Landslide Hazard Mapping in Cilegon With Geographic Information System (GIS)

Enden Mina[1*], Rama Indera Kusuma[2], Woelandari Fathonah[3], Muhammad Iqbal Beckham Rafabi[4]

[1,2,3,4]Departement of Civil Engineering, Faculty of Engineering, Sultan Ageng Tirtatasa University, Indonesia

Article Info

Article History:

Accepted March 10, 2024
Approved April 10, 2024
Published April 29, 2024

Keywords:

Landslide, Threat, Geographic Information System, Cilegon

ABSTRACT

Natural disasters are disasters caused by events caused by nature. One of the natural disasters that continues to lurk in society is landslides. Landslides are the process of ground movement in an inclined or vertical direction from its original position as a result of gravity. Disaster Risk Assessment is an integrated mechanism to provide a comprehensive picture of a region's disaster risk by analyzing the Danger of Natural Disaster, Threat Level, Loss Level and Regional Capacity of dealing with threats of natural disaster. Geographic Information System (GIS) is a computer-based system used to store and display geographic information. GIS systems are designed for collecting, storing and analyzing geographic data at a location. Cilegon is a municipality in Banten Province, Indonesia. Cilegon is at the northwestern tip of the island of Java, on the edge of the Sunda Strait, with an area of 16.259 hectares, with a population of 450,271 people. This hazard map study includes map modeling stages carried out with ArcGIS software. This research uses Digital Elevation Model (DEM) images and Land Movement Susceptibility Zone Map. Based on the results of mapping the potential landslide hazards of Cilegon, of the 8 districts in Cilegon Municipality, only 5 districts have the potential for landslide hazards. It can also be concluded that Cilegon has a high potential landslide danger with area of 4273 hectares. The districts that have a landslide danger are Pulomerak, Grogol and Ciwandan districts with high landslide hazard level.

Available online at http://dx.doi.org/10.36055/fondasi

Corresponding Author:

Enden Mina,
Departement of Civil Engineering, Faculty of Engineering,
Sultan Ageng Tirtatasa University
Jl. Jendral Soedirman Km 3, Banten, 42435, Indonesia.
Email: enden@untirta.ac.id

1. INTRODUCTION

Disasters are events that threaten and disrupt people's lives and livelihoods caused by both natural and/or non-natural factors and human factors, resulting in human casualties, environmental damage, property loss and psychological impacts. Meanwhile, natural disasters are disasters caused by events or a series of events caused by nature, including earthquake, tsunami, volcanic eruption, flood, hurricane and landslide [1].

One of the natural disasters that continues to lurk in society is landslide. Landslide is the process of ground movement in an inclined or vertical direction from its original position as a result of gravity [2]. Landslides can occur in areas with high rainfall intensity, steep slope conditions, varied rock and geological structures and land use that is less suited to the characteristics of the land. Landslide

incidents are a problem for the community, especially in slope or hilly areas. Landslides are still difficult to detect and it is difficult to know the potential for landslides in an area, which makes landslide events difficult to avoid or prevent. In this case, a disaster risk assessment regarding landslides was carried out to prevent further damage and loss of life, and it is hoped that it can form appropriate evacuation routes for areas prone to landslides [3].

Disaster Risk Assessment is an integrated mechanism to provide a comprehensive picture of a region's disaster risk by analyzing the level of danger, level of threat, level of loss and regional capacity [4]. By conducting a landslide disaster risk study, local governments can identify areas with the greatest potential for landslides and can therefore take action to reduce the risk of landslides [3-4].

Disaster risk assessment involves a mapping process carried out using geographic information systems. Geographic Information Systems (GIS) are computer-based systems used to store and display geographic information. GIS systems are designed for collecting, storing and analyzing geographic data at a location [5]. In this research, the Geographic Information System was used to map landslide hazards in Cilegon. Cilegon is a municipality in Banten Province, Indonesia. This city has an area of 16.259 Ha [6].

2. METHODS

This research was carried out using the overlay mapping and scoring method with ArcGis software. This map modeling process was carried out using the method of preparing landslide disaster risk map based on the Technical Module for Preparing Landslide Disaster Risk Assessments published by the Directorate of Disaster Risk Reduction of the National Disaster Management Agency in 2019 (based on Regulation of the Head of the National Disaster Management Agency (BNPB) No. 2 of 2012). This module explains the stages of preparing a risk map for landslide disasters, and in this research the study carried out is a study of the danger of landslides. The area studied in this research is the City of Cilegon which consists of 8 districts and 43 administrative villages. Historical data collection was carried out at the Cilegon Regional Disaster Management Agency Office (BPBD), as well as data collection for landslide hazard map modeling purposes was carried out from the official DEM Nasional (DEMNAS) website, the Geological Disaster Mitigation Portal (Portal MBG) and the Geospatial Information Agency (BIG). In this research, there were 7 stages carried out from data preparation to landslide hazard map modeling.

2.1 Landslide Hazard Map Modeling Stages

In this research, several stages were carried out to create a landslide risk map model for The City of Cilegon. There are 6 maps that will be modeled during the research, and as follows [7]:

1. Preparation;
2. Slope Map;
3. Landslide Potential Zone Map;
4. Potential Landslide Source Map;
5. Potential Avalanche Runout Zone Map;
6. Landslide Hazard Map;
7. Classification Table of Landslide Hazard Areas.

2.1.1 Preparation

In this research, the data used to start the landslide hazard map modeling stage is in the form of a map. These three data are:

1. Digital Elevation Model (DEM)
2. Land Movement Zone Map

3. Administrative Map of the Cilegon Region

These three maps are used during the map modeling stage. The Digital Elevation Model Map is used in modeling slope map and potential runout zones, while the Land Movement Zone Map is used in mapping potential landslide zones and sources of potential landslides. The Cilegon Regional Administration Map will be used to tabulate the area of landslide hazard affected areas.

2.1.2 Slope Map

A slope map is a map that shows slope areas with slopes according to the slope percentage range on the map. Slope mapping is carried out using DEM (Digital Elevation Model). In GIS software, slope map modeling is carried out to obtain a slope map by using the DEM as the base map of this step. After obtaining a map of the slope appearance, proceed with the slope classification with the following classification [8]:

1. 0% – 15%. (Flat)
2. 15% – 25%. (Slightly Steep)
3. 25% – 45%. (Steep)
4. Above 45%. (Very Steep)

The slope classification is the slope range in percent where the percentage of slope is expressed in slope height or slope elevation divided by slope length [9].

In the slope map modeling process, the Slope tool from GIS software is involved, then the modeling results are reclassified to obtain a slope classification based on the slope percentage. This process also involves smoothing the modeling results map with a nibble function.

2.1.3 Landslide Potential Zone Map

A landslide potential map is a map that shows areas that have the potential for landslides. In this research, the potential landslide area is based on the zone prone to ground movement which is located on a slope with a slope above 15% [4]. Modeling of Landslide Potential Map using slope map and ground movement vulnerability zones map is carried out by simplifying the Slope parameter above 15% in the ground movement vulnerable zones.

2.1.4 Potential Landslide Source Map

Analysis of potential landslide material base zones or Runout is carried out to determine the potential area of landslide material bases. Runout is a type of shallow landslide or flow of avalanche material (Shallow/Debris Landslide). Runout can also be interpreted as the lowest part of a landslide path where the landslide material slows down and stops moving. Modeling of the runout zone map is first carried out by determining potential landslide sources, which are relative sources of landslide material that has the potential to move and move from its position. The first step of making avalanche runout map is to create the potential landslide source map.

The potential landslide source map is modeled with conditions where the ground movement vulnerability class in an area is medium to high on slopes with a slope above 45% [3-4].

The output result of this modeling operation is a map of potential landslide sources. After obtaining a map of potential landslide sources, then a potential runout zone map is modeled.

2.1.5 Potential Avalanche Runout Map

The algorithm used for modeling potential avalanche runout zone map is the flow direction algorithm available in the TauDEM Tools toolbox.

Terrain Analysis Using Digital Elevation Models (TauDEM) is a toolbox for ArcGIS that is used for hydrological analysis of digital elevation model map. In this research, the modeling method used is the flow path modeling method which models the direction of flow of landslide material based on the shape of the slope flow from the DEM.

There are three tools used from the TauDEM toolbox, namely:

1. Pit Remove;
2. D-Infinity Flow Direction;
3. D-Infinity Avalanche Runout.

2.1.6. Landslide Hazard Map

Landslide hazard map modeling was carried out after modeling the runout potential zone map. The landslide hazard map modeling involves landslide potential zone map and runout potential zone map. The output map from this stage is a landslide hazard class map for Cilegon. After obtaining a landslide hazard class map, area tabulation is then carried out to obtain the hazard area per district.

2.1.7 Classification Table of Landslide Hazard Areas

The classification of landslide hazard areas begins by tabulating the area of landslide hazard areas on the regional administration map with the area per sub-district. The tabulation results are then exported into Excel format so that the level of landslide danger in a sub-district can be collected and assessed, which is continued to the sub-district level and finally to the city level. After carrying out the broad hazard classification, a landslide hazard classification table for Cilegon was obtained, with hazard classification per district.

3. DISCUSSION

This hazard map study includes map modeling stages carried out with ArcGIS software. This research uses Digital Elevation Model (DEM) images and Land Movement Susceptibility Zone Map, with a cell size of 30x30 meters using the WGS 1984 UTM zone 48S Coordinate System. These two maps are used during landslide hazard map modeling, where the DEM map is used to form slope map and the Land Movement Susceptibility Zone map is used to model landslide potential zones. The landslide hazard map modeling stage consists of creating 5 maps and 1 table consisting of [10]:

1. Slope Map;
2. Landslide Potential Zone Map;
3. Map of Potential Landslide Sources;
4. Potential Runout Zone Map;
5. Landslide Hazard Map;
6. Landslide Hazard Classification Table for the administrative area of Cilegon Municipality.

The focus of this research is the landslide hazard map of Cilegon. This hazard map was created to determine the potential danger of landslides and the severity of landslide danger in affected areas in Cilegon Municipality.

3.1 Slope Map

Slope map modeling is carried out to obtain a slope map with the slope area representing the percentage of slope in a city area expressed in percent. Slope percentage mapping was carried out using Digital Elevation Model map, and carried out with the slope tool, reclassify and nibble function. The slope map in this modeling stage shows areas with slope percentages that fall into the following 4 slope ranges [8]:

a. Flat (0 – 15%)
b. Slightly Steep (15-25%)
c. Steep (25-45%)
d. Very Steep (above 45%).

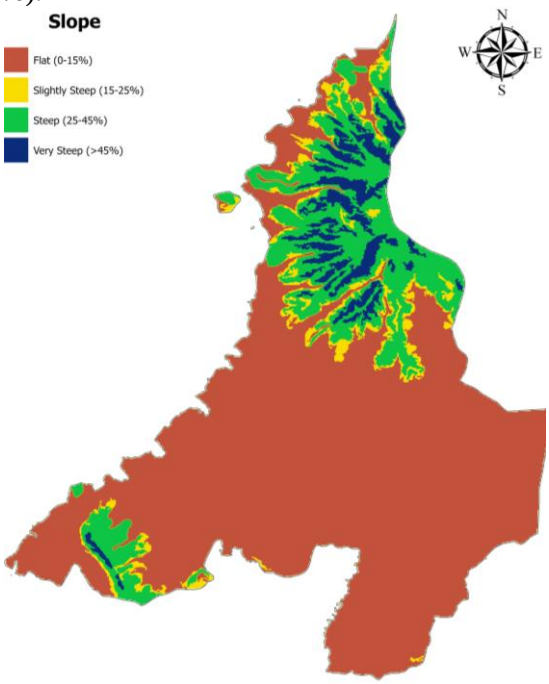

Figure 1. Slope Map

From the map on **Figure 1.,** it appears that the Pulomerak and Grogol Districts are dominated with steep slope due to its neighboring mountain (Merak Mountain). Meanwhile in the Ciwandan District, there are areas with steep slope around the village of Gunung Sugih and Kepuh.

3.2 Potential Landslide Zone Map

The potential landslide zone map is a map that shows areas that have the potential for landslides with areas susceptible to ground movement located on slopes above 15%, or at slope angles above 8.51º [9].

The ground movement vulnerability zone map at this stage represents the level of vulnerability of an area to ground movement that causes landslides. This map has three levels of ground movement vulnerability, namely:

a. Low
b. Moderate
c. High

The modeling process uses a Raster Calculator and is carried out with a conditional function by stating that slope areas above 15% have ground movement values based on the ground movement vulnerability zone map.

From **Figure 2.** can be seen that the Pulomerak and Grogol Districts due to its mountainous environment have the most of potential for landslide in Cilegon, while Ciwandan District has the area with highest landslide potential due to its high soil vulnerability around Gunung Sugih region.

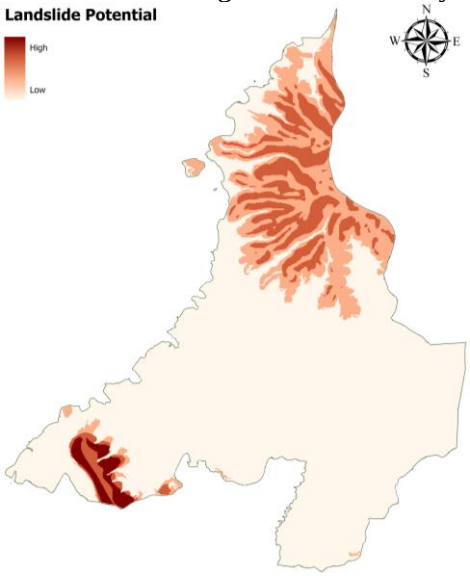

Figure 2. Landslide Potential Zone Map

3.3 Potential Landslide Source Map

After obtaining a potential landslide map model, then modeling the potential landslide source map is carried out. A potential landslide source map is a map that shows the starting point of a potential landslide in an area.

Modeling of potential landslide source map is carried out using Raster calculations on slope map and land movement susceptibility map with zone parameters with moderate to high ground movement susceptibility in slope areas above 45%.

Figure 3. shows many source of potential landslide around the region of Merak Mountain north of Cilegon and there are few at Gunung Sugih Region.

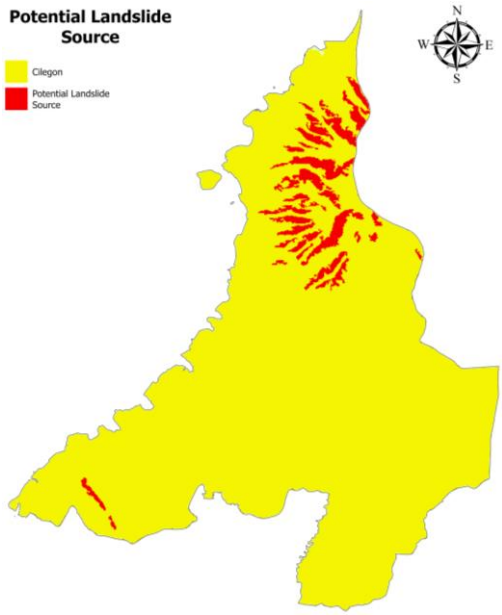

Figure 3. Potential Landslide Source Map

3.4 Potential Avalanche Runout Map

The Potential Avalanche Runout Map is a map that shows areas that have the potential to be affected by landslides [11]. This map modeling involves a Digital Elevation Model map and a potential landslide source map using the TauDEM (Terrain Analysis Using Digital Elevation Models) Toolbox. There are three tools used from the TauDEM toolbox, namely :

1. Pit Remove
2. D-Infinity Flow Direction
3. D-Infinity Avalanche Runout

First, Pit Remove is used to identify low elevations on the DEM map and raising their elevation to the level of the lowest pour point around their edge, making them even with the surrounding area [12]. Second, Flow Direction is carried out to Assigns a flow direction based on the Delta-infinity flow method [13]. And third, Avalanche Runout is a landslide flow analysis operation using the Delta-infinity flow method defined as the steepest slope on the 8 triangular facet formed in a 3x3 grid cell window centered on the grid cell of interest [14].
The result is the map shown in **Figure 4.** Where it shows that avalanche runout scatters around Pulomerak Region where most of the runout ended on the Merak coast.

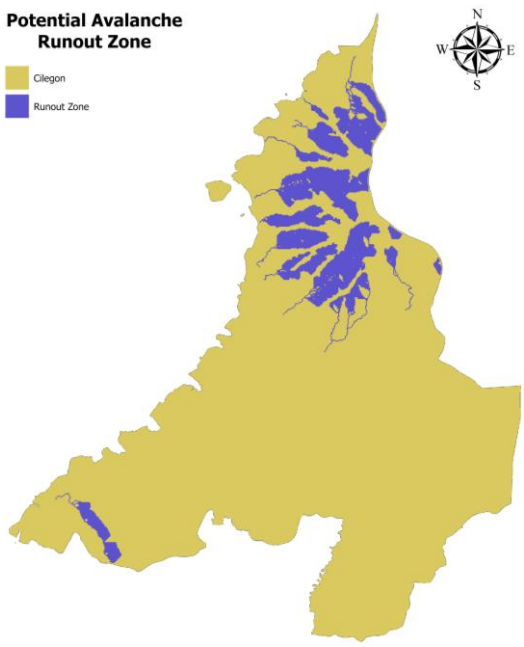

Figure 4. Potential Avalanche Runout Map

3.5 Landslide Hazard Map

Landslide hazard study is the assessment stage of landslide hazard map modeling which is used to obtain conclusions from the results of the hazard index (H) map modeling in the form of hazard classes. Hazard classes are classified based on the grouping of hazard index values as follows:

1. Low ($H \leq 0.333$).
2. Moderate ($0.333 < H \leq 0.666$).
3. High ($H > 0.666$).

The landslide hazard map modeling was carried out by combining two maps, namely the runout potential zone map and the landslide potential zone map. The mapping conditions for the landslide hazard map consist of 60% runout potential zone map and 40% landslide potential zone map.

From this modeling stage, a landslide hazard index map is obtained. The index map is then classified according to the hazard index value (H) with the following conditions:

1. Index values below 33% fall into the low landslide danger class;
2. Index values above 66% fall into the high landslide danger class;
3. Between the two conditions above, it falls into the moderate landslide danger class.

The map on **Figure 5.** Shows areas that are prone to landslides and the level of danger faced by the area. Most of Pulomerak and Grogol Districts are mostly prone to high landslide hazard, where as Ciwandan is prone to medium landslide hazard.
The next stage is to classify the landslide hazards faced by the districts in Cilegon.

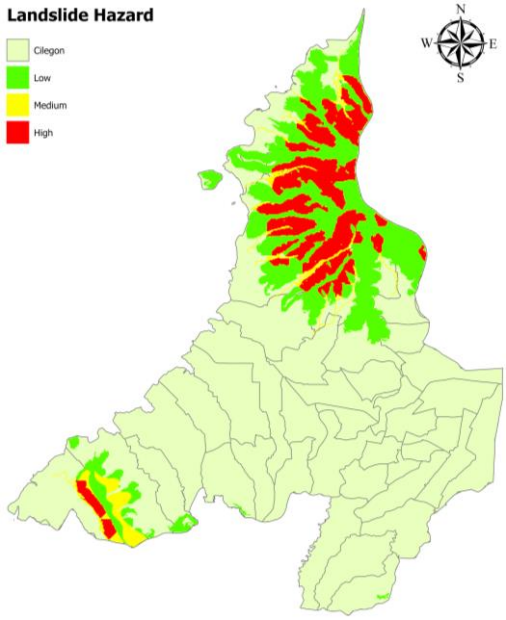

Figure 5. Landslide Hazard Map

3.6 Landslide Hazard Classification

Classification of landslide hazards is carried out by tabulating the area of landslide hazard areas with the administrative map of the Cilegon. The tabulation results are then exported into Excel where the names of administrative villages are sorted by district.
Classification of landslide hazards starts from the administrative village level where the largest hazard area will be taken to determine the hazard class faced by each village. After that, at the district level, it is taken from the worst-hit village, and at the city level it is taken from the worst-hit district.

Table 1. Landslide Area and Hazard Level for Districts

No.	Districts	Hazard	
		Area (Ha)	Level
1	Cibeber	5	Low
2	Purwakarta	631	Low
3	Ciwandan	535	High
4	Grogol	1189	High
5	Pulomerak	1913	High

Overall Hazard Area	**4273**	**High**

3.7 Area Comparison With Reference Data

To compare the size of the Cilegon City landslide hazard area, the 2016 Cilegon City Landslide Disaster Risk Map from the Cilegon City Disaster Risk Study 2016 – 2020 was used [15]..

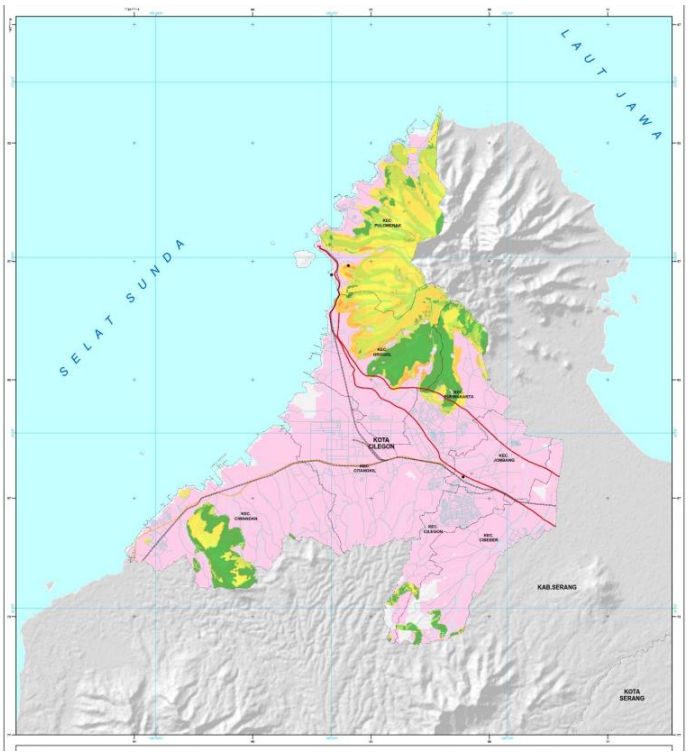

Figure 6. Landslide Risk Map 2016 – 2020

From this map, there are 2 districts that have the highest risk of landslides, namely Pulomerak and Grogol. With indications of the risk of landslides in the southern part of Ciwandan District, Purwakarta District, around the South Ring Road which is included in the Cibeber District and Cilegon District Areas. The following is a list of districts at risk of landslides along with the area at risk and landslide risk class:

Table 2. Landslide Area and Hazard Level for Districts (2016 – 2020)

No.	Districts	Hazard	
		Area (Ha)	Level
1	Ciwandan	651	HIgh
2	Pulomerak	1870	High
3	Purwakarta	587	Medium
4	Grogol	1269	Medium
5	Cibeber	104	Medium

6	Cilegon	55	Medium
	Overall Hazard Area	**4536**	**High**

When compared with the results of mapping using the overlay method in this study, the total area at risk of landslides as a whole is 263 hectares. The two maps also show that Pulomerak and Grogol sub-districts have the highest landslide danger in Cilegon. The difference from the reference data is that in the level of landslide danger, the lowest danger in the reference data shows a medium level of danger, whereas in the mapping results using the Overlay method there is a low level of danger and there are no sub-districts with a medium level of danger. some differences such as:

1. Cibeber and Purwakarta districts in the mapping results are at a low danger level, while in the reference data they are at a medium danger level.
2. Ciwandan District is at a high landslide danger level in the reference data, whereas in the mapping data the district is at a high landslide danger level.
3. Cilegon District has no landslide danger in the mapping results, whereas in reference data, the District is in moderate landslide danger.
4. Grogol District in the mapping results is included in the high danger level, while in the reference data it is included in the medium danger level.

Table 3. Landslide Area and Hazard Level Comparison

No.	Districts	Hazard Area		Difference Percentage
		2016 – 2020	Mapping Result	
1	Pulomerak	1870	1913	2%
2	Grogol	1269	1189	6%
3	Purwakarta	587	631	7%
4	Ciwandan	651	535	18%
5	Cibeber	104	5	95%
6	Cilegon	55	-	-
Overall Hazard Area		**4536**	**4273**	**6%**

From the table above, there is a difference in the area of the landslide area with the area of the landslide area from 2016 – 20202 data shows the area is higher than the area from the mapping results, namely a difference of 263 hectares, or 6% of the total area of danger in 2016.

In historical landslide hazard studies, landslide hazard assessment is based on parameters of slope slope above 15%, slope length, slope direction, rock type, distance from active faults, soil type, soil solum depth, rainfall and slope stability.

4. CONCLUSION

Based on the results of mapping the potential landslide hazards of Cilegon using the Digital Elevation Model Map and the Land Movement Vulnerability Zone Map of Cilegon, of the 8 districts in Cilegon Municipality, only 5 districts have the potential for landslide hazards. It can also be concluded that Cilegon has a high potential landslide danger with area of 4273 hectares. The districts that have a

landslide danger are Pulomerak, Grogol and Ciwandan districts with high landslide hazard level. As well as Purwakarta and Cibeber districts with low landslide hazard level.

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