

## Landslide Disaster Vulnerability Analysis of the Tourism Sector in West Bandung Regency

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### Abstract

One of the regions in Indonesia with a relatively high risk of landslides is West Bandung Regency, West Java Province. Given its active land use and dense population, this area becomes more vulnerable to the impacts of natural disasters. The objective of this research was to identify the elements and contributing causes of landslide vulnerability, especially for West Bandung Regency's tourism sector.

The robust vulnerability scenarios were generated by using Spatial Multi-Criteria Evaluation (SMCE). Four scenarios of equal vulnerability, social vulnerability (SV), physical vulnerability (PV), and environmental vulnerability (EV) are produced using the SMCE technique.

According to the scenario results, three districts, Rongga, Cipatat, and Parongpong, show dynamic vulnerability, whilst the remaining districts show consistent classes. The quantity of visitors and physical infrastructure, such as access to the road, are examples of social elements that significantly impact the degree of vulnerability. The study's findings led to the creation of three vulnerability classes in West Bandung Regency: low class, with values between 1.34 and 1.78, medium class, with values between 1.79 and 2.07; and high class, with values between 2.08 and 2.36. The photo-tagged map of road access and tourist destinations in West Bandung Regency provides in-depth insight into the factors that influence the vulnerability of tourist destinations, taking into account disaster risks due to geographical conditions, infrastructure readiness, and the effectiveness of mitigation efforts in balancing tourism development and environmental resilience.

### Introduction

West Bandung Regency is one of the regencies in West Java Province. This regency has a fairly high potential for landslides. This is supported by a report from Pusat Vulkanologi dan Mitigasi Bencana Geologi (Center for Volcanology and Geological Disaster Mitigation/PVMBG) (2018), it was reported that in the 2009 until 2018 period there were 144 landslide disasters. In March 2024, a landslide occurred in Cipongkor District, West Bandung Regency which resulted in 10 people being declared missing with 3 of them dying and 2 residents suffering serious injuries (Rivaldi, 2024). The landslide affected 142 families or 527 people with material losses in the form of 30 houses and 2 prayer rooms. The evacuation process is also quite difficult due to high rainfall, steep slopes, and the potential for subsequent landslides is still high because the landslide material has a fairly high depth (Nugroho and Nugroho, 2020). The disaster risk mapping and evaluation study document for West Java Province mandated by the Badan Nasional Penanggulangan Bencana (National Disaster Management Agency) has now been approved by the Governor. However, the available mapping is not detailed enough because it still uses a national scale, namely 1:250,000. PUPR (2015) identified that West Bandung Regency has topographic conditions dominated by steep slopes, where most of the rock constituents are andesite and andesite breccia which have water-resistant properties. This condition causes the soil above the rock to easily experience erosion or movement. The steep slopes in West Bandung Regency are also due to the fact that parts of West Java Province are located on active mountain routes, forming mountains and hills.

This diversity of topographical conditions is accompanied by the formation of quite diverse socio-cultural dynamics as well. The geomorphological conditions that provide tourism potential in this area, especially in the districts of Lembang, Padalarang, Cikalongwetan, Ngrampah, and Cipeundeuy, have resulted in this area becoming a tourism area in West Bandung Regency (Nugraha et al, 2017). The number of tourists in West Bandung Regency in the last three years has shown an increasing trend, with a total of 4,218,503 visits in 2021, 4,512,890 in 2022, and 4,618,707 in 2023 (Departement of Tourism and Culture of West Bandung Regency, 2023). Of the total 39 tourist locations in West Bandung Regency, tourist destinations include Lembang Park Zoo, Kampung Daun, Orchid Forest, and Floating Market, which are some of the most popular locations and attract more tourists than other locations. In fact, in 2019 Bandung was designated as one of the leading culinary tourism destinations by the Minister of Tourism (Susanti and Ika, 2019). The government considers the tourism sector a key focus in its development initiatives. (Yulia et al, 2021). Tourism activities in the form of natural beauty, culinary delights, and local wisdom can attract tourists from within and outside the region so that they can be

developed to support the regional economy. However, the West Bandung Regency Government has challenges in developing the fairly high tourism potential in West Bandung due to the threat of landslides. Apart from that, West Java Province is close to the subduction zone in the South Sea Region of Java Island, making it more vulnerable to other geological disasters.

Landslides are a natural disaster that often occurs in Indonesia after floods, as a dangerous phenomenon, especially in mountainous tropical areas which can cause high risks, in terms of economic losses, casualties and environmental problems (Putuhuru et al., 2017; Hadmoko, et al., 2009). Landslides can occur due to natural processes in changes in the structure of the earth's surface and disturbances in the stability of the soil or rocks that make up the slope (Panek et al., 2019). Meanwhile, according to Arsyad (2010), landslides can occur if three conditions are met, namely (1) the slope is steep enough, (2) there is a layer below the soil surface that is watertight and soft as a sliding surface, and (3) there is enough water in the soil, so that the soil layer immediately above the waterproof layer becomes saturated. The landslide that occurred in West Bandung Regency has caused many impacts and losses for its residents. Efforts to reduce impacts are carried out by preparing mitigation plans taking into account aspects of danger, physical and social vulnerability and disaster risk (Arif et al., 2017; Afifah et al., 2020; Guillard-Gonçalves and Zêzere, 2018; Kurnia and Hizbaron, 2020).

Vulnerability is the level of loss that can be experienced by affected elements such as communities or society with a certain level of severity as a result of certain hazards (Bankoff et al., 2004; Christianawati and Hizbaron, 2022; Cutter et al., 2003; Hizbaron et al., 2020; Pradana et al., 2018). Meanwhile, according to Hapsoro and Buchori (2015), Vulnerability is the level of vulnerable of a system to the impacts of climate change, including climate variability and extremes, or as a series of conditions and/or consequences of social, physical, economic and environmental factors that have a negative impact on disaster prevention and management efforts (Bakornas PB, 2007). Several factors, including physical, social, economic, environmental conditions and processes occurring within a community, determine how vulnerable a community is to the impacts of a disaster. Social vulnerability is a description of the social inability of a community to face disasters (Rahmanintyas and Setyono, 2015). According to Peraturan Kepala BNPB (Regulation of the Head of BNPB) number 2 of 2012, social vulnerability can be seen from population density, sex ratio, disabled population ratio, and population age group ratio. Economic vulnerability is the economic inability of a community, for example, in terms of insurance availability, savings ownership, or side income when a disaster occurs (Hizbaron et al., 2015, 2021; Josiana and Hizbaron, 2019). Economic vulnerability can be seen from the underprivileged population and the area of agricultural land (Tamtomo and Priyana, 2020). Environmental vulnerability is environmental sensitivity or exposure which is a combination of biophysical and socio-economic factors (Hidayati and Setyono, 2015). Environmental vulnerability can be seen from evacuation routes, proximity to cliffs, road conditions, and road width (Ruslanjari et al, 2020). Therefore, reducing the impact or risk of a disaster can be done by minimizing vulnerability by carrying out a vulnerability assessment (Ruddin et al, 2022). This vulnerability assessment can be carried out spatially or community-wise (Daninati and Sariffudin, 2015). This research was conducted with the aim of [1] analyzing the distribution of vulnerability to landslides and [2] determining the relationship between the distribution of vulnerability to the tourism sector in West Bandung Regency.

## Research Context

West Bandung Regency has a fairly high potential for catastrophic spills but information related to the vulnerability conditions of the population is still unavailable. Vulnerability, understood as a condition of incapacity of a community or community in the face of disasters, becomes an important point, especially when associated with the potential threat of a landslide disaster that exists in the West Bandung district. Previous research that has linked the vulnerable aspects of the tourism sector has also been carried out in Yogyakarta and Central Java due to the threat of windstorms and earthquakes (Christianawati and Hizbaron, 2022; Hizbaron et al., 2020). The study considers the disaster vulnerability index to be an important indicator in predicting bad conditions due to the potential threat of landslides, in relation to the tourism sector in the West Bandung district. The tourism department of West Bandung district recorded as many as 51 tourist attractions spread across West Bandung with a total of 4,622,194 visits in 2023. In some cases of landslides, the loss affects a number of tourist attractions, especially as a result of the landslide that occurs on the road that breaks the connection to the tourist attraction as well as the touristic area itself.

The research area includes 16 districts that are part of the West Bandung Regency including Lembang, Parongpong, Ngamprah, Padalarang, Batujajar, Cihampelas, Saguling, Cililin, Cipatat, Cipeundeuy, Cisarua, Cikalongwetan, Gununghalu, Rongga, Sindangkerta, and Cipongkor with a population of 1,847.096 people. In general, the area of West Bandung regency is closely related to its vulnerability to landslide disasters given the natural conditions with steep slope slopes in some of its areas. According to the record of events by the Regional Disaster Management Agency of West Bandung itself, during the year 2023 there have been as many as 25 landslides in several districts in West Bandung Regency, resulting in damage to infrastructure and buildings to deaths.

The study uses the Spatial Multi Criteria Evaluation (SMCE) method to assess the vulnerability of landslides in the West Bandung Regency. The use of this method produces a number of scenarios that can be given consideration to the possibilities that may occur through the input of parameters that form the disaster vulnerability database. Previous research that has used SMCE, among other things applied in Dieng due to flooding, and Bogor district due to landslide (Pradana et al., 2018; Sauri and Hizbaron, 2016). Qualitative descriptive analysis was carried out using secondary data obtained from several service units in the West district of Bandung including the Social Services, Central Statistics Agency, the Settlement

Service, the Regional Disaster Management Agency, as well as the Environmental Services. Secondary data collected included data on the population, facilities and housing, vegetation coverage and abuse data in the Western district used as a parameter for determining the level of vulnerability.

The research on the vulnerability of landslides in West Bandung Regency to the tourism sector is processed using the SMCE (Spatial Multi Criteria Evaluation) method. (Figure1). The vulnerability parameters studied in this study include social, physical, and environmental vulnerabilities. (Table 1). Economic vulnerability is not included because it is difficult to measure spatially and data limitations, such as community income and financial resilience to disasters. This information is not always available or consistent across regions, making it difficult to analyze. However, this aspect remains important for further research to provide a more comprehensive analysis. The variable on each parameter refers to the National Disaster Management Board's (BNPB) Head Regulation No. 2 of 2012.

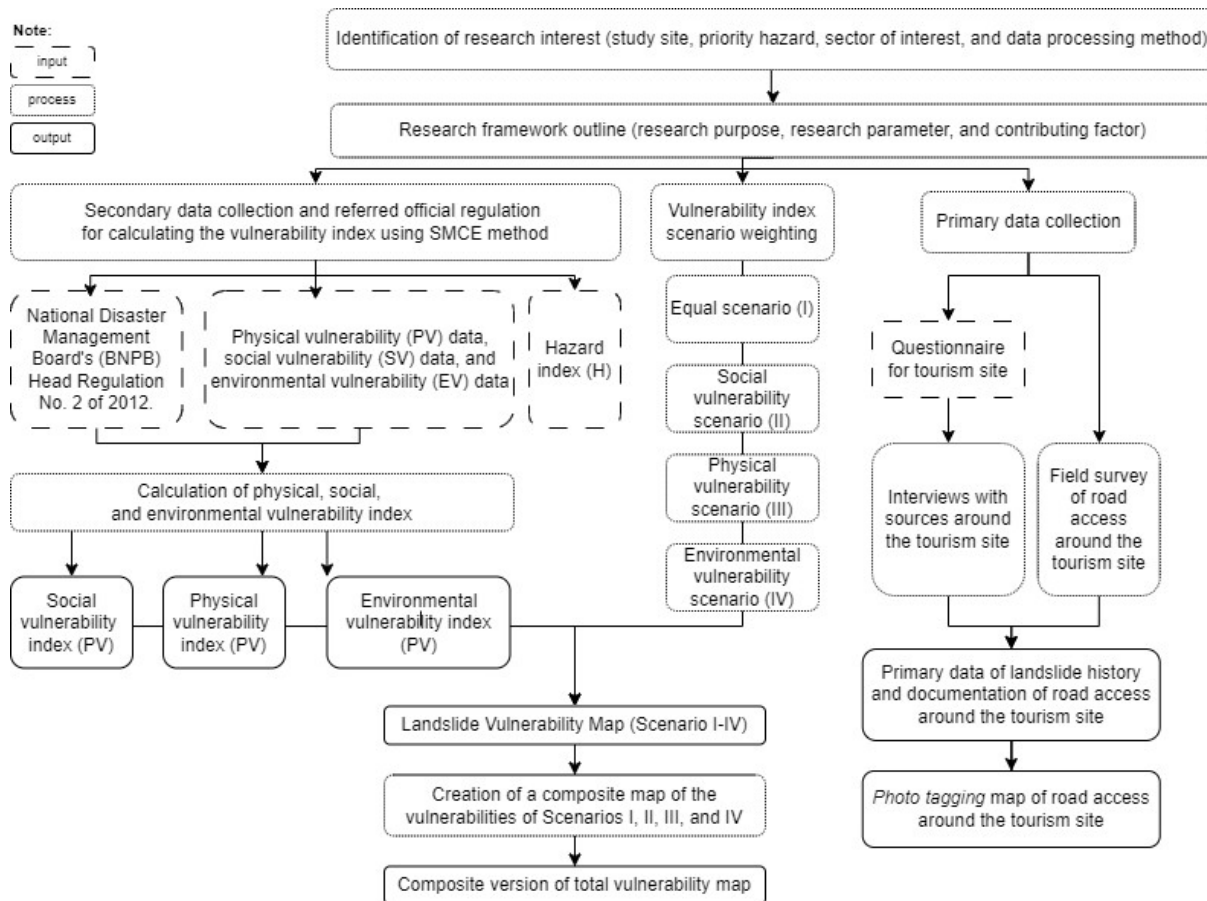


Figure 1. Research framework

Social vulnerability was analyzed using several variables including population density ratio, sex ratio and the poverty ratio approached to the social welfare community approach, disability rate, and age group. In addition to social vulnerability, physical vulnerability is evaluated using parameters of the number of public facilities including educational facilities at each level, private facilities, hotels, and cooperatives, the number and critical facilities that include hospitals, puskesmas, and reservoirs, as well as number of homes at each disaster. Other types of vulnerability are environmental vulnerabilities with parameters such as protected forest, natural forest, mangrove forest, and buffalo bushes. The calculation of monetary losses on physical vulnerability parameters refers to the loss value records issued by the Regional Disaster Management Agency of the West Bandung Regency. In addition to using the three vulnerability indices, the hazard index is also a factor of calculation in determining the level of vulnerability by using several criteria including geological formation, distance to rivers, land use, slope slope, and also fractures by using the weighing method to obtain a hazard score on each incident. As can be seen in Table 1 below indicates the role of each indicator towards the objective of the analysis that is vulnerability. The value (+) indicates a direct relationship between the indicator and vulnerability, meaning that the higher the number of housing facilities, for example, the higher its vulnerability potential. While the value (-) means that both indicators and vulnerabilities are not linear, it is assumed that the more mitigation efforts are made the less vulnerable they are.

**Table 1.** Spatial Multi Criteria Evaluation for Ideal (SMCE-Ideal), Social Vulnerability (SMCE-KS), Physical Vulnerability (SMCE-KF), and Environmental Vulnerability (SMCE-KL)

No	Criteria	Factor	Description	Data Source
1	Physic	Number, area and price per meter of public facilities public facilities, critical facilities, price and area of the house,	Number of critical, public and housing facilities (+) Land price (+)	Secondary data from 1. Educational Agency 2. Central Statistics Agency 3. Regional Disaster Management Agency 4. Settlement Agency 5. West Bandung Regency
2	Social	Population density ratio, sex ratio, poverty gap, disability ratio, age group ratio, tourism site visitors	Population density ratio (+), sex ratio (+), poverty gap (+), disability ratio (+), age group ratio (+), tourism site visitors (+)	Secondary data from 1. Social Agency 2. Central Statistics Agency 3. Department of Tourism and Culture West Bandung Regency
3	Environment	Natural forest Protected forest Mangrove forest Shrubs	Area of vegetation cover (+)	Secondary data from 1. Environmental Agency, West Bandung Regency

Note: (+) has a contribution to increase the vulnerability value.

Several scenarios are set in this study. Scenario weighting is done by varying the weight value of each calculation parameter through a qualitative assessment of each parameter. This study is expected to produce four scenarios as shown in Table 2 with a balanced (ideal) scenario, social vulnerability scenario, physical vulnerability scenario, and environmental vulnerability scenario. The weighting is intended to determine and compare the contribution of parameters to the level of vulnerability in an area. This weighting scenario is designed to reduce subjectivity in determining the weights in this study.

**Table 2.** Landslide Vulnerability Weighting Scenario in West Bandung Regency,

Scenario	Social Vulnerability (SV)	Physical Vulnerability (PV)	Environmental Vulnerability (EV)	Hazard
I (Equal)	0.25	0.25	0.25	0.25
II (SV)	0.35	0.20	0.20	0.25
III (PV)	0.20	0.35	0.20	0.25
IV (EV)	0.20	0.20	0/35	0.25

Through data processing, three total vulnerability classes in the study area to landslide disasters were determined for each scenario through the calculation of range values. The difference in weight of each parameter which then produces a different vulnerability index for each scenario is intended to obtain the most appropriate scenario to be implemented practically in disaster management at the government level (Hizbaron et al., 2012). This makes the vulnerability classification index expressed in a range of one to high and three classes are obtained, namely low vulnerability (1.34 - 1.78), medium (1.79-2.07), and high (2.08-2.36) (Table 3).

**Table 3.** Vulnerability Classification.

No	Vulnerability Index Range	Vulnerability Class
1	1,34 - 1,78	Low
2	1,79 - 2,07	Moderate
3	2,08 - 2,36	High

## Result

This study produced at least 4 vulnerability mapping scenarios as elaborated by the research method. The results obtained include the following:

### 3.1. Equal Vulnerability Scenario

The ideal scenario's weighting determines that each component contributes equally to the degree of vulnerability of West Bandung Regency's tourism industry. This indicates that the scenarios addressed by this scenario are those in which all indicators go through essentially the same dynamics from the present to the future. In scenarios where one parameter is emphasized, the ideal scenario's equalization of the weights of physical, social, environmental, and hazard vulnerability is used as a reference scenario for examining the vulnerability index (Afifah and Hizbaron, 2020).

According to Hizbaron et al. (2012), the equality of weights indicates that every parameter represents equal importance in the dynamics of the vulnerability index of the tourism sector in the studied area. The vulnerability class distribution in the Rongga, Cipongkor, Cihampelas, Batujajar, Padalarang, Ngamprah, and Cisarua Districts is low, ranging from 1.34 to 1.78 out of a range of 3. The districts of Gununghulu, Sindangkerta, Cililin, Saguling, Cipatat, Parongpong, Cikalongwetan, and Cipeundeuy are included in the intermediate vulnerability class. Only in Lembang District is the tourism industry susceptible to catastrophic landslide events (Figure2). This conclusion correlates with the eastern portion of West Bandung Regency—that is, Lembang District—being an epicenter of the tourism sector expansion (Listiana et al., 2023).

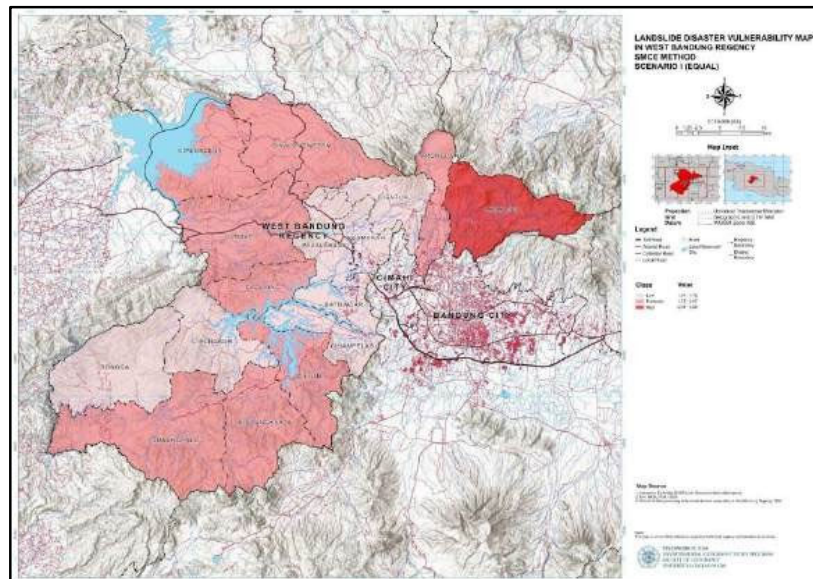
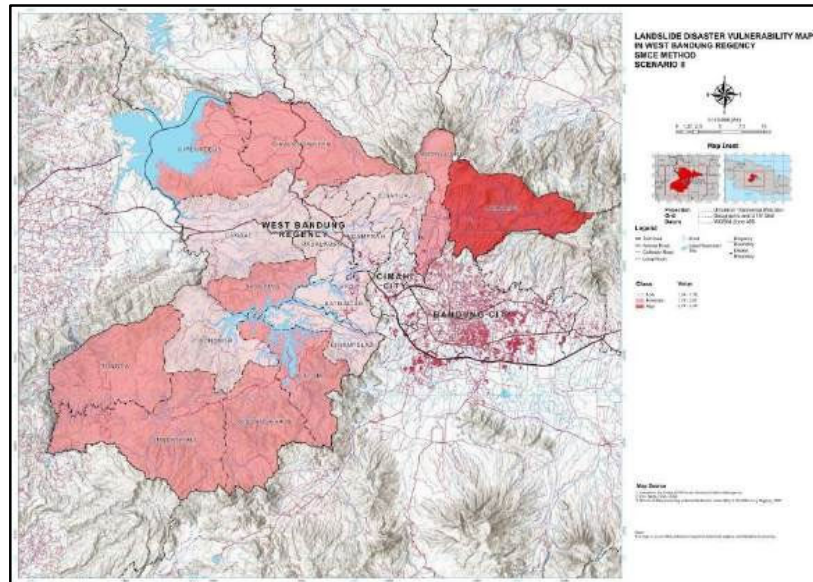


Figure 2. Landslide Disaster Vulnerability Map in West Bandung Regency Scenario I (Equal)

### 3.2 Social Vulnerability Scenario

Social vulnerability in an area can describe the level of social fragility in that area, which has the potential to cause damage, disruption and harm due to the occurrence of a disasters, hazards, and threats (Rahmaningtyas, N., and Setyono, J. S., 2015). This scenario is interpreted as the potential distribution of vulnerability if the social factors causing vulnerability have a more dynamic probability compared to other factors. The aspects that determine social vulnerability in a region can be observed through population density, gender ratio, disability ratio, age group ratio, and the number of tourists. The districts in West Bandung Regency that are the subject of this research on social vulnerability have a geometric pattern that is almost same to the geometric pattern of the ideal scenario (Figure 3).



**Figure 3.** Landslide Disaster Vulnerability Map in West Bandung Regency Scenario II

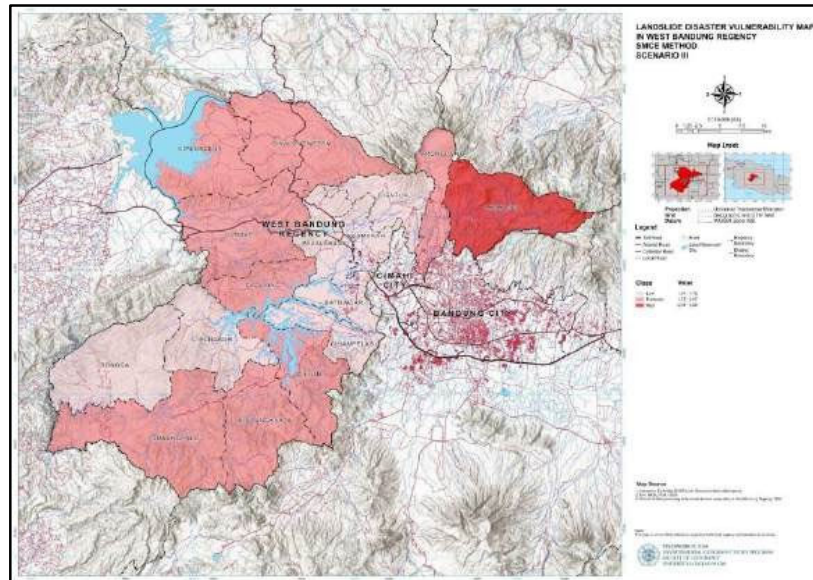
The district Padalarang, Ngrampah, Batujajar, and Cihampelas are included in areas that higher with level of vulnerability due to several aspects compared to other districts, like a Padalarang and Ngamprah, which have a high population density exceeding 3,500 people/km<sup>2</sup>. The districts of Rongga, Gununghulu, Cililin, Cipongkor, Parongpong, and Lembang have a moderate level of social vulnerability because some of these areas have relatively high population density, disability ratios, and poverty ratios. Meanwhile, the districts of Sindangkerta, Saguling, Cipatat, Cisarua, Cikalongwetan, and Cipeundeuy are categorized as having low vulnerability with an index of 1.34 to 1.78. Some districts that are classified as having low vulnerability indeed tend to have lower population density compared to those with moderate or high vulnerability.

The level of social vulnerability in each district significantly impacts the tourism sector in West Bandung Regency. Districts with high vulnerability encounter greater risks due to factors such as population density and the strain on infrastructure from social activities. Meanwhile, moderately vulnerable districts, like Lembang and Parongpong renowned tourist destinations require adaptive strategies to promote sustainable tourism while addressing social risks, including economic disparities and accessibility challenges for vulnerable groups. On the other hand, districts with low vulnerability have the potential to serve as alternative tourism hubs, providing a more balanced environment for tourism development without placing excessive demands on local resources.

### **3.3 Physical Vulnerability Scenario**

The assessment of landslide disaster potential in West Bandung Regency was through Multi-Scenario Disaster Vulnerability Weighting based on the Spatial Multi-Criteria Evaluation (SMCE) Method with several scenarios, one of which is Scenario III, which represents physical vulnerability. Physical vulnerability is a component of vulnerability characterized by the potential for loss or damage to physical objects if affected by a threat (Mantika et al., 2020). This scenario is interpreted as the potential distribution of vulnerability if the physical factors causing vulnerability have a more dynamic probability compared to other factors. In this study, physical vulnerability is divided into three variables: public facilities including kindergarten/early childhood education (TK/RA), elementary school (SD/MI), junior high school (SMP/MTS), senior high school (SMA/MA), vocational high school (SMK), mosques, prayer rooms, churches, hotels, and active cooperatives (data from 2022 and 2023); critical facilities including hospitals, community health centers (puskesmas), and lakes/reservoirs; and houses. Scoring was conducted by calculating these three variables by multiplying the total number by the average area of all aspects of the variables in each district in West Bandung Regency according to the prices of each aspect of the variables based on the guidelines of the West Bandung Regency Disaster Management Agency (BPBD).

The classification results of areas for landslide disaster vulnerability using scoring methods has seven districts classified as low vulnerability with an index ranging from 1.34 to 1.78. These districts are Cisarua, Ngamprah, Padalarang, Batujajar, Cihampelas, Cipongkor, and Rongga. Then, districts classified as moderate vulnerability have an index ranging from 1.79 to 2.07. These include Parongpong, Cikalongwetan, Cipeundeuy, Cipatat, Saguling, Cililin, Sindangkerta, and Gununghalu. Finally, only one area was classified as high vulnerability with an index ranging from 2.08 to 2.36, which is Lembang district (Figure 4).



**Figure 4.** Landslide Disaster Vulnerability Map in West Bandung Regency Scenario III

The analysis of landslide disaster vulnerability classification in West Bandung Regency based on Scenario III further shows that the quantity and area of each land use are the firsts aspects influencing the final result of classification landslide vulnerability through the SMCE Method in Scenario III, which deals with physical vulnerability. The weighting of scoring results for each variable (public facilities, critical facilities, and houses) become the second aspect affecting the final classification of landslide vulnerability using the SMCE method in Scenario III. Lembang district is the only district in West Bandung Regency with a high classification for landslide disaster vulnerability based on Scenario III, due to the larger quantity and area of various land uses including public facilities, critical facilities, and houses compared to other districts. This is proven by the largest number of residential buildings in West Bandung Regency, which are located in Lembang district, with a total residential land use area of 14,942,270.66 m<sup>2</sup>. The highest buildings in Lembang district may be attributed to the cool climate, which enhances the quality of life for residents there (Azharani et al., 2024).

The number of residential buildings in Lembang district interpreted the increasing rate of population growth which continues over time. This growth has influenced various public facilities that support the dynamics of community life (Rumengan et al., 2019). The development of public facilities in Lembang district is can separated from the roles of the community, private sector, and government, given the area's natural potential. In other hands to the cool climate, Lembang district has pristine natural conditions and fertile soil. This is interpreted from the presence of plantation fields such as coffee and tobacco, livestock farming, and various natural conservation areas that can serve as tourist destinations (Putri et al., 2024).

The higher of buildings in an area without subsequent land conservation efforts can increase the potential for landslide disasters, especially in hilly regions like Lembang district in West Bandung Regency. Based on Scenario III in the method used in this study, land use involving public facilities, critical facilities, and residential buildings is crucial for determining landslide vulnerability in West Bandung Regency. The quantity and area of these buildings are the most significant aspects for assessing the vulnerability classification of a region to landslides. The several districts in West Bandung Regency, like Parongpong, Cikalongwetan, Cipeundeuy, Cipatat, Saguling, Cililin, Sindangkerta, and Gununghalu, require attention from the community and government due to their moderate classification of landslide vulnerability. It is also essential for areas with a low classification of landslide vulnerability in West Bandung Regency, such as Rongga, Cihampelas Cisarua, Ngamprah, Padalarang, Batujajar, and Cipongkor, to be monitored further by the community or government.

High physical vulnerability in West Bandung Regency, particularly in densely populated areas with numerous public facilities, poses a significant threat to the tourism sector. The expansion of tourism infrastructure without sufficient land conservation measures exacerbates landslide risks, especially in hilly terrains. To balance safety and tourism growth in these disaster-prone areas, sustainable land management practices and controlled tourism development are essential. Preventive actions or prevention are the most appropriate measures to take if a area has not yet experienced a landslide disaster, so that the disaster can be avoided. Preventive actions for landslides in highland areas can include not constructing buildings and removing vegetation on slopes, as well as excavating or cutting cliffs vertically. Additionally, providing education to the community about the impacts of landslides is essential. Than , there are mitigation actions or decreasing risk to reduce the risk of landslides in a area. These action can include terracing, constructing buildings with strong foundations, and reducing the steepness of slopes. If an area frequently experiences landslides, additional actions are

required, such as restoring impacted areas through reforestation, sealing cracks on slopes to prevent rapid water flow, and restricting access to the area for construction, given its high susceptibility to landslides.

### 3.4 Environmental Vulnerability Scenario

The scenario IV in the study of landslide disaster vulnerability in West Bandung Regency give a highest weight to environmental vulnerability to illustrate the significant losses from environmental damage caused by landslides. The environmental vulnerability is assessed based on the vegetation conditions in West Bandung Regency (Fitria, 2016). According to the SMCE classification, the environmental vulnerability in Scenario IV can be divided into three classes: low, moderate, and high. The landslide disaster vulnerability map for West Bandung Regency in Scenario IV can be seen in Figure 5.

The types of vegetation in West Bandung Regency are divided into protected forests, natural forests, mangrove forests, and shrublands. In Scenario IV, the districts of Lembang and Parongpong are classified high vulnerability. This is due to Lembang district having 2,541.66 hectares of protected forest, 1,373.97 hectares of natural forest, and 126.60 hectares of shrubland. Parongpong district also interpreted a similar phenomenon to Lembang, with 1,354.75 hectares of protected forest, 78.74 hectares of natural forest, and 302.97 hectares of shrubland. district of Cipeundeuy, Cikalongwetan, Saguling, Cililin, Sindangkerta, and Gununghalu are classified as having moderate vulnerability. district Cikalongwetan, Saguling, Cililin, Gununghalu, and Sindangkerta show vegetation patterns similar to Lembang and Parongpong but have lower population densities and physical vulnerability parameters, such as fewer public facilities, compared to Lembang and Parongpong. Cipeundeuy has a low of protected forest, take it in the moderate vulnerability class. districts with low vulnerability in Scenario IV include Rongga, Cihampelas, Cipongkor, Batujajar, Cipatat, Padalarang, Ngrampah, and Cisarua due to their low levels of protected forest, except for Cisarua. district Cisarua shows a lower value in environmental vulnerability parameters related to the presence of natural forest.

Administrative areas located in mountainous areas certainly affect land use and vegetation. Steeper slopes are impact to access and utilization of land by humans. Slopes have a high potential for landslides, so that land use become limited and necessitates increased vegetation to minimize the risk of landslides. As a result, mountainous areas tend to have higher vegetation cover compared to areas with flatter slopes. Flat-sloped areas are often used by humans for residences and daily activities. Therefore, areas with flat slopes contribute to lower environmental vulnerability values compared to areas with steeper slopes, as the environmental losses experienced by areas with steeper slopes and more vegetation are higher. Further, the relationship between environmental vulnerability and tourism is particularly evident in Lembang and Parongpong, where natural landscapes play a vital role in attracting visitors. However, damage to vegetation and the threat of landslides pose significant risks to tourist sites and supporting infrastructure. Given that mountainous areas with steeper slopes have a higher landslide risk, conservation-focused tourism management is essential. Strategies such as controlled land use, reforestation, and sustainable tourism policies are necessary to preserve ecosystem stability, mitigate disaster risks, and ensure the long-term viability of the region's natural attractions.

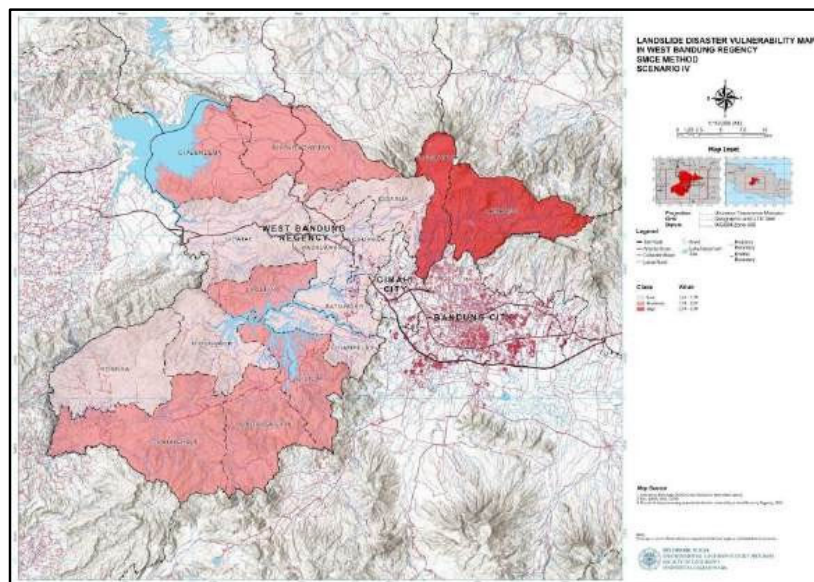


Figure 5. Landslide Disaster Vulnerability Map in West Bandung Regency Scenario IV

### 3.5 West Bandung Regency Landslide Disaster Vulnerability Map

The disaster vulnerability map for landslides in West Bandung Regency is derived from a composite result of the four vulnerability scenarios obtained using the SMCE method previously. A balanced assessment was conducted on the scoring results of the SMCE-ideal, SMCE-KS, SMCE-KF, and SMCE-KL scenarios. Based on this assessment, as observed in (Figure6), a pattern of landslide vulnerability levels was produced in each district of West Bandung Regency. With these results, and matched with the field validation that has been carried out, the composite vulnerability scenario map was chosen as the scenario that best reflects the field conditions. This mapping result indicates that one district has a high vulnerability class that Lembang district, eight districts have a medium vulnerability class including Parongpong, Cikalong Wetan, Cipeundeuy, Cipatat, Saguling, Cililin, Sindangkerta, and Gununghalu districts, while seven other districts are classified as having low vulnerability, which includes Cisarua, Ngamprah, Padalarang, Batujajar, Cihampelas, Cipongkor, and Rongga districts.

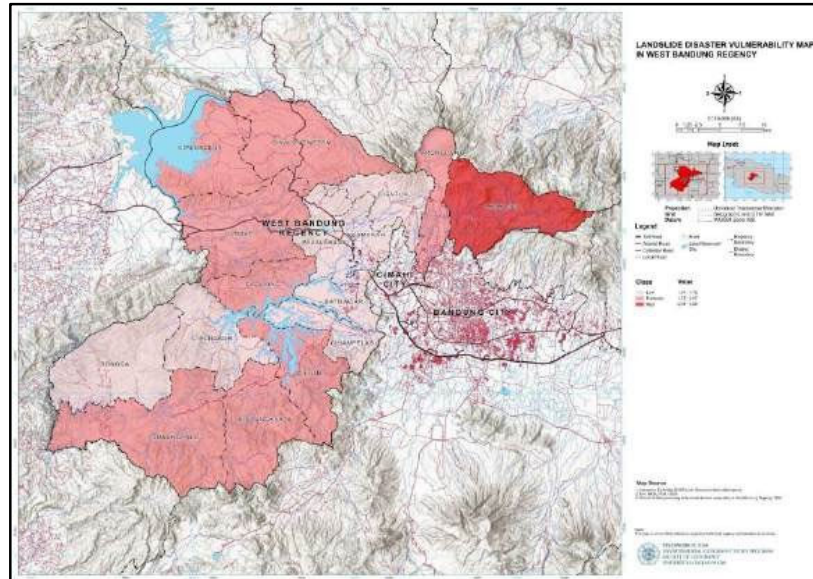


Figure 6. Landslide Disaster Vulnerability Map in West Bandung Regency

### 3.6 Vulnerability Patterns Between Scenarios

The results of the five scenarios above indicate that there are several districts with dynamic characteristics. These dynamic districts can result from differences in vulnerability variables. Some of these dynamic districts are Parongpong, Cipatat, and Rongga. The district of Parongpong is classified as high vulnerability in the environmental vulnerability scenario, meanwhile in other scenarios, it falls into the moderate vulnerability. In the different of district Parongpong, Cipatat is categorized as moderate in the equal vulnerability, physical vulnerability, and composite scenarios, but is classified as low in the social vulnerability and environmental vulnerability scenarios. Rongga is also categorized as moderate only in the social vulnerability scenario, while in the other three scenarios, it is classified as low.

The differences among the four scenarios also produce areas with consistent characteristics. Some areas with consistent results across all scenarios include Gununghalu, Sindangkerta, Cililin, Cipongkor, Cihampelas, Saguling, Batujajar, Padalarang, Ngamprah, Cipeundeuy, Cikalongwetan, Cisarua, and Lembang. These districts fall into the low and moderate vulnerability groups; however, Lembang is uniquely categorized as high vulnerability across all scenarios. This indicates that the values for social vulnerability, physical vulnerability, environmental vulnerability, and hazard risk in Lembang are significantly higher compared to those in other districts of West Bandung Regency. The high values suggest that Lembang has lower preparedness and higher potential damage in the event of a disaster (Arief and Pigawati, 2015). Improvements are needed in social quality, physical quality such as public and critical facilities, and environmental quality, such as forest area, to reduce vulnerability in the Lembang district.

### 3.7 Visitor Trends in Tourism Sites

West Bandung Regency is one of the regency that has many natural and artificial tourism sites. This cannot be separated from its strategic position, namely close to the Jabodetabek (Jakarta, Bogor, Depok, Tangerang, Bekasi) metropolitan area as an area with quite high tourist arrivals. According to data from the West Bandung Regency Tourism and Culture Office,

tourist visits to attractions in the region totaled 4,618,707 in 2023. Most tourists who come to West Bandung Regency take tourist trips to tourism site spread across West Bandung Regency such as National Parks, Nature Tourism Parks, Nature Reserves, mountains, caves, peaks, agrotourism, water recreation, science and technology museums, valleys and protected forests see Figure 7.

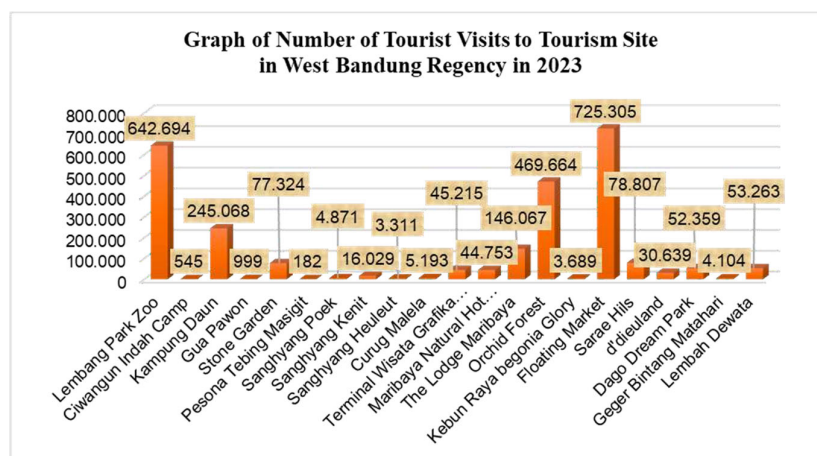


Figure 7. Graph of Number of Tourist Visits to Tourism Site in West Bandung Regency in 2023

Lembang Park Zoo, Kampung Daun, Orchid Forest, and Floating Market are tourist attractions that have a higher number of visitors than other tourism sites in West Bandung Regency. The development of tourism in Parongpong and Lembang District is currently showing quite rapid progress as indicated by the graph of the number of tourist visits which is quite high. In 2023, the number of tourists at the four tourism sites will be 642.694 people, 245.068 people, 469.664 people and 725.305 people respectively. Based on Figure 7, it can be seen that family tourist attractions such as zoos and water recreation have a higher attraction than natural tourist areas such as cliffs and museums.

The high number of tourist visits is one of the factors that influences the potential for landslides. It is feared that the realization of a balance between tourism activities and environmental sustainability will not be in line considering the high number of tourists. One respondent who works as a stall seller around the Lembang Park Zoo said that there had been landslides around the tourist location, especially on the access road that leads to the Lembang Park Zoo (Jalan Kolonel Matsuri). This is because the Lembang Park Zoo tourist location has a gentle topography and minimal slopes with fairly frequent access to the tourist location (Sudrajat, 2024). The landslide caused disruption to road access for tourists to reach tourist attractions, because landslide material covered the road. In this way, there are fewer tourists visiting, so the tourism site experiences a decrease in its attractiveness when the landslide occurs.

Landslides have also occurred in Kampung Daun which occurred around this tourism site area. This happens because the Kampung Daun tourist attraction is flanked by two steep hills. Landslides only occur in the form of bamboo trees falling due to strong winds during rain or bad weather. The last landslide in the tourist area occurred in May 2024, while around the tourist area it has occurred since 2023. Even though a landslide occurred, the disaster did not directly affect tourism activities or tourist visits, and also the construction of tourist attractions did not affect the landslide incident (Maulana, 2024). The high number of visitors is also influenced by road accessibility. Lembang Park Zoo, Kampung Daun, Orchid Forest, and Floating Market are tourism sites that have easy road access to reach. Apart from that, evacuation routes and gathering points are provided by tourism service managers and the government, making evacuation easier when a disaster occurs. In contrast, areas with difficult accessibility such as Tebing Masigit, Ciwangun Indah Camp (CIC), and Guha Pawon have fewer visitors than other tourism sites.

The number of visitors or tourists per month in 2023 is also important to study. This is related to one of the factors causing landslides, namely the frequency of rain in the rainy and dry seasons. Nasiah and Mangunsukardjo (2000) said that soil type, slope slope, vegetation, slope slope, permeability speed, and rainfall intensity influence the occurrence of landslides. The high intensity of rainfall can increase the load on slopes resulting in an increase in water content in the soil, which ultimately triggers landslides (Pierson, 1980; Huang, 2002). Figure 8 presents data on tourist visits to attractions in West Bandung Regency in 2023.

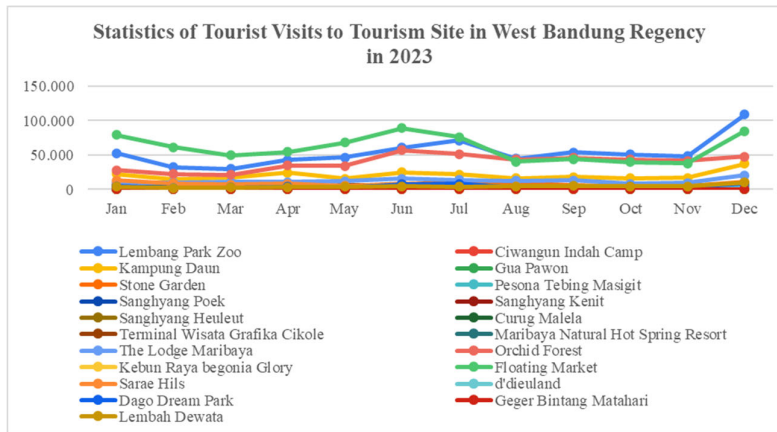


Figure 8. Statistics of Tourist Visits to Tourism Site in West Bandung Regency in 2023

Tourist visit statistics can be used to see the number of visitors each month in a particular year. Based on Figure 8, it is known that the highest number of tourists at tourist attractions in West Bandung Regency is in January, May, June, July and December. If we look at the season classification, the number of visitors tends to be highest in the rainy season. Indonesia has a tropical climate which is influenced by monsoon winds so the rainy season occurs in the months between October and March (Susilo, 2021). The highest peak of tourist visits is in December, which is the rainy season, with the high number of tourist visits in the rainy season increasing the potential for landslides. The high level of rainwater accompanied by the high number of tourist visits can increase the load on the soil structure, so that the potential for landslides increases. On a larger scale, stated in Pradnyasari, et al., (2019), landslides can be destructive, resulting in physical and environmental harm, including structural damage to buildings, bridges, roads, settlements and critical facilities, even threatening loss of life.

## Discussion

### 4.1 Modelling the Composite Vulnerability Scenario

Disaster vulnerability assessment is important in determining disaster mitigation priorities (Mantika, et al., 2020). Based on the five scenarios processed, the most representative scenario was determined in explaining the landslide vulnerability conditions for the tourism sector in West Bandung Regency. The scenario chosen for modeling is the outcome of an amalgamated scenario that was created by fusing four different scenarios: the equal vulnerability scenario, social vulnerability scenario, physical vulnerability scenario, and environmental vulnerability scenario. The composite scenario holistically shows the results of the ideal scenario and the scenario that emphasizes one of the vulnerability parameters. Therefore, this composite scenario is considered to be a scenario that can describe the actual conditions in all districts.

The selection of this scenario is also supported by the results of field validation and interviews (Sandrika, et al., 2020). Field validation focused on the three districts—Parongpong district, Cipatat district, and Rongga district—with dynamic patterns among the five generated vulnerability scenarios are also taken into consideration when choosing the most representative scenario. These dynamic districts are included in the appropriate category in the composite scenario outcomes, according to the field validation results. The field validation was conducted through the following methods: observations of landslides that happened in the relevant districts; observations of vulnerability variables that affected the vulnerability assessment; interviews with locals regarding landslides that happened near tourist attractions in the relevant districts; and government-implemented disaster mitigation measures around tourist attractions.

The distribution of vulnerability classes in the priority scenario, namely the composite scenario, shows similarities with the ideal scenario. This indicates that the modeling of landslide catastrophe susceptibility to the tourism sector in West Bandung Regency yields strong findings. The social vulnerability scenario is not always a priority scenario, despite the fact that the study sector's representative variables—the number of tourists in each tourism site in 2023—compile social vulnerability components. The degree of vulnerability is strongly impacted by the presence of risk elements (elements at risk), as evidenced by the similarity of vulnerability class distribution between districts in the ideal scenario (I) and physical vulnerability scenario (II) with the composite scenario. Yoga, Marfai, and Hizbaron (2020) stated that the complexity of elements at risk in an area is proportional to the probability of a disaster occurrence which further affects the level of vulnerability of the area.

#### 4.2 Validation Results on Dynamic Districts

There are several districts that show different results in each scenario. Parongpong, Cipatat, and Rongga districts are the districts that show different classes in the four scenarios used. This shows that each variable has a different impact on the level of landslide vulnerability for each district (Hardianto, et al., 2020). Field validation is important to determine the appropriate vulnerability class. Field validation was carried out by conducting observations and interviews with local communities in ten tourist sites in West Bandung Regency. The ten tourism sites were distributed across three tourism sites in Parongpong district, six tourism sites in Cipatat district, and one tourism site in Rongga district according to Table 4.

**Table 4.** Tourism Sites Sample

No	District	Tourism Sites
1	Rongga	Curug Malela
2	Cipatat	Sanghyang Kenit, Sanghyang Poek, Sanghyang Heuleut, Pesona Tebing Masigit, Stone Garden, and Guha Pawon
3	Parongpong	Lembang Park Zoo, Ciwangun Indah Camp, and Kampung Daun.

One of the districts that is dynamic in all five scenarios is Parongpong district. Parongpong district borders Lembang district and has a steep slope in the north. The steep slope has implications for the high potential of landslides (Hardianto, et al., 2020). The four scenarios show that Parongpong district is included in moderate classification for the equal vulnerability scenario, physical vulnerability scenario, and social vulnerability scenario, but for the social vulnerability scenario, Parongpong district is included in high classification. While in the composite vulnerability scenario, Parongpong district is included as a moderate classification.



**Figure 9.** (A) Landslide around Ciwangun Indah Camp, (B) Landslide on the evacuation route of Ciwangun Indah Camp, (C) Old landslide in Ciwangun Indah Camp, (D) Landslides in Kampung Daun

Parongpong district for the environmental vulnerability scenario is categorised as high vulnerability. This is considered inappropriate to describe the conditions of Parongpong district. The population density ratio is quite dense in the southern part, but in the northern part of Parongpong district the population density is lower with higher vegetation density. This low population density will affect a lower vulnerability of the landslide areas (Fitria, 2016). Landslides are still found in the northern part of Parongpong district that can be seen in Figure 9, but no landslides were found in the southern part of Parongpong district during the field validation. Ciwangun Indah Camp is one of the tourism sites located in the northern part of Parongpong district that utilises the protected forest. Landslides are still found in this area, especially during the rainy season with high intensity and high frequency of rain. Parongpong district is located in Lembang Fault with a muddy soil texture that affects soil stability and causes land subsidence every year. Kampung Daun is located in the centre of Parongpong district, between two steep hills. Based on respondents, Kampung Daun experienced landslides in May 2024, and bamboo trees fell due to heavy rains and strong winds. Lembang Park Zoo is also located in the central part of Parongpong district, with a gentle slope and a swampy area. Landslides are not found around the tourism site because it has become a developed land and a concrete wall is provided around the tourism site. However, landslides occur and affect the main access road to the tourism sites, especially on Kolonel Masturi road which has implications for a decrease in tourists. The lower number of tourism visitors will also affect the lower vulnerability in Parongpong district. These factors make Parongpong district more appropriate as a medium vulnerability, rather than high vulnerability.

Cipatat district is also one of the dynamic districts for all the vulnerability scenarios. Cipatat district has a complex topographical condition (Faadhilah & Nugroho, 2024). The equal vulnerability scenario and physical vulnerability scenario classified Cipatat district as a medium vulnerability, but for social vulnerability scenario and environmental vulnerability scenario classified Cipatat district as a low vulnerability. In the composite scenario, Cipatat district is categorised as medium. The tourism sites in Cipatat district are located in areas with steep slope topography so it has the potential for landslides.

Cipatat district has a medium class of landslide vulnerability. The high concentration of tourist attractions in Cipatat District contributes to the large number of visitors. Tourism sites locations tend to form clusters so they have the same main roads (Setyanto, 2018). Landslides are found on the main road which can disrupt the accessibility to the tourist sites.

Some of the landslides to one of the tourism sites can be seen in Figure 10. According to the interviews with local communities, landslides often occur when it rains with high frequency. The high number of landslides that occur around tourism sites also results in a higher vulnerability level in this area. Although the population density in Cipatat district is quite low, the presence of tourism sites in Cipatat district will also affect the higher vulnerability of landslides. The higher vulnerability due to the number of tourism sites causes this district to be categorised as a medium vulnerability area.



**Figure 10.** (A) Landslide in Sanghyang Main Road, (B) Landslide that ruined the Sanghyang Main Road, (C) Landslide around Sanghyang Main Road and settlements

The next district with dynamic characteristics in the four scenarios is Rongga district. Rongga district is categorised as low vulnerability, except in the social vulnerability scenario. Rongga also has different topographic conditions (Hardianto, 2020). In the composite scenario, Rongga district is classified as low vulnerability. Landslides are also found in this district. Rongga district is classified as low vulnerability on the composite vulnerability scenario and is appropriate with the existing conditions. The high number of landslides and their effect on physical buildings in this district make it included as the medium vulnerability, but the low population density makes this district vulnerable lower. One of the landslides can be seen in Figure 11. Low population density will result in lower vulnerability, as the number of victims will tend to be lower. The low number of tourism sites also make Rongga district to be categorised as low vulnerability. The lower number of the tourism sites will make the lower number of tourists, which is the reason how Rongga district becomes an area with low vulnerability.



**Figure 11.** Landslide around the settlement area in Rongga district.

### **4.3 Tourism Road Accessibility**

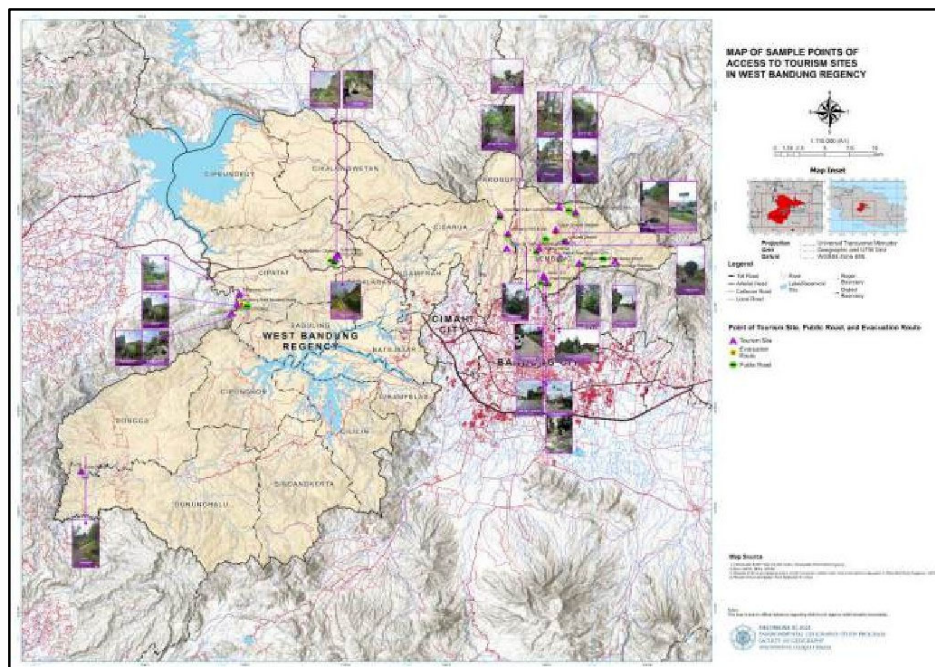
Districts in West Bandung Regency have high tourism potential (Kinasih, et al., 2023). This can be proven by the large number of tourism sites in West Bandung Regency. The existence of these tourism sites will draw tourists to visit West Bandung Regency. Road access is one of the things that can affect tourism sites. The easier access to tourism sites, will make the higher number of tourists who will visit the tourism sites. The existence of this road access will also affect the level of landslides vulnerability, the easier access, the easier it will be for the tourists to evacuate from the landslide area, so that vulnerability will be lower with this easy road access.

Lembang district is the only district with high vulnerability. The tourism potential in Lembang district is also high, supported by a great number of tourism sites compared to other districts in West Bandung Regency. The condition of tourism in Lembang district is already more developed than other districts. The easy access to tourism sites is one of the developments to support tourism (Wahyono, et al., 2022). Roads with decent quality materials and wide roads will support

tourists to access tourism more easily. This easy road access will also make it easier for the community to take evacuation actions when there is a disaster. Although Lembang district has a high vulnerability, the existence of good road access is expected to reduce the number of victims.

On the other hand, Cipatat and Rongga districts have more difficult road access to the tourism sites. Some of the road conditions can be seen in Figure 12. Poorer road conditions can have an effect on the low number of the tourists that will visit the tourism site (Sari, 2020). Some access to tourism sites in Cipatat district, such as Stone Garden and Pesona Tebing Masigit are still dirt roads covered with rocks. These conditions will endanger the tourists and can damage the vehicle used when visiting these tourism sites. The slope of the road which is still very steep and slippery can also endanger the visitor if they are not careful. The roads on these two tourism sites are classified as difficult to access by four-wheeled vehicles. This condition may impede evacuation access during natural disasters, such as landslides, potentially increasing response time and risk. In Sanghyang Poek, Sanghyang Kenit, and Sanghyang Heuleut in Cipatat district, the road access to those three tourism sites is quite good. The road is supported with asphalt and can be passed using four-wheeled vehicles. However, in these tourism sites, many landslides were found and there were road bodies that were damaged by landslides, which will increase vulnerability in this area.

There is only one tourism site in Rongga district, namely Curug Malela. The tourists need to walk to reach the tourist point, that there are no vehicles that can reach the tourist point (Karini & Astiana, 2022). The road to the Curug Malela parking area is still asphalt, but the road to Curug Malela itself is still soil and rocks, so vehicles cannot reach the nearest point and need to walk to reach Curug Malela. This condition will complicate evacuation activities if landslides happen near Curug Malela, which still have a high potential to occur in the area. As a result of this, it is necessary to build an evacuation route, so that the evacuation process can be done easily and reduce the number of victims.



**Figure 12.** Map of Sample Points of Access to Tourism Sites in West Bandung Regency  
(Source: data processing, 2024)

#### 4.4 Mitigation Efforts

The high potential of tourist attraction and the threat of landslides in West Bandung Regency is a challenge for the government and the community. Tourism activities can improve the economy, but the threat of landslides can cause losses in the form of casualties and materials (Sutrisnawati, 2018). The threat of landslides that are not handled properly will reduce tourism sites because visitors will have a fear of travelling in areas with landslides vulnerability. Some landslides mitigation efforts have been made by the government in tourism sites and roads, which can be seen in Figure 13. These efforts include the construction of gabions, the creation of evacuation routes, the provision of evacuation routes signs, landslides warning signs, and the construction of disaster alert posts.



**Figure 13.** (A) Disaster Alert Post, (B) Landslide Prone Warning Signs, (C) Landslide Prone Warnings, (D) Gabion Utilization, (E) Evacuation Route Signs

Signs related to landslide warning information and evacuation routes are quite common in areas with moderate and high vulnerability such as Lembang, Cipatat, and Parongpong district. Many tourism sites are found on the edge of the highway so the evacuation route for tourist and local communities can follow the fastest route away from landslide vulnerable areas. The government provides evacuation signs, widening roads, and increasing vegetation cover. In addition, gabions and grasses can also be found on the sides of the road to increase water infiltration. Slopes with high steepness and vulnerable to landslides are also built with concrete walls to minimise losses. A disaster alert post was built on the roadside in Lembang district which is a high vulnerability district for landslides. Mitigation efforts made by the government are good enough, but there are still shortcomings both in terms of maintenance and allocation of funds. Figure 12B shows that the signs warning of landslides vulnerable areas have begun to be covered by vines so that the signs become less visible. Repairing and cleaning activities at the Kampung Daun tourism sites still use private fund, because they have not received funds from the government. Gabions around Sanghyang Poek, Sanghyang Kenit, and Sanghyang Heuleut tourism sites are also found to be damaged. Bamboo is planted on the steep slopes near the parking area of the tourism site to increase water absorption and reduce erosion rates (Basri, 2013). Apart from the government, there is assistance from the social community, such as Saung Angklung Mang Udjo who provided assistance in the form of bamboo seedling at the Guha Pawon tourists site in Cipatat District.

## Conclusion

This landslide disaster vulnerability research in West Bandung Regency produces outputs in the form of distribution of landslide disaster vulnerability levels in each district in West Bandung Regency, in relation to the tourism site which is depicted through the Landslide Disaster Vulnerability Map of West Bandung Regency along with identification of tourism site sectors as depicted in the Photo Tagging Map of Road Access in the Tourism Sites in West Bandung Regency. According to the vulnerability mapping that has been carried out, it is known that one district has a high vulnerability class, namely Lembang district, eight districts have a moderate vulnerability class including Parongpong, Cikalong Wetan, Cipeundeuy, Cipatat, Saguling, Cililin, Sindangkerta, and Gununghalu districts, while seven other districts are classified as having a low level of vulnerability including Cisarua, Ngamprah, Padalarang, Batujajar, Cihampelas, Cipongkor, and Rongga districts. Population and building density are parameters that influence the level of vulnerability of a district, considering that these two parameters are risk elements that will be affected if a disaster occurs.

Distribution of vulnerability to the tourism sector in West Bandung Regency is carried out to predict adverse conditions due to potential landslide disaster threats to the tourism sector. The value of landslide disaster vulnerability in the tourism sector affects the number of tourist visits. The higher the level of landslide vulnerability in the tourism sector, the more likely it is to have an impact on the number of tourists which tends to decrease. Based on the results of field validation, the main factor influencing the distribution of landslide vulnerability in the tourism sector is the impact of the number of visitors on supporting facilities, especially road access. The existence of site road access affects the level of disaster vulnerability. Easier road accessibility can reduce the value of landslide disaster vulnerability because it facilitates evacuation when a disaster occurs. But the effects on tourism go beyond the sheer volume of visitors. It is necessary to take consideration of tourists' social vulnerability, which includes their risk of harm, psychological distress, and interruption of their travel arrangements. Visitors may be particularly at risk during a landslide occurrence since they tend to not be familiar with the local topography and emergency protocols. Language barriers, reliance on tour operators, and the possibility of restricted access to emergency services all contribute to the social vulnerability. In addition, several mitigations against landslide disasters in tourism site have been attempted by tourism service managers and the government to minimize the number of fatalities and material losses due to landslide disasters when a disaster occurs, including making

gabions, making evacuation routes, providing evacuation route signs, warning signs for landslide hazards, and making disaster alert posts. Although these mitigations might not adequately address the social vulnerabilities of each visitors, for instance the warning signs in the native tongue might not work well for tourists from other countries, these are considered as a response to the conditions of vulnerability and disaster threats around the tourist attraction.

## Suggestion

The government and relevant parties in charge of the disaster management can be encouraged to prioritize allocating resources for mitigation of potential landslide occurrences and to scale up the efforts to identify areas that are susceptible to catastrophic landslides. Managers of tourism sites may assess the degree of vulnerability surrounding the sites and scale up the current landslide mitigation efforts. The author hopes that research with the same study can be carried out again in more depth considering the level of vulnerability to landslide disasters that threaten which can directly affect the developing tourism sector in West Bandung Regency.

## Acknowledgement

The author would like to thank the Department of Environmental Geography, Universitas Gadjah Mada for organizing the implementation of Field Work III 2024. We also would like to thank Dr. Dyah Rahmawati Hizbaron, S.Si., MT, M.Sc. as our supervisor who has provided direction and support during the implementation of this research.

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