Analysis of Landscape Impact on Post-Earthquake, Tsunami, and Liquefaction Disasters in Palu City, Central Sulawesi

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Abstract. Sulawesi is an island that is affected by three main plate basins namely the Pacific Ocean plate, the Indo-Australian plate, and the Eurasian continent plate which produces several faults and causes intensive seismicity and other disasters in the region. Palu City as the Capital of Central Sulawesi Province is a disaster-prone area such as earthquake, tsunami and liquefaction. The impact of the disaster caused huge losses especially since the area has a high population. The importance of disaster mitigation plans in the area so that casualties, damage to public facilities, and other losses can be minimized. The mitigation plan consists of several stages namely the preparation, analysis, synthesis, and making the plan recommendations. Overall, Palu City is prone to disasters. The area that has a high level of vulnerability to 3 disasters has a total area of 446 hectares. Whereas for areas that have a high level of vulnerability to 2 disasters and 1 disaster has a total area of 3364 hectares and 3873 hectares respectively. There are 3 zones based on potential disasters in Palu City. Zone A is a zone that is prone to earthquake hazards. The total area of Zone A is 9100 hectares. Zone B is a zone for mangrove forest planting areas. The total area of Zone B is 572 hectares. Zone C is a zone that is prone to liquefaction hazards. The plant is expected to be able to absorb saturated ground water and reduce soil movement so it does not shift. The total area of Zone C is 1556 hectares. Disaster-prone areas are recommended to be relocated to safe areas in accordance with the recommended relocation locations. The recommended relocation area is on a flat slope of 6093 hectares and on a gentle slope of 5557 hectares.

Keywords: Carrying Capacity for Evacuation, Disaster Prone, Mitigation, Palu City

1. Introduction

Sulawesi island is made by three main plate basins namely the Pacific Ocean plate, the Indo-Australian plate, and the Eurasian continent plate which produces several faults and cause seismicity to increase and spread in this region. The Palu Koro Fault System is a fault that crosses Sulawesi Island [1]. The Palu Koro fault system is the main active fault in the Sulawesi region consisting of a combination of horizontal faults that cut through the central part of Sulawesi Island including Palu City. The Central Sulawesi fault system has completed the collision, obduction (interconnected plates), and placement (Strengthening of the plates) processes in Sulawesi and caused intensive seismicity in this region [2]. According to [3] on September 28 2018 an earthquake with a magnitude of 7.7 SR was located at 0.18 latitude and 119.85 east longitude with a depth of 10 kilometers which caused tsunamis and liquefaction in Palu and Donggala. Planning for mitigation of areas prone to earthquakes, tsunamis and
liquefaction is a first step to reduce the greater impact if one day a disaster occurs again. The plan can reduce the number of casualties and damage to public and private facilities such as buildings, highways, bridges, and others. Research is needed on the analysis of the impact of landscapes in the aftermath of the earthquake, tsunami and liquefaction in Palu City, Central Sulawesi.

The objectives of this study are: (1) analyzing the landscape impacts and hazards caused by the earthquake, tsunami and liquefaction occurring in Palu City; (2) identify post-disaster land use changes; (3) plan mitigation areas accompanied by information on land carrying capacity and landscape restructuring in areas prone to earthquakes, tsunamis and liquefaction.

2. Methods
2.1. Study site and time
The location of the study was conducted in Palu City, Central Sulawesi Province, an area which was affected by the earthquake, tsunami and liquefaction. The time of the study was conducted in October 2018 to July 2019.

![Figure 1 Study sites](source: Palu City Regional Development Planning Agency)

2.2. Study Methods
The method used in this research is descriptive and spatial analysis methods. The stages of the research include the stages of preparation, analysis, synthesis, and plan recommendations.

- The preparation phase is the stage which consists of the stage of collecting data or finding information needed related to the research location. The preparation phase also prepares to record parties who have data supporting research information. The data needed includes urban spatial data, land use data, hazard zone data, geological data, topographic data, hydrological data, vegetation, climate, accessibility and circulation, facilities and infrastructure, and socio-economic data of the population.

- The analysis phase is the stage analysis by spatial and descriptive methods. The spatial method is carried out by identifying thematic maps of Palu City, disaster impact maps and maps of earthquake, tsunami and liquefaction-prone areas. Descriptive analysis is carried out on all aspects to determine the potential and constraints then discussion will be carried out to develop potential constraints.

- This synthesis phase is the integration stage of the analysis results in the form of zone identification maps with an overlay system. These results form the basis for determining landscape restructuring, disaster mitigation areas, and calculations for the carrying capacity of mitigation areas.

- The final synthesis results in the form of a disaster mitigation space zone plan for areas prone to earthquake, tsunami and liquefaction equipped with facilities that
accommodate the needs of refugees as well as calculations of carrying capacity in each area that will be used as a place of refuge. Analysis of the carrying capacity of the site according to [4] is the area provided divided by the standard area required per individual. In general the formula for carrying capacity of the site is

\[
\text{Carrying Capacity} = \frac{\text{Area Provided (m}^2\text{)}}{\text{Standard area required each person (m}^2\text{ person}^{-1})} \quad \ldots (1)
\]

3. Results and Discussion
3.1. Analysis
3.1.1. General Conditions
Palu City administration area consists of 8 sub-districts and 46 urban areas. The total area of the sub-districts is West Palu at 8.28 km\(^2\), Tatanga at 14.95 km\(^2\), Ulujadi at 40.25 km\(^2\), South Palu at 27.38 km\(^2\), East Palu at 7.71 km\(^2\), Mantikulore at 206.80 km\(^2\), Palu North of 29.94 km\(^2\), and Tawaeli of 59.75 km\(^2\).

3.1.2. Topography

According to [5] concerning the area arrangement related to land slope, the classification of slope is divided into 5 classes with flat slope (0-8)% , ramps (8-15)% , rather steep (15-25)% , steep (25-45)% , and very steep (>45)% . The slope of land with flat classification in Palu City is 13915.81 hectares. The slope of the land with the classification of ramps is 6019.69 hectares. While the slope with a rather steep is 6585.14 hectares, steep is 9738.27 hectares, and very steep amounted to 1897.72 hectares.

3.1.3. Landuse
The total area of Palu City is 38161 hectares which is dominated by forests with an area of 14242.93 hectares, shrubs with an area of 9467.32 hectares, residential buildings with an area of 5261.81 hectares, and plantations with an area of 3803.88 hectares. The extent of land use in Palu City is presented in Table 1.
Table 1 Landuse

| No | Landuse            | Wide (Hectar) | Persentase |
|----|--------------------|---------------|------------|
| 1  | Forest             | 14242.93      | 37.53 %    |
| 2  | Field              | 789.32        | 2.08 %     |
| 3  | Another open field | 553.31        | 1.45 %     |
| 4  | Other non-residential buildings | 58.54 | 0.15 % |
| 5  | Residential buildings | 5261.81 | 13.86 % |
| 6  | Rock/ sand         | 45.29         | 0.11 %     |
| 7  | Industrial and trade buildings | 109.66 | 0.28 % |
| 8  | Bush               | 9467.32       | 24.95 %    |
| 9  | Public facilities  | 91.73         | 0.24 %     |
| 10 | Rice field         | 302.98        | 0.79 %     |
| 11 | Salt pond          | 19.30         | 0.05 %     |
| 12 | Mining Area        | 284.33        | 0.74 %     |
| 13 | Water body         | 252.00        | 0.66 %     |
| 14 | Meadow             | 1662.40       | 4.38 %     |
| 15 | Plantation         | 3803.88       | 10.02 %    |
| 16 | Sabana             | 999.19        | 2.63 %     |

3.1.4. Climate

Climate plays a role in changing the development of soil profile because it is affected by rainfall and temperature. The climate that influences soil development is a micro-scale climate. Rainfall is related to effective humidity which influences the movement of water in the soil. The intensity of rain can increase water infiltration into the ground and increase the amount of groundwater.

Mutiara Palu Air Station in 2017 noted that the minimum air temperature occurred in January, amounting to 21.9 °C. Then in April the temperature in the city of Palu reached a maximum point of 33.8 °C. The lowest average air temperature occurred in June which was 26.7 °C and the highest average air temperature occurred in December amounted to 28.3 °C. The lowest air humidity occurred in December which reached 74.9 percent, while the highest air humidity occurred in June which was 84.0 percent.

Mutiara Palu Meteorological Station in 2017 noted that the highest air pressure occurred in July which was 1012.0 mb while the lowest air pressure occurred in December which was 1010.4 mb. Meanwhile the lowest wind speed occurs in January, June, July, August, September, and December, which is 4 knots, the lowest wind speed occurs in February, March, April, May, October, and November at 5 knots. The dominant wind direction in 2017 will head northwest from April to December. In January to March the direction of the wind goes north.

In 2017, the highest rainfall occurred in June which was 166 mm. The average number of rainy days occurred in October, which was 25 days, while the least number of rainy days occurred in December as many as 14 days. Meanwhile the highest solar irradiance in 2017 occurred in October at 67%, while the lowest solar irradiance occurred in February at 49%.

3.1.5. Vegetation

Previously in Palu there was a large mangrove forest. According to Mohamad Syarif, in an article tracing mangrove forests in Palu Bay by [6], he said that in the past there were still many mangrove forests in the Kale area located in the coastal area of Layana Indah Village, Matikulore District, Palu City. Mangrove forests start from Salu Bai which is now a warehouse until in front of Kebun Sari in the 1980s.

In 1987 the moment of the peak of mangrove forests became a mainstay commodity for export in Central Sulawesi. At that time the exploitation of mangrove forests occurred on a large scale. Mangrove wood exports have surpassed 19,320 cubic meters or 613,798,961 dollars [6]. Being a mainstay of exports in Central Sulawesi, mangrove forests are increasingly decreasing in size. Being the Capital of Central Sulawesi, Palu City must also provide land for
its community activities. Therefore, land use change is getting wider and resulting in the loss of mangrove forests in the city. The loss of mangrove forests also eliminates their functions. The function of mangrove forests is as a barrier to abrasion and erosion, spawning water animals, habitat for several animals, and buffering tsunami waves.

Not all of the Palu Bay area can be planted with mangrove trees due to its tidal and ocean depth factors. On Talise Beach there is a mangrove tree that made history that the bay used to have a mangrove forest. The tree is named after the local community by the name of the Single Tree because only the mangrove tree grows on Talise Beach. On September 28 the mangrove tree was damaged by the tsunami waves. The tsunami disaster made aware of the importance of the existence of mangrove forests as vegetation that can withstand tsunami waves.

Public awareness about the importance of mangrove trees increased after the tsunami on September 28, 2018. Young people in the city of Palu who are members of the Palu City Nature Lover Community responded to this opportunity. There are a number of events held by the Palu City Nature Lover Community such as planting mangrove seedlings in several places. One of the locations for planting mangrove seedlings is around the Singles Tree which was carried out on May 19, 2019. About 300 mangrove seedlings consisting of *Rhizophora apiculata* and *Rhizophora stylosa* species were planted in the area. This is the first step in rehabilitating mangroves in Palu Bay.

3.1.6. Circulation
The disaster caused several damaged roads in Palu City. Damaged roads have varying degrees of damage from cracking to total breaking up. In areas along Palu Bay that were affected by the tsunami, many roads were severely damaged. The created wave wall cannot withstand a tsunami and has an impact on the road next to it. The distance of the embankment with the road that is too close makes the road collapse because the embankment cannot sustain. Most roads in the liquefaction area experience a total break because the land in the area has decreased and shifted.

3.1.7. Facilities and infrastructure
The disaster caused several buildings that provided public services to be damaged such as hospitals, public service offices, ports and airports. Hospitals that were damaged by the earthquake made the disaster victims had to be rushed to another hospital. This makes other hospitals experience patient enslavement. The bodies of the disaster victims were too many and were only placed in the hospital grounds. The stench caused by the body was very strong because the body had been unidentified for days and was waiting for his family to come. Damage to public service offices such as BPBD offices disrupts the service process. Some offices also suffered damage and could not be used for work for several months. The airports and ports that stop operating have hampered many residents who want to use this transportation to evacuate themselves back to their area of origin.

Most residents whose houses were affected by disasters in the city of Palu will choose to flee to their relatives’ places if the place is felt safe from disaster. This is because in the refugee camp there are still many inadequate facilities such as clean water and the limited number of public toilets. Safety and comfort in the refugee camps is also very lacking because the economic conditions a week after the disaster are still unstable. The government cooperates with state-owned companies to build buildings with mild steel for temporary shelters for disaster victims. In Petobo there is a temporary shelter that is inhabited by around 2000 families for the victims of the disaster.

3.2. Disaster Analysis
Natural disasters that occurred in Palu City on September 28, 2018 resulted in many losses and casualties. The disaster occurred at 18.02 WITA, beginning with an earthquake measuring 7.7 on the Richter scale and was followed by the tsunami and liquefaction. Data on disaster
victims and affected buildings can be seen in Table 2 and Table 3.

### Table 2 Recapitulation of data on victims of the earthquake, tsunami and liquefaction of the city of Palu in 2019 phase II

| No | Districts       | Number of casualties | Victim | Number of Event Venues |
|----|----------------|----------------------|--------|------------------------|
|    |                |                      |        | Die | Lost | Earthquake | Tsunami | Liquefaction |
| 1  | Mantikulore     | 359                  |        | 317 | 85  | 36         | 356     | 10          |
| 2  | Palu Selatan    | 816                  |        | 658 | 158 | 38         | 79      | 699         |
| 3  | Tatanga         | 121                  |        | 76  | 45  | 26         | 86      | 9           |
| 4  | Tawaeli         | 163                  |        | 155 | 8   | 7          | 156     | 0           |
| 5  | Palu Timur      | 375                  |        | 348 | 27  | 44         | 309     | 22          |
| 6  | Palu Utara      | 74                   |        | 59  | 15  | 9          | 63      | 2           |
| 7  | Palu Barat      | 1031                 |        | 863 | 168 | 42         | 194     | 795         |
| 8  | Ulujadi         | 200                  |        | 136 | 64  | 75         | 122     | 3           |
|    | Amount          |                      |        | 3182 | 2612 | 570       | 1365     | 1542        |

Source: Palu City Regional Development Planning Agency

### Table 3 Recapitulation of building condition data due to the earthquake disaster, tsunami and liquefaction of the Palu City in 2019 phase II

| No | Districts       | Building Conditions | Amount | Damage Due |
|----|----------------|---------------------|--------|------------|
|    |                | RB      | RS | RR | HL | RB | RS | RR | HL | GB | GB | TS | TK |
| 1  | Mantikulore     | 2445    | 3957 | 4667 | 471 | 11540 | 1243 | 9838 | 452 | 7           |
| 2  | Palu Selatan    | 1737    | 2422 | 4195 | 1439 | 9829 | 11 | 7107 | 0 | 2711      |
| 3  | Tatanga         | 1744    | 2460 | 3341 | 0 | 7545 | 622 | 6923 | 0 | 0         |
| 4  | Tawaeli         | 851     | 1387 | 2324 | 442 | 5004 | 0 | 4368 | 636 | 0         |
| 5  | Palu Timur      | 1358    | 1661 | 1683 | 109 | 4811 | 7 | 4795 | 9 | 0         |
| 6  | Palu Utara      | 267     | 592  | 1030 | 291 | 2810 | 0 | 1836 | 344 | 0         |
| 7  | Palu Barat      | 2300    | 1491 | 1461 | 3538 | 8790 | 64 | 3896 | 332 | 4498      |
| 8  | Ulujadi         | 882     | 1965 | 2393 | 230 | 5470 | 3 | 5067 | 397 | 3         |
|    | Amount          | 11620   | 15935 | 21094 | 6520 | 55169 | 1950 | 43830 | 2170 | 7219     |

Keterangan

- RB : Rusak Berat (Severely damaged)
- RS : Rusak Sedang (Moderately damaged)
- RR : Rusak Ringan (Damaged lightly)
- HL : Hilang (Lost)
- GB : Gempa Bumi Sesar (Fault Earthquake)
- GBS : Gempa Bumi (Earthquake)
- GB : Gempa Bumi (Earthquake)
- TS : Tsunami
- TK : Likuifaksi (Liquefaction)

Source: Palu City Regional Development Planning Agency

### 3.2.1 Earthquake

An earthquake of 7.7 SR occurred on September 28, 2018, destroying tens of thousands of buildings in the city of Palu. The vibrations from the earthquake triggered a tsunami and liquefaction in Palu City. The point of the earthquake was located 27 kilometers northeast of Donggala, Central Sulawesi, with a depth of 10 kilometers. The point of the earthquake is at coordinates 0.18° south latitude 119.85° east longitude. The closest distance from the earthquake point to the city of Palu is in the District of Tawaeli. The sub-district is within a radius of 60 kilometers. The farthest distance from the earthquake point to Palu is in the Districts of South Palu and Tatanga. The two districts are within a 90 kilometer radius. Although the earthquake distance is quite far from Palu City, the impact of the damage caused is very detrimental and risky. Damage to buildings in the city of Palu due to the earthquake was also influenced by the strength of the construction. Therefore building damage is scattered randomly and varied. There are those who experience severe, moderate, and mild effects.
Safe distance for residential areas so that the area is stable is more than 1000 meters. The vulnerable distance if an earthquake occurs with a high enough magnitude is 100-1000 meters. While the distance that is very prone to damage due to earthquakes is less than 100 meters [7]. This is a serious threat because Palu City, the capital of Central Sulawesi and has a high population, is located in an earthquake prone area and is also crossed by the Palu Koro Fault System.

The approach to determine earthquake hazard in an area is the Peak Ground Acceleration (PGA) approach. PGA is an illustration of the relationship between the intensity of local ground motion, earthquake magnitude, and distance from the source of the earthquake [8]. This approach is an approach by looking at seismic footage somewhere somewhere that has happened in the past. PGA can be used as a basis for mapping that can determine areas with earthquake hazard in an area in Palu City.

3.2.2. Tsunami
Tsunami vulnerability can be seen from the distance of a place to the coastline. This is based on the reach of tsunami currents. This can be used as a parameter for analyzing tsunami-prone areas. According to [9] concerning the border of the coastline, the minimum distance of the coastline from the highest tide point towards the land is 100 meters. One of the objectives of
determining the border of the coastline in the Presidential Regulation is to protect and protect the lives of people living in coastal areas and small islands from the threat of disaster.

Based on the results of the mapping of tsunami prone areas, the farthest tsunami coverage areas are along the Palu River. The farthest reaches of the tsunami that had a high impact in Palu City were around 800 meters from the coastline. For the farthest reach of a tsunami with moderate impact around 1200 meters. The farthest reach of a tsunami with a small impact of around 2000 meters.

![Figure 5 Tsunami affected map](source)

Low ground elevations and contour ramps are very potential with the reach of tsunami currents. This range can be very far depending on the force of the thrust of tsunami currents and the barrier of tsunami currents. If the force of the thrust of the tsunami current and the barrier is neglected then the ground level is very influential on the reach of the tsunami current.

![Figure 6 Altitude Vulnerability Map to Palu City Tsunami](source)

3.2.3. Liquefaction
Liquifaction disasters occur because of the presence of land that is dominated by the size of sand experiencing water saturation vibrated by a sudden earthquake. This makes the pore water pressure increase so that it exceeds the friction strength of the soil. It is this process that causes the liquefaction and the material making up the soil into the sand as if floating
through the water. Liquefaction makes the ground surface move decreases, shifts, and loses endurance to mount objects on it. This is very dangerous because the building above it can collapse and endanger the people inside it. People who have settled in the area should understand this and are advised to relocate to areas with low levels of liquefaction vulnerability. Lack of public knowledge about liquefaction and the dangers posed and how to save themselves is a task that must be resolved immediately. Efforts to increase knowledge about liquefaction disasters hopefully can reduce the level of damage and casualties.

Areas affected by liquefaction that occur in Balaroa and Petobo villages are included in areas with very high liquefaction potential zoning. The total area of potential liquefaction is very high in the city of Palu of 982.97 hectares. The total area of high liquefaction potential in the city of Palu is 1734.06 hectares. The area of potential moderate liquefaction in the city of Palu is 6535.80 hectares. The remaining 29055.60 hectares are areas with low liquefaction potential.

![Figure 7 Liquefaction Potential Map of the City of Palu](source)

Based on the geological and hydrogeological maps, an overlay map is obtained that shows areas with geological substrate in the form of sand and high groundwater. The area is vulnerable to liquefaction disaster.

![Figure 8 Map of Geological & Hydrological Analysis of the Liquefaction of Palu City](source)

4. **Synthesis**

Based on an analysis of the vulnerability of each disaster in the city of Palu, a merger was carried out to obtain a map of all the vulnerabilities of the earthquake, tsunami and liquefaction.
Figure 9  Map of the results of the merging analysis of each disaster
Source : ATR/BPN, BMKG, DINAS TATA RUANG, PUSGEN, BADAN GEOLOGI, and BNPB

The results of the merging of the map will be divided based on the code described in the formula below.

Figure 10  Combined Map of the Earthquake, Tsunami and Liquidity Disaster of Palu City
Source : ATR/BPN, BMKG, DINAS TATA RUANG, PUSGEN, BADAN GEOLOGI, and BNPB

In the code "CX1X2X3" is a code that describes the disaster zone in the city of Palu. Code C is the number of high levels of disaster vulnerability in the city. Code C consists of letters A, B, C, and D which indicate the number of disasters with a high level of vulnerability. Code X1 is a number that describes the vulnerability to an earthquake disaster. Code X2 is a number that describes the vulnerability to the tsunami disaster. Code X3 is a number that explains the vulnerability to liquefaction disaster.

5. Plan Recommendations
Recommendations for areas that will be used as a place for evacuation of disasters should be free from the threat of disaster with a high level of vulnerability. The area with the safe category chosen is the existing green open space in Palu City. The selected area is also an area with a slope of land with a flat to sloping category.

According to [10] the carrying capacity needed per individual is 20 m² for disaster evacuation areas. For a public toilet, it can be used for 50 people. According to [11] the minimum basic need for clean water for one person reaches 121 liters per day. These needs include the need for drinking water, cooking, washing clothes, bathing, cleaning, and worship purposes.
The recommendations for landscape restructuring in Palu City are divided into 3 zones. Zone A is a zone that is prone to earthquake hazards, Zone B is a zone for mangrove forest planting areas, and Zone C is a zone that is vulnerable to liquefaction hazards. Zone A is a zone that will be used as a conservation forest around the Palukoro Fault danger zone and earthquake prone areas. In this zone plants will be planted that can withstand the movement of the soil due to earthquake vibrations. The plants used are plants with broad roots, strong stems, and not easily fallen. Recommended types of plants are used such as *Samanea saman*, *Delonix regia*, *Spathodea campanulata*, *Pterocarpus indicus*, and *Swietenia mahagoni*.

Zone B is a zone that will be used as a mangrove forest formation, Pes-caprae formation and Barringtonia formation. The mangrove forest can be used as a buffer against tsunami waves if one day the tsunami occurs again. Apart from being a buffer against tsunami waves, mangrove forests can reduce erosion and abrasion and become a buffer area between land and sea. Mangroves can also be spawning areas for marine biotics. The recommended mangrove formations are *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora stylosa*, *Avicennia lanata*, and *Avicennia marina*. Coastal plants form 2 zoning namely Pes-caprae and Barringtonia. Pes-caprae Formation is a formation that is in the highest tide area in the coastal region. This formation has plant species that are able to grow in high salinity soils, have the ability to adapt to dry sand, are resistant to wind, resistant to nutrient-poor soils and are resistant to high soil temperatures and have roots deep ones. Recommended plants for the Pes-caprae formation are Casuarina equisetifolia and Cocos nucifera. Whereas the Barringtonia Formation is the last zone formation directly adjacent to other types of forest ecosystems. Plants in this formation are shiny and thick leafy. Recommended plants for the Barringtonia formation are *Barringtonia asiatica*, *Calophyllum inophyllum*, *Terminalia*.
catappa, Cerbera manghas, and Erythrina variegate.

Zone C is a zone that will be used as a conservation forest in areas prone to high liquefaction. The plants used in the zoning are soil-extracting plants which have long and deep roots into the soil. The plant is expected to be able to absorb saturated ground water and reduce soil movement so it does not shift. The recommended plants are plants with broad and deep roots and have high evapotranspiration ability. Recommended plant types for Zone C are Samanea saman, Delonix regia, Paraserianthes falcataria, acacia crassicarpa, Shorea selanica, and Swietenia macrophylla.

6. Conclusions And Suggestions

6.1. Conclusions

Based on the analysis of the landscape impacts and hazards caused by disasters, Palu City is a city that is very vulnerable to earthquakes, tsunamis and liquefaction. The area that has a high level of vulnerability to these 3 disasters has a total area of 446 hectares. Whereas for areas that have a high level of vulnerability to 2 disasters and 1 disaster has a total area of 3364 hectares and 3873 hectares respectively. Areas that do not have high levels of vulnerability or can be said to be safe from 3 disasters have a total area of 30262 hectares. The safe area should be the focus of the Palu City development plan going forward.

Changes in post-disaster land use are expected to reduce the impact of disaster risk in the future. There are 3 zones based on potential disasters in Palu City. Zone A is a zone that is prone to earthquake hazards. The total area of Zone A to be used as conservation forest is 9100 hectares. Zone B is a zone for mangrove forest planting areas. In this zone plants will be planted that can withstand the movement of the soil due to earthquake vibrations. The plants used are plants with broad roots, strong stems, and not easily fallen. The total area of Zone B is 572 hectares. Zone C is a zone that is prone to liquefaction hazards. The plants used in the zoning are soil-extracting plants which have long and deep roots into the soil. The plant is expected to be able to absorb saturated ground water and reduce soil movement so it does not shift. The recommended plants are plants with broad and deep roots and have high evapotranspiration ability. The total area of Zone C is 1556 hectares.

Disaster-prone areas are recommended to be relocated to safe areas in accordance with the recommended relocation locations. The recommended relocation area is on a flat slope of 6093 hectares and on a gentle slope of 5557 hectares. The size of the area is sufficient to accommodate an area prone to disaster for relocation.

6.1. Suggestions

The results of this study are expected to be recommendations for development plans in Palu City that are resistant to earthquake, tsunami and liquefaction. This research is expected to improve mitigation plans in Palu City in order to reduce losses and loss of life. The evacuation area recommendations also need to be supported by all parties, including government, related agencies, and the community in Palu City. Decision making about regional development planning in Palu City must have an analysis of disaster considering that Palu City is a city that is very prone to disasters.

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