquake, followed by a tsunami and liquefaction.

Multi-Disaster Hazard Areas in Palu City

Overall, the data used to determine the most endangered areas in Palu City uses official data, which is then returned to produce disaster data for the city of Palu. In determining the area with the most multi-hazard aspects, a scoring technique is used by weighting the score and providing a class interval to produce the area with the highest multi-hazard impact in Palu City.

Table 1. Determination of Multi-hazard Level Value Weighting

No.	Earthquake Danger Level	Value	Tsunami Danger Level	Value	Fault Boundary Danger Level	Value	Liquefaction Hazard Level	Value
1	Tall	3	Tall	3	Tall	3	Tall	3
2	Keep	2	Keep	2	Keep	2	Keep	2
3	Low	1	Low	1	Low	1	Low	1

From the hazard-level score criteria, the sum and division of the scores of each variable are carried out using the interval formula i = R/N (Sugiyono, 2013).
Remarks: i = Class Interval
R = Maximum and minimum Score Difference
N = Number of Classes
So that the vulnerability level score is obtained as follows:

Multi-hazard level
(8-12) Height
(4-7) Medium
(1-3) Low

Based on the results of the analysis, the urban areas of Palu city, namely West Palu and East Palu sub-districts, are areas with areas that are identified as areas that are very vulnerable to various types of disasters, which makes the Palu city center area an area with various disasters, namely earthquakes, tsunamis, fault boundaries, and liquefaction that increase the complexity and level of risk for residents and infrastructure in Palu City.

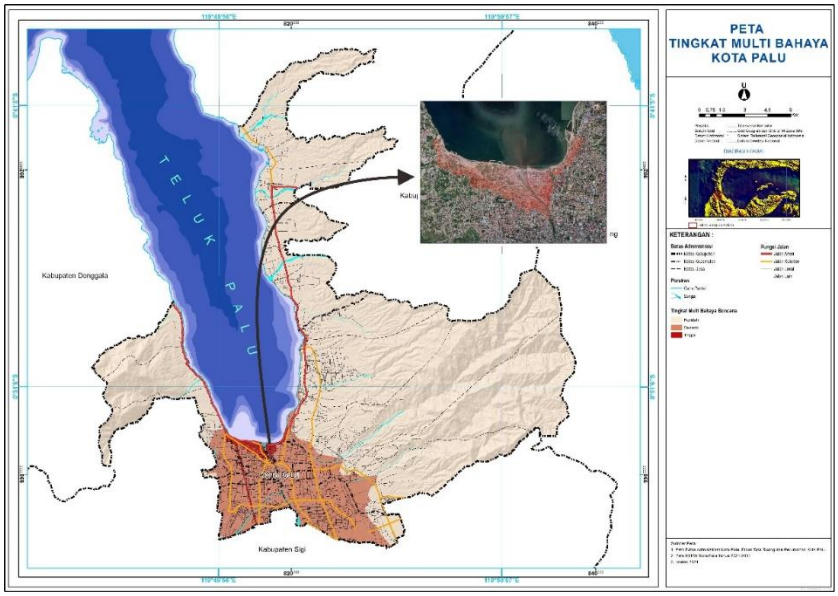

Figure 2. Multi-Hazard Levels of Palu City

Social Vulnerability of Palu City

The city of Palu is located on the Palu-Koro fault line, one of Indonesia's active faults. This fault is the primary source of earthquakes, which can cause other disasters, namely tsunamis and liquefaction, which have the potential to damage infrastructure and buildings and also have an impact on social conditions. The analysis in this discussion discusses the multi-hazard disaster-prone areas in Palu City, consisting of earthquakes, tsunamis, fault boundaries, and liquefaction, and analyzes the level of social vulnerability to multi-hazard disaster-prone areas as a form of disaster risk reduction for the most risky area zones with high exposure and socially vulnerable groups.

In this case, social vulnerability in Palu City refers to the extent to which the community is vulnerable to the impact of existing disasters. This vulnerability is influenced by various factors, in this study, based on the theoretical synthesis and variables that have been determined, the social vulnerability for the danger area in the city of Palu is measured as the population density exposed to disasters, seen from the characteristics of the population, vulnerable age population, female population, occupation, people with special needs, and also the level of education.

Palu City Social Vulnerability Assessment

Social vulnerability assessments in the context of disasters involve various factors that can affect a community's ability to survive, respond to, and recover from the impacts of disasters. In this study, the assessment of social vulnerability is based on several important indicators, such as population density, number of female population, vulnerable age, disability group, education level, working population, and the existence of disaster preparedness groups, which is determined by the ratio

value of each indicator which is then weighted which then the result of the value of each indicator is added and given a value using the class interval formula.

Table 2. Determination of Social Vulnerability Value Weights

Population Density	Value	Female Residents	Value	Vulnerable Age	Value	Disability Groups	Value
Low Vulnerability	1	Low Vulnerability	1	Low Vulnerability	1	Low Vulnerability	1
Medium Vulnerability	2	Medium Vulnerability	2	Medium Vulnerability	2	Medium Vulnerability	2
High Vulnerability	3	High Vulnerability	3	High Vulnerability	3	High Vulnerability	3

Working Residents	Value	Disaster Preparedness Group	Value
Low Vulnerability	1	There is a KSB	1
Medium Vulnerability	2	There is no KSB	3
High Vulnerability	3		

From the hazard-level score criteria, the sum and division of the scores of each variable are carried out using the interval formula i = R/N (Kingma, 1991).
Remarks: i = Class Interval
R = Maximum and minimum Score Difference
N = Number of Classes
So that the vulnerability level score is obtained as follows:

Social Vulnerability of Palu City
(17-21) High
(12-16) Medium
(7-11) Low

Social vulnerability assessments based on factors such as population density, female population, vulnerable age, education level, employment status, disability groups, and the existence of Disaster Preparedness Groups provide an overview of the level of risk faced by communities in dealing with disasters. Each

of these factors is interrelated and strengthens or weakens vulnerability. Based on the calculation results, it was found that the city of Palu is at risk of social vulnerability, ranging from moderate to low vulnerability, and also low vulnerability in Mantikulore village. The form of distribution of various population indicators, such as population density, female population, vulnerable age, education level, employment status, and disability groups, is homogeneous in each village, causing the same level of social vulnerability in each village.

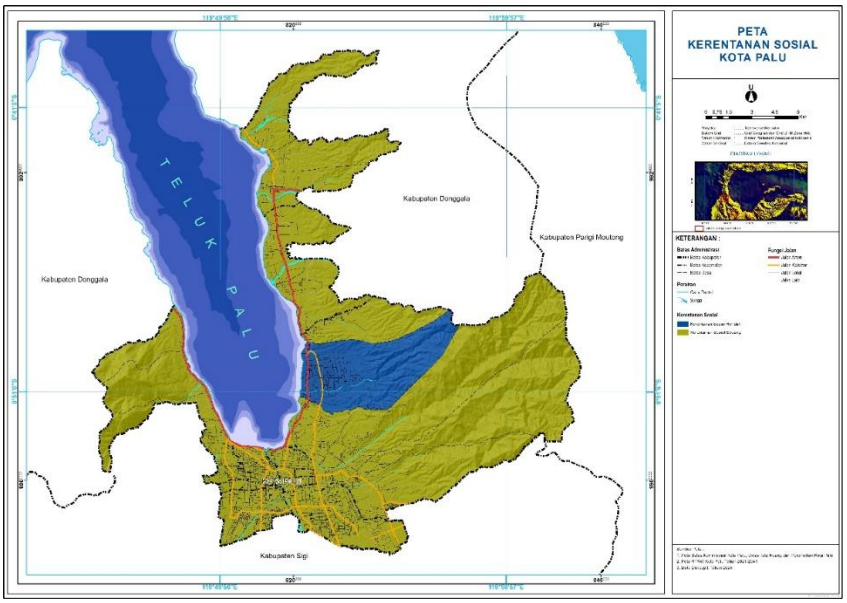

Figure 3. Distribution of Disaster Preparedness Groups

Social Vulnerability of Multi-Peer Regions

Multi-hazard social vulnerability is the vulnerability of communities to various types of disaster threats simultaneously or continuously. In the Palu city area, which is vulnerable to the dangers of earthquakes, tsunamis, fault boundaries and liquidation, social vulnerability becomes more complex due to various factors that make a group weaker in terms of preparedness, response, and recovery after a disaster. Based on the results of the analysis of the calculation of multi-age areas and areas with social vulnerability, the value of social vulnerability to multi-hazard areas in Palu City was obtained. The coastal area is an area with high social vulnerability to multiple hazards. The coastal suburbs are the central area of Palu city, which has the most dangers that affect each other, and is also in the center of Palu City. The condition of population distribution based on homogeneous vulnerable groups causes the value of social vulnerability to have the same effect on all disaster hazards in Palu City.

CONCLUSION

Multi-hazard social vulnerability in Palu City—prone to earthquakes, tsunamis, liquefaction, and fault lines—is exacerbated by socioeconomic and physical factors,

disproportionately affecting women, children, the elderly, people with disabilities, and low-income populations. High-risk areas like East and West Palu face compounded challenges due to dense populations, limited resources, and low disaster awareness. Future research should explore integrated disaster risk reduction (DRR) strategies, focusing on strengthening preparedness groups, community-based interventions, and inclusive policies. The study uses mixed methods (GIS mapping, surveys, and policy reviews) to enhance resilience in Palu while providing a model for other multi-hazard regions.

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