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Disaster Risk Mitigation of Landslide for Sustainability of Geothermal Production in Bandung Regency, West Java Province, Indonesia

H Kumalasari^{1,2}, R H Koestoer^{1,3}, H S Hasibuan^{1,3}

¹School of Environmental Sciences, University of Indonesia

Jl. Salemba Raya No. 4 Jakarta 10430

²Directorate of Geothermal, Directorate General of New, Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources

Jl. Pegangsaan Timur No. 1 Menteng, Jakarta 10320

³Coordinating Ministry for Economic Affairs Jl.Lapangan Banteng Timur No.2-4, Jakarta Pusat 10710

Email: hera.pabum@gmail.com

Abstract. Indonesia, an archipelagic nation which lies on the tectonic plate namely pacific ring of fire, it addresses for how Indonesia has 129 active volcanic mountains. Although it geologically prone for endangered areas for earthquake and volcanic eruption, but beneath the vicinity of mountain edifice, lies geothermal potential energy. Most of Indonesian geothermal located on the mountain hills and a slope, that condition makes geothermal area prone to landslide. One of which can be found in Bandung Regency, West Java Province, Indonesia. The increasing risk landslide phenomena in Indonesia are related to natural physical factor and socio-economic conditions. The aims of this research are to analyze the risk level of landslide disaster which is reviewed by the aspects of hazard threat, vulnerability and capacity, and to give mitigation alternatives. The method of this research has been conducted by assessment of weight and scoring technique as well as spatial analysis using Geographical Information System (GIS). The result of the study shows most of the area of the study is in medium risk level that is prone to landslide occurrence with the broad of 7,420.4 Ha or 57% of the study area. Mitigation effort in facing landslide in the study area is aimed to maintain the sustainability of utilization of renewable energy which is geothermal energy that will be reviewed from three aspects sustainability, namely environmental, economic, and social.

1. Introduction

Indonesia is located between three active plates of tectonic which are Eurasian, Pacific, and Indo-Australian plates. The collision between those three tectonic plates causes the formation of a ring of fire in Indonesia is forming 500 volcanic cones and more than 200 volcanic mountains, 129 of those 200 are active volcano [20]. Even though volcanic mountains and earthquakes that are located in geological lane usually cause massive destruction, this condition has a positive impact which is abundant geothermal potentials [12].

Geothermal energy is the natural heat energy from the earth that is transferred to the earth's surface by conduction and convection [21]. In general, geothermal or hydrothermal systems are based on geological, geophysical, hydrological and technological criteria consisting of three main elements:



reservoir rocks, geothermal fluids that contribute heat to the soil surface and hot rocks or magma as heat sources [6]. Geothermal is a renewable and sustainable energy. The potential of geothermal energy in Indonesia is scattered throughout the islands of Sumatera, Java, Bali, Nusa Tenggara, Maluku and Sulawesi [5]. In general, high-temperature geothermal fields are located in volcanic areas with high reliefs, steeply morphological terrain, thermal-altered rocks and high rainfall [11]. Those are forming a combination of potential trigger for landslides occurrence.

This study is using two key factors that have a correlation to landslide disaster risk level, those are a natural physical factor and socio-economic conditions through the level of hazard threat and level of vulnerability. Natural physical factor is defined by slope, rainfall, and also geological condition. While socio-economic conditions cover the population density, vulnerable groups to disaster ratio, as well as human activities that can affect the change in land use. Land use can trigger ground movements risk because it affects the existing land cover [9]. Land conversion from forest to agriculture and the effect of reduction of buffer zone may increase the potential for landslides [16]. Land that is not covered by vegetation or seasonal plant farmland causes the plant roots cannot hold the soil on the slope so the landslide may easily occur [18].

Landslide risks are assessed from the aspect of hazard threat, vulnerability, and capacity. The vulnerability is related to the ability of people to protect themselves from harmful effects without the help of others [7]. Landslide vulnerability is increasing along the infrastructure development as the impact of population growth [14]. Based on the statement of the problem mentioned above, the dangerous potentials of a landslide may occur at Geothermal Power Station is substantial. However, the risks can actually be mitigated. This study focuses on the analysis of landslide disaster risk at Pangalengan geothermal field as well as its mitigation to minimize the risks. Availability of distribution of disaster vulnerability maps, landslide hazard threat level maps, early warning system, control actions, and the development of effective planning and policy can minimize landslide hazard [10]. Landslide mitigation measures include spatial planning, forest functions restoration on the hillside of development controls in accordance with environmental carrying capacity [13].

The aims of this research are to analyze the risk level of landslide disaster which is reviewed by the aspects of hazard threat, vulnerability and capacity, and to give mitigation alternatives. This research is theoretically benefited by giving a contribution to the scientific development especially in environmental science and disaster mitigation. Furthermore, this research can be used as a reference for other researchers. The practical benefit of this research is to give inputs to the administrator, public and also the geothermal field operator in order to manage landslide problem in that area.

2. Methodology

The research method has been used is a combination of qualitative and quantitative. The quantitative method in this research had been conducted by assessment of weight and scoring technique as well as spatial analysis using Geographical Information System (GIS). While the qualitative method was acquired by data and information collected through questionnaire and interview. The assessment of landslide risk level in this research is based on Chief Regulation of Indonesian National Disaster Management Agency No. 2, 2012, on General Guidelines for Disaster Risk Assessment [2].

2.1. Hazard threat analysis

The hazard threat analysis was done by using susceptibility to landslide zone map of Bandung District published by Geological Agency in 2009 combined with data of incident events and distribution of landslide potential at Pangalengan Geothermal Field, West Java Province.

2.2. Vulnerability analysis

The analysis of vulnerability describes the communities or population condition in order to disaster readiness [2]. The vulnerability analysis consists of four components which are a social vulnerability, economic vulnerability, physical vulnerability, and environmental vulnerability [2].

$$VL = (SV \times 40\%) + (EV \times 25\%) + (PV \times 25\%) + (EV \times 10\%) \quad (1)$$

Note:

VL = Vulnerability level

SV = Social vulnerability

EV = Economic vulnerability

PV = Physical vulnerability

EV = Environmental vulnerability

Source: Chief Regulation of Indonesian National Disaster Management Agency No. 2, 2012, about General Guidelines for Disaster Risk Assessment

2.3. Capacity analysis

Capacity is an ability of an area and population's action for reducing hazard threat and potential damage due to structural, planned, and built-in disaster [3]. The capacity level can be addressed by strengthening the population's and administrator's ability in order to reduce the disaster level. The capacity level consists of five components which are regulations and institutional for treating disaster, early warning system, disaster education, reducing basic risk factors, and building alertness. The counting of the capacity level is based on Chief Regulation of Indonesia National Disaster Management Agency, Number 3, 2012, on Guidelines of Capacity Assessment in Facing Disaster which consists of 88 statements.

2.4. Disaster risk analysis

Disaster risk is loss potential affected by disaster happened in an area within a certain time that brings death, injury, hazarding life situation, safe loss, evacuation, property damaged or lost, and also an interruption of citizen's activity [1]. The analysis of landslide disaster risk through overlay is between the landslide hazard threat map, vulnerability map, and capacity map supported by the geographic information system.

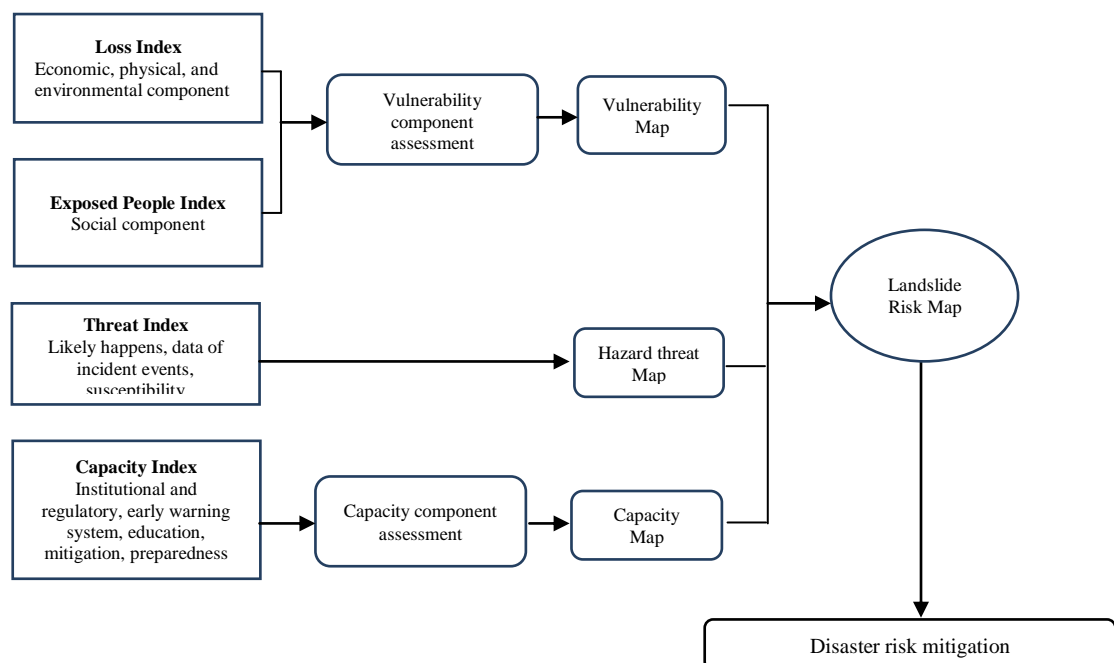


Figure 1. Method of landslide risk analysis and disaster mitigation methods

3. Result and discussions

3.1. Hazard threat level

The hazard threat analysis was done by using susceptibility to landslide zone map of Bandung District published by Geological Agency in 2009 combined with data of incident events and distribution of

landslide potential of the study area. The level of hazard threat in the study area consists of low, medium and high level.

Figure 2 shows the hazard threat level of landslide disaster in the study area is mostly categorized in low landslide hazard level with 6,158 ha or 48% of the study area. Low landslide hazard level is a condition of rare landslide occurrences if not triggered by other factor and old landslide has been stabilized during the past period [4]. The low landslide hazard level in this area consists of Sukamanah Village, Wanaka Village, Banjarsari Village, Kertasari Village, and Puncak Besar. The slope conditions in the area have a flat to steep slope or on a slope of land up to 15%. This location is very suitable as a center of activity, residential area, agricultural and plantation land.

The high hazard threat level located on 1,914.8 ha area or 15% of the study area. This zone, landslide located in a zone that is actively moving, landslides can occur when rainfall is high, strong erosion, and land-poor coverage vegetation [4]. The high hazard threat level in the study area lies on the slope of Mount Bedil, Mount Wayang, Mount Windu, Mount Hartman, Mount Malabar and Puntang Mountain. This area located on a very steep slope to almost erector on a slope of land above 30%. This zone had a landslide on May 5, 2015, a landslide occurs at Cibitung Village located at the slope of Bedil Mount. The landslide causing 9 people fatalities, 8 people injured, severe damage to buildings houses, pipelined geothermal steam production, and agricultural land. Based on the results of the investigation of a landslide on 5 May 2015, caused by rain for 3 consecutive days and a change of land use from forest to agricultural land on the Bedil mountain slopes.

The medium hazard threat level is found on of 4,880.1 ha area or 37% of the study area. This zone, landslide may occur in this area if the slope to be disturbed or old landslide may be activity, especially when induced by high rainfall and erosion [4]. The medium hazard threat level is spreading along the study area and generally located on a steep slope or on a slope of land above 15%.

3.2. *Vulnerability level*

The vulnerability level is obtained from the combination of the weight value of social vulnerability, economic vulnerability, physical vulnerability, and environmental vulnerability. In terms of vulnerability analysis, it is known that most of the study areas are at a high level of social vulnerability. This is due to the fact that most of the study areas have the high population density that is located in 11 villages causing more people to be exposed in case of disaster. This is in line with the opinion of [22]. Based on the analysis, it is found that the level of social vulnerability in the study area is categorized as high. Factors causing high social vulnerability include high population density, high rates of sex ratios and high age-group ratios, this is in line with the opinion of [8].

Economic vulnerability in the study area assessed from the value of productive land and the contribution of Gross Regional Domestic Product (GDP) in the sector. Agriculture is the main sector in the study area that supported by the fertile soil conditions and a number of springs. Development sector in the study area is also supported by the establishment of “agro-politan” area. The development of the agricultural sector should not aim economic objectives solely, but should also consider the sustainability of the environment. Agricultural land on steep slopes can increase the potential for a landslide, this is in line with the opinion of [18]. The high value of productive land and the contribution of GDP is closely related to the economic losses if the productive land is affected by the disaster so that the income level of the people and the regions will decrease.

Physical vulnerability in the study area consists of the number of houses, public facilities, and critical facilities. Based on the results of physical vulnerability analysis that the damage value of houses and public facilities is categorized high, this is related to a population density of most study areas are categorized as high. The condition is in line with the opinion of [14]. The level of physical vulnerability of most of the study areas is in the medium category, which means that the damage and loss of houses, public facilities, and critical facilities is high and costs are high enough for post-disaster recovery.

Environmental vulnerability is related to the type of vegetation covering the land or land use in the study area. Based on the analysis results it is known that most of the study areas are at low level of

environmental susceptibility. Potential landslides can occur because horticultural crops cannot hold or binding the soil during continuous rain. This is in line with the opinion that land cover is one of the trigger factors and increases the risk of land movement or landslide [9].

Figure 3 shows that most of the study areas are at a medium vulnerability level located in 9 Villages or 53% of the study area. A high vulnerability rate of 26% of the study area and low vulnerability area of 21% of the study area. Mekarjaya village is the village that has the highest vulnerable level in the study area. Cinanggela Village and Santosa Village have the lowest vulnerability level. It is influenced by the low value of physical vulnerability.

3.3. Capacity level

The capacity level is the combination between weight values from five capacity aspects which are: regulations and institutional of treating disaster, early warning system, disaster education, reducing basic risk factors, and building alertness in all lines. The capacity level shows the readiness and ability of an area and its citizen is facing disaster. The higher capacity value which an area has, the lessen disaster risk level will be.

Table 1. Capacity level

Capacity Factor	Weight Value					
	Pangalengan Subdistrict	Kertasari Subdistrict	Cimaung Subdistrict	Pacet Subdistrict	Banjaran Subdistrict	Ciparay Subdistrict
1. Regulation and institutional of treating disaster	0,52	0,52	0,52	0,52	0,52	0,52
a. Body of law and policy of reducing disaster risk	0,14	0,14	0,14	0,14	0,14	0,14
b. Sources for reducing disaster risk activities	0,13	0,13	0,13	0,13	0,13	0,13
c. Community's participation and decentralization	0,14	0,14	0,14	0,14	0,14	0,14
d. Forum / community link for reducing disaster risk	0,11	0,11	0,11	0,11	0,11	0,11
2. Early warning system and review of disaster risk	0,30	0,28	0,25	0,25	0,28	0,25
a. Review of disaster area	0,08	0,08	0,08	0,08	0,08	0,08
b. Monitoring system, archiving, and spreading disaster potential data	0,06	0,06	0,06	0,06	0,06	0,06
c. Early warning system	0,11	0,09	0,06	0,06	0,09	0,06
d. Area risk assessment	0,05	0,05	0,05	0,05	0,05	0,05

3. Disaster education	0,4	0,36	0,36	0,35	0,39	0,36
a. The availability about disaster information	0,08	0,08	0,08	0,08	0,08	0,08
b. Disaster education	0,09	0,09	0,09	0,09	0,09	0,09
c. The multi disaster risk research method	0,11	0,11	0,11	0,11	0,11	0,11
d. Strategy to build community awareness	0,12	0,08	0,08	0,07	0,11	0,08
4. Reducing basic factor risk	0,37	0,36	0,35	0,34	0,36	0,34
a. Reducing disaster risk	0,07	0,07	0,06	0,05	0,07	0,06
b. Planning and policy of reducing social vulnerability	0,05	0,05	0,05	0,05	0,05	0,04
c. Planning and policy of reducing economy vulnerability	0,05	0,04	0,04	0,04	0,04	0,04
d. Planning and settlement management	0,08	0,08	0,08	0,08	0,08	0,08
e. Steps of reducing vulnerability	0,08	0,08	0,08	0,08	0,08	0,08
f. Assessment procedure of disaster risk impact	0,07	0,07	0,07	0,07	0,07	0,07
5. Disaster education	0,47	0,47	0,47	0,47	0,47	0,47
a. Policy, institutional technique capacity	0,14	0,14	0,14	0,14	0,14	0,14
b. Contingency plan	0,10	0,10	0,10	0,10	0,10	0,10
c. Finance and logistic backup	0,12	0,12	0,12	0,12	0,12	0,12
d. Review of post-disaster	0,11	0,11	0,11	0,11	0,11	0,11
Total	2,06	1,99	1,95	1,93	2,02	1,94

The analysis result of capacity level shows that it has 1.93-2.06 values in all area of the study or it is categorized as medium and high capacity level. The medium capacity level area shows that several components are good enough and the rest need to be improved to increase the capacity value. The

capacity of government and population influence of the disaster risk level, if the capacity level is high then the disaster level will be lower. The capacity factors that have high value are regulation and institutional of treating disaster and building alertness in all lines. On the other hand, the capacity factors that need improvement to reduce disaster risk level are early warning system and review of disaster risk, disaster education and reducing basic factor risk.

3.4. Disaster risk level

Disaster risk is the potential loss caused by a disaster in an area within a certain period of time such as death, injury, illness, loss of security, displacement, damage or loss of property, and disruption of community activities [1]. The risk of landslide disaster is influenced by the physical condition of the region such as slope, geology, rainfall, soil type, land use, and social condition of the community and regional capacity. The risk level of the landslide disaster of the study area is divided into three levels, i.e. high risk, medium risk, and low risk that the location is spreading in the study area.

Most of the area of the study is in medium risk that is prone to landslide occurrence with the broad of 7,420.4 Ha or 57% of the study area. Meanwhile, the spread of medium landslide risk level is in the land use of plantation, residential land, and mountain peak with the designation land as a protected forest.

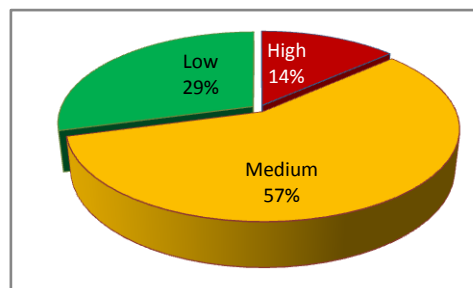


Figure 2. Disaster risk level

High-risk level has a land area of 1,749.9 ha or 14% of the total area. The locations of the high-risk level can be found in the slopes of Bedil Mountain, Wayang Mountain, Windu Mountain, Malabar Mountain, Puncak Besar, and Haruman Mountain. Those areas have high-risk level because they are located in very steep slopes and rugged, as well as the opening of the land of forests into agricultural land creating increasing vulnerability so the risk becomes higher.

The low-risk level is located in residential land and agricultural land. The low-risk level is in 3,783.2 Ha or around 29% of the study area. The land with low-risk level is good land for developing the residential area and its facilities, agricultural land, production forest, and other land purposes in 0-15% tilt. The area development in low-risk level with above 15% slopes' tilt is not allowed but could be developed as a buffer zone or protected area.

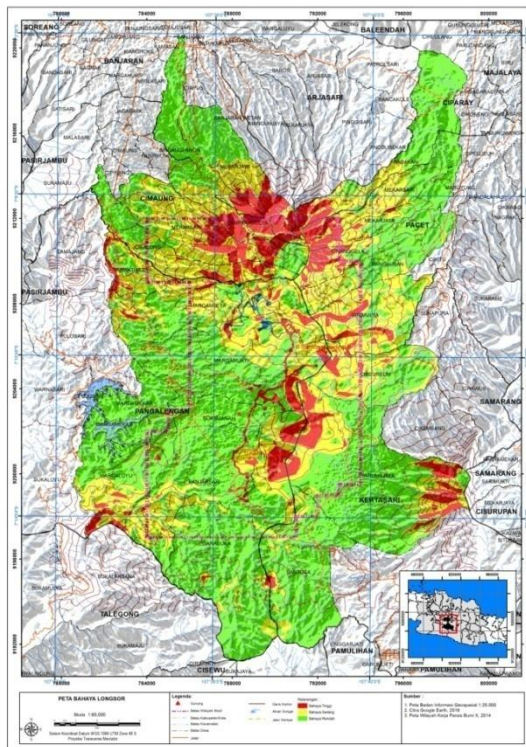


Figure 3. Map of landslide hazard threat level

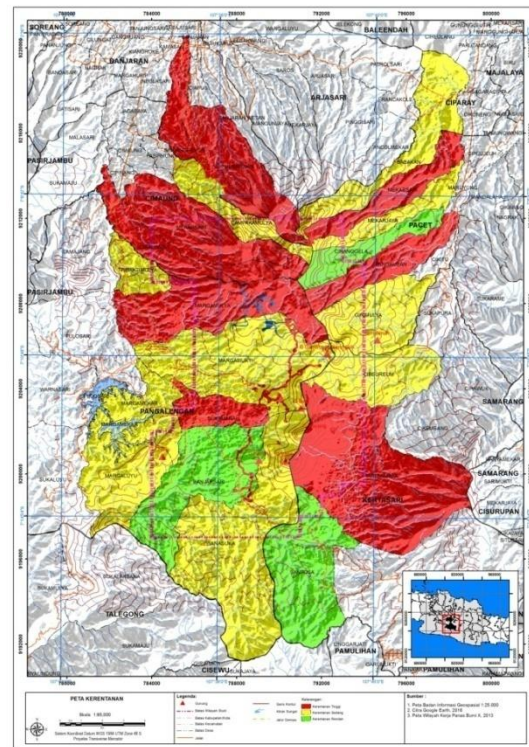


Figure 4. Map of vulnerability level

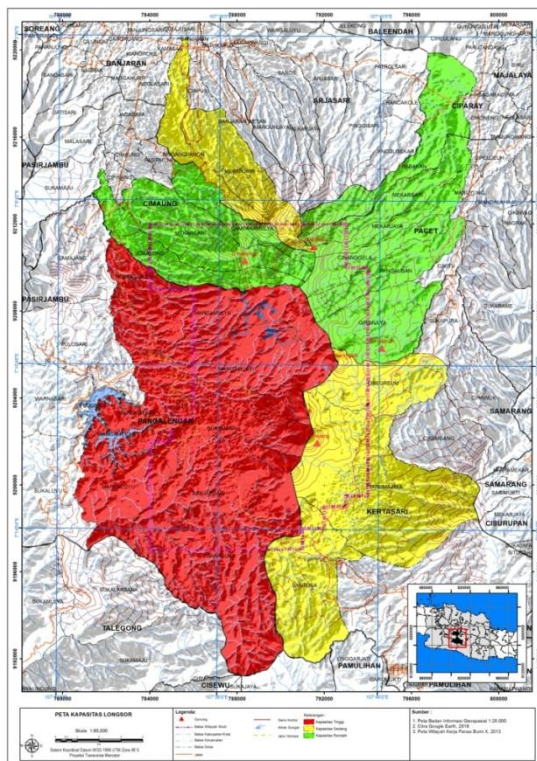


Figure 5. Map of capacity level

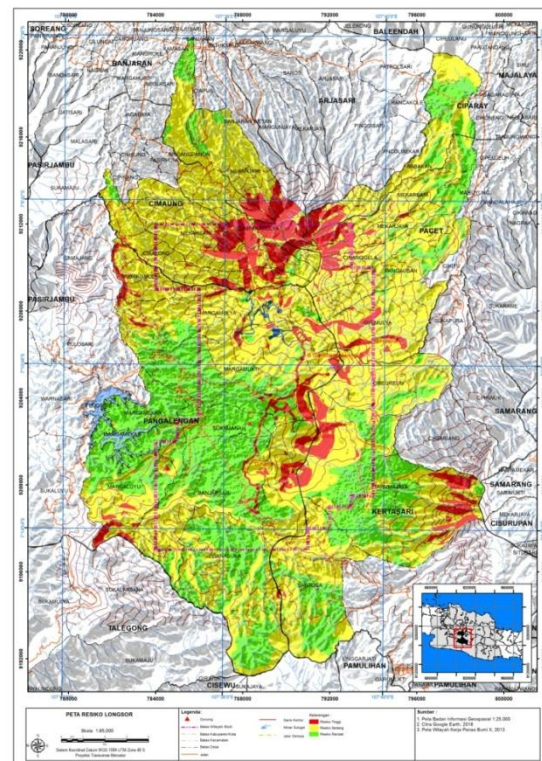


Figure 6. Map of disaster risk level

3.5. Disaster mitigation

Mitigation effort in facing landslide in the study area is aimed to maintain the sustainability of utilization of renewable energy which is geothermal energy that will be reviewed from three aspects, namely environmental sustainability, economic sustainability, and social sustainability.

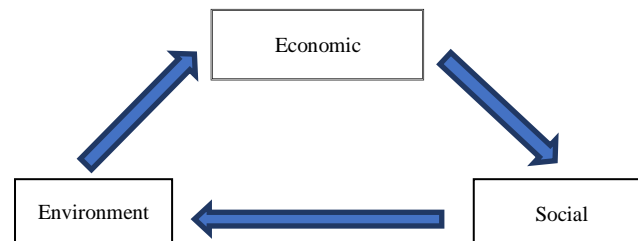


Figure 7. Landslide mitigation effort based on disaster risk level

The environmental sustainability is related to geothermal production sustainability. The utilization of geothermal has closed system or hydrothermal system that creating a sustainable cycle. One of the important aspects to maintaining geothermal sustainability is by protecting the recharge area. It means that we have to protect the environmental sustainability especially forest located around the study area. The mitigation effort that can be done is by doing reforestation, but it must be adjusted to the conditions of the land. Mountain' slopes that have been a landslide or there are crack need to be done of geotechnical engineering. Mountain slopes that changes in land use also need to be restored to function as a forest by planting plants that can strengthen cliffs, ex: Cemara Gunung Tree. Cemara Gunung Tree is a type of plant is able to reduce the occurrence of landslides, canopy light and has been shown not to interfere with agricultural productivity and produces easily, so the potential for development [15].

Another landslide mitigation effort in the study area is the development of agroforestry system. Agroforestry is a sustainable agricultural system with vegetation diversity concept and increases land productivity [23]. The management of agroforestry systems needs to involve community participation in strengthening community capacity aimed at adaptation, mitigation of landslides and increasing productivity of sustainable land [15]. The advantages of agroforestry development are maintaining soil fertility and moisture, improving soil and nutrient structure, and increasing land productivity [19]. Agroforestry development can also provide economic benefits to the community but must be attention environmental carrying capacity condition.

Social sustainability which is related to the workers' and local people's safety is the main goal of landslide mitigation. One of the people's activities that is vulnerable to a landslide is an agricultural activity located around PLTP especially in the areas that are prone to landslide. Those areas are including the river slopes and mountain with more than 15% tilt slopes. The mitigation effort to increase the workers' and local people safety could be done through zoning system in the arrangement spatial planning of the study area.

4. Conclusions

Most of the study area is in medium risk level with 9.738.2 Ha or 75% area of the study. Medium risk level shows that the disaster that can be dangerous for worker's and people's lives as well as great material and financial loss. The distribution of medium risk level can be found in plantation land and mountain's peak aimed as protection forest. Meanwhile, the high-risk level can be found in the slopes of Malabar Mountain, Bedil Mountain, Wayang Mountain, Windu Mountain, and Haruman Mountain. Those areas have high-risk level because they are located on very steep slopes. The misusing land, a conversion from forest to agricultural land also increases the vulnerability and the value risk.

Geothermal energy is a source for the future energy with abundant availability resources. Naturally, a geothermal field in area study located around medium to high landslide hazard threat level. Geothermal activity doesn't cause landslide disaster, but it could encounter for potential landslide if

land conversion and horticultural activities are conducted intensively on the critical area around geothermal facilities. Alternative mitigation effort of landslide disaster through long-term planning is the arrangement of spatial planning with zonation system. Implementation of a good spatial arrangement aimed to reduce the risk level of landslide disaster so that environmental sustainability, geothermal production sustainability, and social sustainability can be maintained.

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