Vulnerability Assessment of Landslide Areas in Ci Manuk Upstream Watershed, Garut District, West Java Province

Muhammad Edgar Fauzan[#1], Astrid Damayanti[#2], Ratna Saraswati[#3]

[#]*Department of Geography, Universitas Indonesia, Beji, Depok, 16424, Indonesia*
E-mail:[1]edgarfauzan@gmail.com; [2]astrid.damayanti@sci.ui.ac.id; [3]ratna.saraswati77@gmail.com

Abstract— **Landslide is challenging to detect and predict. Settlements are not always located on ideal land according to designated areas, such as settlements in a landslide area. Ci Manuk Upstream watershed, Garut District, West Java Province, has critical land due to human intervention. The environment is more sensitive to the components in the environmental system, so when it rains, landslide disasters are prone to happen. This study aims to predict and analyze the vulnerability settlement of landslide in Ci Manuk Upstream watershed, Garut District, West Java Province. The research method is done gradually, beginning with using Stability Index Mapping (SINMAP) method to generate a landslide potential area, then using a spatial analysis method to determine the landslide-prone area and finally assessing the vulnerability of the settlements in the landslide area. The results show that 43.88% of the total area is a potential landslide area, then 19.04% is a high landslide-prone area, and 30.80% is the vulnerability of the settlement areas in the high landslide area. This study also shows that the landslide potential area is dominant at slope >25%, dystrudept soil type, and rainfall rate of >3500 mm/year. The landslide-prone settlement areas tend to be in the landslide zone of SINMAP modeling, and vulnerable settlements have tended to be south of the watershed because of the low quality of buildings and high population densities.**

Keywords— **landslide; settlement; SINMAP; vulnerability.**

I. INTRODUCTION

Landslide is challenging to detect and predict. Settlements are not always on the ideal land following predetermined land use, for example, in a landslide area. In Indonesia, there are 573 incidents for landslide disaster of 2,163 total disaster incidents occurring from 1 January to 31 December 2017 [1]. The occurrence of the landslide caused 109 deaths, 150 injured, 46,326 people displaced, and 1,651 damaged houses consisting of 585 heavily damaged, 403 moderately damaged, and 663 slightly damaged [1]. This is because of the topography in Indonesia mostly has steep slopes and very fertile soils, hence why the community often utilize the land for agricultural activities without thinking about the risk of disasters that occur due to the land clearing on the slopes [2].

The slope is not the only factor causing landslide disaster, but physical factors and social factors can also influence the occurrence of landslide disaster [3]. Physical considerations include slope, rainfall rate, and geological conditions in the area. Social factors in the form of human activities can also affect the landslide disaster, such as land use in the form of settlements [4].

There are 22 districts or cities in West Java that vulnerable to landslide, and one of them is Garut Regency [5]. The area of Garut is located at the Ci Manuk Upstream and in the southern province of West Java. Active volcanoes surround it. The general condition of the land topography is bumpy, hilly, mountainous, thick weathered soil, and supported by a high rainfall rate that is accumulative [6]. The topography makes the region very prone to landslide disaster.

Most areas that have a high category in landslide disasters are in the Ci Manuk Upstream area [7]. Administratively in 2016, landslide potential occurs in Ci Manuk Upstream, covering 21 sub-districts and spread over 121 villages/locations with a total area of 53.61 km2. Ci Manuk Upstream has a critical land since 1984 by getting more damage by human interventions [8]. As a response from this watershed damage, the environment becomes increasingly sensitive to existing components in the environmental system, so when the rain happens, it is easy for a landslide to occur [9].

Identification and prediction of potential landscape and vulnerability of landslides can be done quickly by using Geographic Information System [10]. GIS will facilitate the analysis and presentation of spatial information, especially related to the determination of potential areas and

vulnerability level of landslide disaster [11]. This research is expected to be useful for the community to recognize areas vulnerable to landslides and to provide information to the local governments to facilitate mitigation in the regions that are vulnerable to landslides.

Research on potential landslides with SINMAP method has been widely used. Deb and El-Kadi, with his research Susceptibility assessment of shallow landslides on Oahu, Hawaii, under extreme-rainfall events. This study was conducted on an area of 38,400 hectares divided into four regions based on soil type and hydrological characteristics. Deb uses data in the form of the Digital Elevation Model (DEM), soil type, and soil characteristics used as parameters in SINMAP, hydrological data in the form of rainfall, and landslide events from 1949 to 2006 [12].

Andriono studied the vulnerable area of the landslide in Ci Tarik Sukabumi District. This research uses a descriptive approach to the SINMAP method. Researchers use altitude data in the form of a Digital Elevation Model (DEM) compiled with physical variables of soil type, cohesion, friction angle, and soil Moisture index (T/R) and climate data in the form of rainfall. Furthermore, the potential area of landslides in an overlay with residential spatial data and avalanche event data (fact) [13].

Then, Wibowo, with the title identification of landslide vulnerable in Cicalengka sub-district, Bandung Regency. This research uses the SINMAP modeling method. The data used is Rupa Bumi Indonesia (RBI) map, land type map, land use map and cohesion data of Internal friction angle (Φ), T/R which obtained from research result of Department of Soil Science Erosion Control and Land Conservation, Institute of Soil Science and Plant Cultivation in Pulawy, Poland [14].

The objective of the study is to analyze the distribution of potential areas to landslides in Ci Manuk Upstream Watershed, analyzing the distribution of settlement areas are prone to landslides in Ci Manuk Upstream Watershed and analyzing the distribution of vulnerable settlements in high landslide area in Ci Manuk Upstream Watershed, Garut District, West Java Province.

II. MATERIAL AND METHOD

SINMAP modeling (Stability Index Mapping) is used to determine the landslide vulnerable settlement areas [15]. Variables used include slope, soil type, and rainfall rate. Determination of landslide disaster potential areas is performed by using the SINMAP method by entering cohesion, angle friction, and ratio of transmissivity to effective recharge (T/R) value and validated by landslide occurrence point (fact). Furthermore, landslide-prone areas are determined by overlaying land-use variables in the form of settlements with landslide potential areas. The landslide vulnerable settlement areas are determined by using overlay methods of physical and social vulnerability variables, which are building quality and population density. Systematically, SINMAP method has the equation to set the Stability Index (SI) slope is as follows [16]:

$$SI = FS = \frac{C + cos\theta \left[1 - min\left(\frac{R\,\alpha}{T sin\,\theta}, 1\right)r\right]tan\,\phi}{sin\,\theta} \qquad (1)$$

Description:
SI = Stability Index
FS = Safety Factor
C = Cohesion (kN/m^2)
θ = Slope (%)
R = Recharge rate (m/d)
T = Transmisivity (m^2/d)
a = Specific catchment area (m^2/m)
r = Ratio of water and soil density
Ø = Friction angle (^{o})

TABLE I
VARIABLES AND SOURCES

No.	Variable	Source
1	*Rupa Bumi Indonesia* (RBI) Map scale 1:25.000	*Badan Informasi Geospasial* (BIG)
2	Precipitation Ci Manuk in 2010-2016 scale 1:50.000	*Balai Pengelola Daerah Aliran Sungai Ci Manuk - Ci Tanduy and Dinas Pekerjaan Umum dan Penataan Ruang*
3	Soil type scale 1:50.000	*Balai Besar Litbang Sumberdaya Lahan Pertanian* (BBSDLP)
4	Slope scale 1:25.000	Digital Elevation Model (DEM)
5	Land use scale 1:25.000	*Peta Rupa Bumi Indonesia* (RBI) from *Badan Informasi Geospasial* (BIG)
6	Landslide events (fact) in 2016-2017	*Badan Penanggulangan Bencana Daerah* (BPBD) and survey
7	Building quality	Survey
8	Population density in 2017	*Badan Pusat Statistik* (BPS)

The data needed for this research are spatial and tabular, as well as other supporting data obtained from related institutions, such as *Badan Nasional Penanggulangan Bencana* (BNPB), *Badan Pusat Statistik* (BIG) and *Badan Informasi Geospatial* (BIG). Besides, direct observations in the field are also conducted to test the validation of the landslide point and data quality building. In determining the area of landslide potential in Ci Manuk Upstream, data processing is needed with variables of the slope, soil type, and rainfall rate using SINMAP method to obtain landslide disaster potential area and validation with the landslide occurrence point (fact) [17]. Then, to determine the landslide-prone residential areas, it is necessary to use land-use variables in the form of settlements overlaid with potential landslide areas, then the overlay results will result in landslide-prone regions [18]. Then, the variables of physical and social vulnerability are building quality and population density, which then analyzed overlay again with the landslide-prone area, so that will get the result of vulnerable landslide areas in the Ci Manuk Upstream area [19]. These are the data and sources used in Table 1.

Model accuracy in predicting potential avalanches will need to be tested for success levels. One of the recent validations is knowing the number of landslides that occur in the model slope stability class. Modeling based on the study indicates that mudslides occur markedly in a type of unstable slopes [20]. Modeling results are good when most of the data for incidents of low avalanches are in a class of potential small slides to a potential high landslide [21]. Systematically, the number of landslides in the region is not stable, divided by the total number of landslides times 100%.

III. RESULTS AND DISCUSSION

A. Landslide Potential Areas in Ci Manuk Upstream Watershed Based on SINMAP

The output of SINMAP modeling resulted in Stability Index in the form of raster data [22]. Which are then classified into six classes; stable, moderately stable, quasi-stable, lower threshold, upper threshold, and defended landslide potential [10]. These classes are based on the Stability Index (SI) SINMAP in Table 2 [23]. In this study, stable, moderately stable and quasi-stable classified into one stable class. Ci Manuk Upstream Watershed is dominated by a stable area of 817.54 km^2 or about 56.12%, and the rest around 639.23 km^2 or 43.88%, which indicates the area that may occur landslide (Low, Moderate, and High landslide potential). SINMAP modeling in this study area has an accuracy of 81.57%.

TABLE III
AREA OF LANDSLIDE POTENTIAL OF CI MANUK UPSTREAM WATERSHED

No.	Class	Area	
		km^2	%
1	Stable (SI >1.5)	671.13	46.07
2	Moderately Stable (1.5 > SI > 1.25)	59.93	4.11
3	Quasi-Stable (1.25 > SI > 1.0)	86.48	5.94
4	Lower Threshold (1.0 > SI > 0.5)	327.40	22.47
5	Upper Threshold (0.5 > SI > 0.0)	74.87	5.14
6	Defended (0.0 > SI)	236.96	16.27
Total		1456.77	100.00

B. Validation of Landslide Potential Area

The location of landslides in Ci Manuk Upstream Watershed is sourced from Badan Penanggulangan Bencana Daerah (BPBD) 2016 to 2017 with the number of landslide incidents as many as 38 points and spread in 33 villages. Landslides occur in villages of Sukahurip, Barusuda, Sukarame (Cilawu Subdistrict), Cintanagara, Penyembong, Mulyasari, Karyamukti, Cipangramatan, Mekarsari, Mangkurakyat, Ngamplang, Karyamekar, Sukamulya, Padamukti, Sukatani, Karamatwangi, Sukanegla, Sukamatri, Kotawetan, Hegarsari, Sukarame (Leles Subdistrict), Jangkurang, Haruman, Leles, Karanganyar, Pakenjeng, Padaawas, Caringin, Cinta, Cintamanik, Jayawaras, Sukajadi, and Cimanganten (Fig 1).
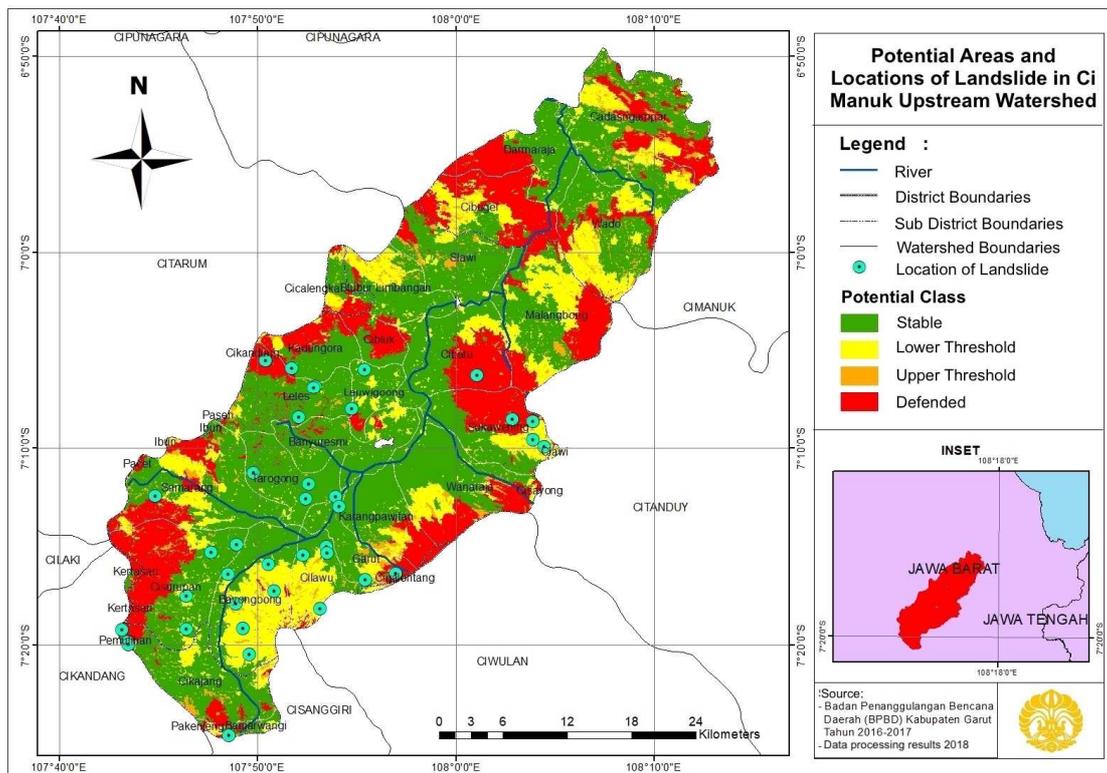
Fig. 1 Potential Areas and Locations of Landslide in Ci Manuk Upstream Watershed Based on SINMAP

The location point of the landslide event is used to check the accuracy of the SINMAP modeling results by the overlay method. The overlay result of landslide occurrence location with landslide potential area (stability index) shows that there are 7 points of landslide occurrence that are in relatively stable area or not having any landslide potential, while 31 points of landslide occurrence are in landslide-prone area with Low, Moderate, and High class (Fig 2) and the levels are in Table 3.
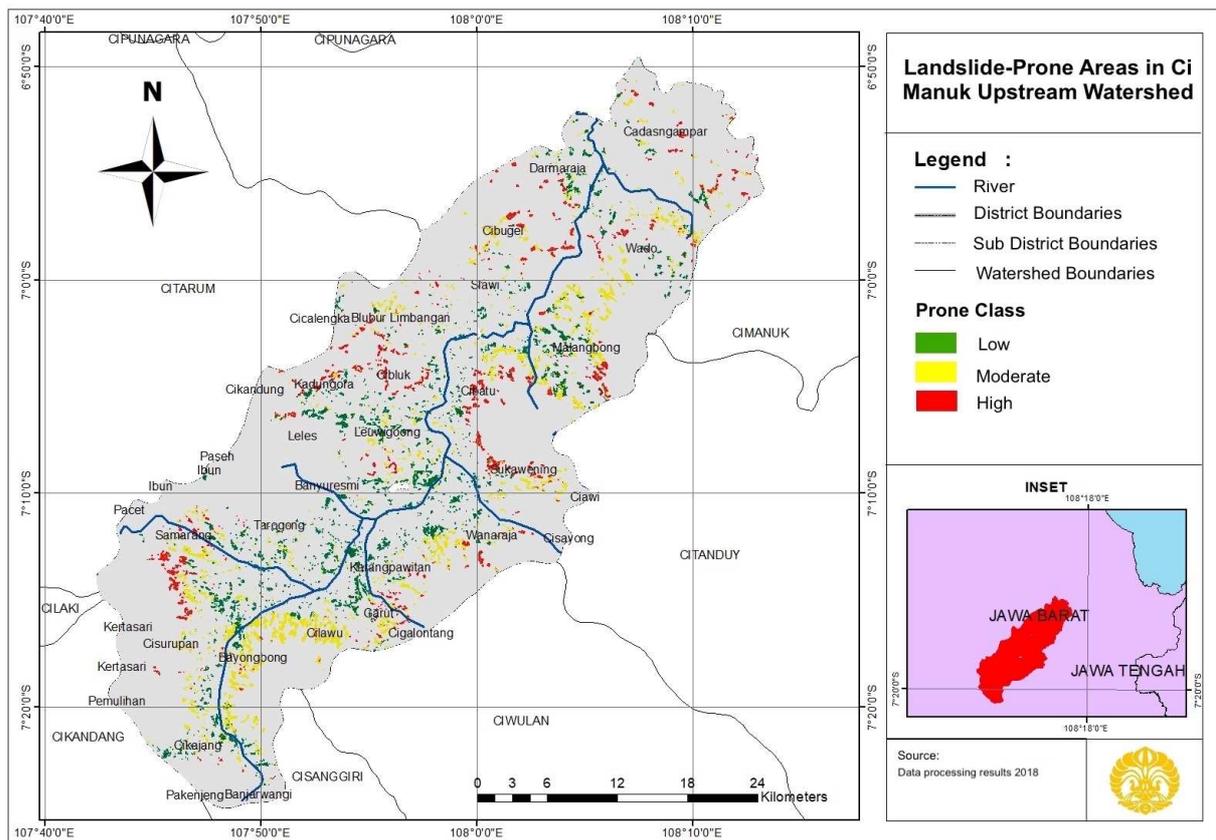
Fig. 2 Landslide-Prone Areas in Ci Manuk Upstream Watershed

C. Landslide-Prone Areas in Ci Manuk Upstream Watershed.

The landslide-prone areas in Ci Manuk Upstream Watershed have a total area of 66.70 km². The landslide-prone regions are generated from an overlay between the landslide potential area and the residential area. Most of the area is in an area with a slope of >25%. Landslide-prone areas are divided into three classes, namely Low landslide-prone, Moderate landslide-prone, and High landslide-prone. The distribution of the landslide-prone regions in Ci Manuk Upstream Watershed can be seen in Fig 2. In the southern or Upstream watershed, the landslide-prone areas are dominated by Low and Moderate classes (29.70 km² or 44.53%), while in the downstream basin, it is dominated by High-class areas (12.70 km² or 19.04%). In the downstream basin, the areas are dominated by Low and High landslide-prone. The extent and percentage of each vulnerable class can be seen in Table 3.

TABLE IIII
AREA AND PERCENTAGES OF LANDSLIDE-PRONE AREAS CI MANUK
UPSTREAM WATERSHED

No.	Class	Area (km²)	Percentage (%)
1	Low (SI > 1.0)	24.29	36.42
2	Moderate (1.0 > SI > 0.0)	29.70	44.53
3	High (0.0 > SI)	12.70	19.04
Total		66.70	100.00

The extent of landslide-prone areas is smaller than the landslide potential area. Most of the landslide potential areas are in non-residential land use areas, causing most landslide potential areas not to become landslide-prone areas. Fig 3 shows a description of the highly damaged area of landslides in Cibatu District, Karyamukti Village, Kampung Karoya taken using Google Earth *software*. Cibatu District has a steep slope, so in this area, it is very prone to landslides.

Fig. 3 Landslide-Prone Areas in Ci Manuk Upstream Watershed from Google Earth

D. Building Quality in Ci Manuk Upstream Watershed

Building quality is one of the variables to determine the vulnerability of the landslide area in this study. The research area is dominated by permanent building quality with an area of 34.83 km² or 52.22% (Fig 4).
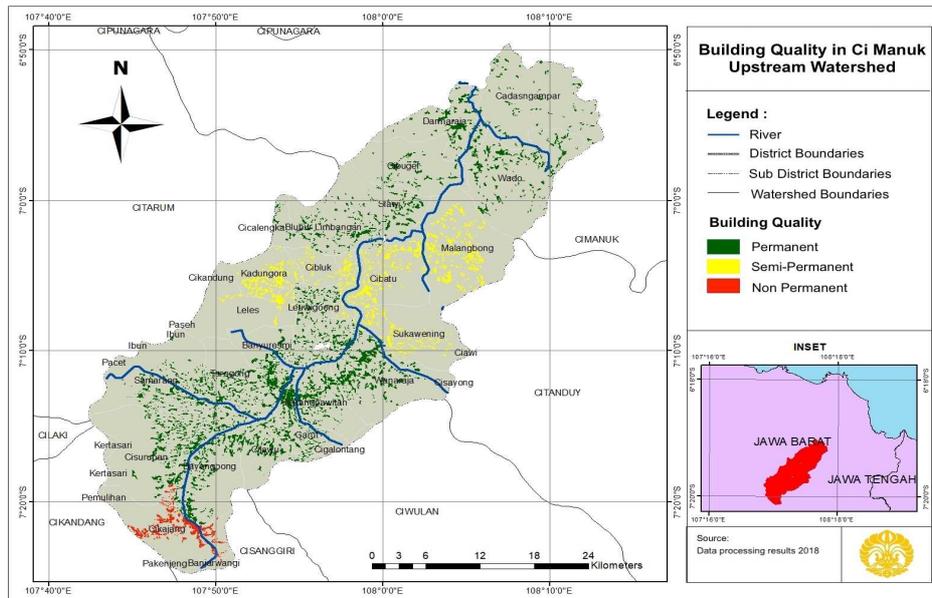
Fig. 4 Building Quality in Ci Manuk Upstream Watershed

In the middle of the watershed is a semi-permanent building (half-bamboo and half-cement). In the south or Upstream of the watershed, there are areas with non-permanent building quality (all still using bamboo). Table 4 shows the extent and percentage of building quality for each class based on building materials [24].

TABLE IV
AREA AND PERCENTAGE OF BUILDING QUALITY CLASS OF CI MANUK UPSTREAM WATERSHED

No.	Building Quality Class of Landslide	Area (km^2)	Percentage (%)
1	Permanent (Cement)	34.83	52.22
2	Semi-Permanent (Half-bamboo half-cement)	25.43	38.13
3	Non-Permanent (Bamboo)	6.43	9.65
Total		66.70	100.00

E. Population Density in Ci Manuk Upstream Watershed

Classification of population density data is needed to determine the vulnerability of landslides, (Fig 5). Based on Fig 5, the population density in Ci Manuk Upstream Watershed tends to be high in the Upstream areas marked by dark color symbols.
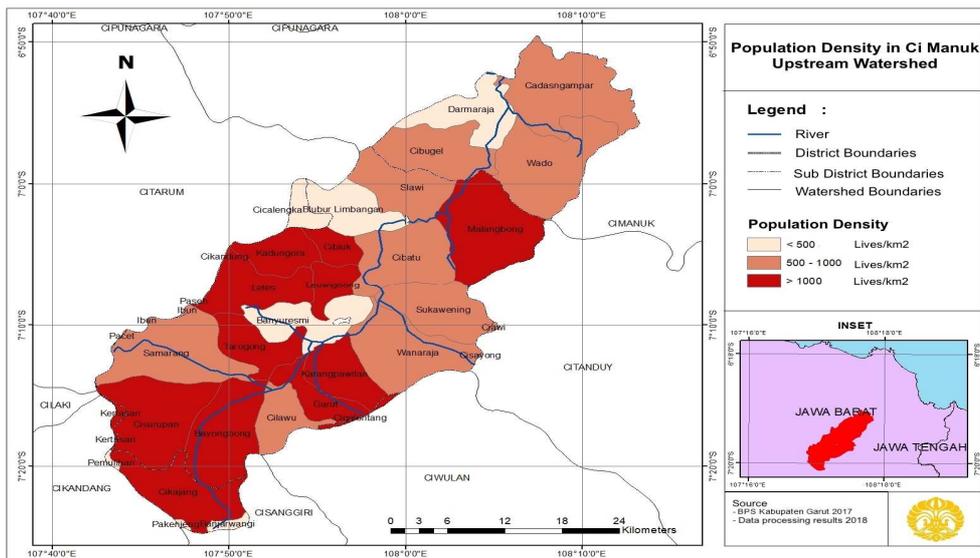
Fig. 5 Population Density in Ci Manuk Upstream Watershed

Then, in the middle to the north or downstream, the watershed is dominated by a symbol with a bright gradation color, which indicates a low and medium density population. The determination of vulnerability class based on population density can be seen in Table 5.

TABLE IV
LANDSLIDE VULNERABILITY CLASS BASED ON POPULATION DENSITY
IN CI MANUK UPSTREAM WATERSHED

District	Population Density (Lives/km^2)	Vulnerability Class
Pakenjeng	459.32	Low
Pamulihan	497.70	Low
Cikajang	1112.97	High
Banjarwangi	340.88	Low
Cilawu	578.77	Moderate
Bayongbong	1116.60	High
Cisurupan	1032.20	High
Samarang	810.30	Moderate
Tarogong	2443.36	High
Garut	3838.86	High
Karangpawitan	2516.33	High
Wanaraja	500.58	Moderate
Sukawening	766.45	Moderate
Leles	1280.19	High
Leuwigoong	1731.43	High
Kadungora	2362.26	High
Cibiuk	1512.35	High
Cibatu	886.48	Moderate
Malangbong	1150.25	High
Blubur Limbangan	166.77	Low
Slawi	794.17	Moderate
Darmaraja	475.53	Low
Cibugel	537.26	Moderate
Wado	913.45	Moderate
Cadasngampar	512.10	Moderate
Banyuresmi	156.78	Low

F. The vulnerability of Landslide Settlement Areas in Ci Manuk Upstream Watershed

The landslide vulnerability area in this study has resulted from the overlay of population density data and the building quality with landslide-prone areas. Therefore, the landslide vulnerability area has the same area and shape as the landslide-prone areas. Areas with high quality of building and low population density tend vulnerability to small landslides, and regions with low building quality and high population density tend vulnerability to high landslides [25]. Vulnerability to landslide levels was analyzed using descriptive spatial analysis. The landslide vulnerability area in Ci Manuk Upstream Watershed has a total area of 66.70 km^2.

Fig. 6 shows the spread of low, moderate, and high landslide vulnerability reasonably evenly in the middle to the south or Upstream watershed. However, in the north (downstream) basin, it is more dominated by moderate landslide vulnerability areas and less dominated by low landslide vulnerability. Vulnerability areas are dominant in the central and southern parts (27.93 km^2 or 41.88%) because villages located in the Upstream watershed have relatively high population densities. In the north or downstream areas are dominated by areas that are vulnerable to low and moderate landslides. The villages there has a relatively low population density, thereby reducing vulnerability to landslides. Low-grade vulnerability areas have the smallest region, which is 18.22 km^2 or 27.32%.
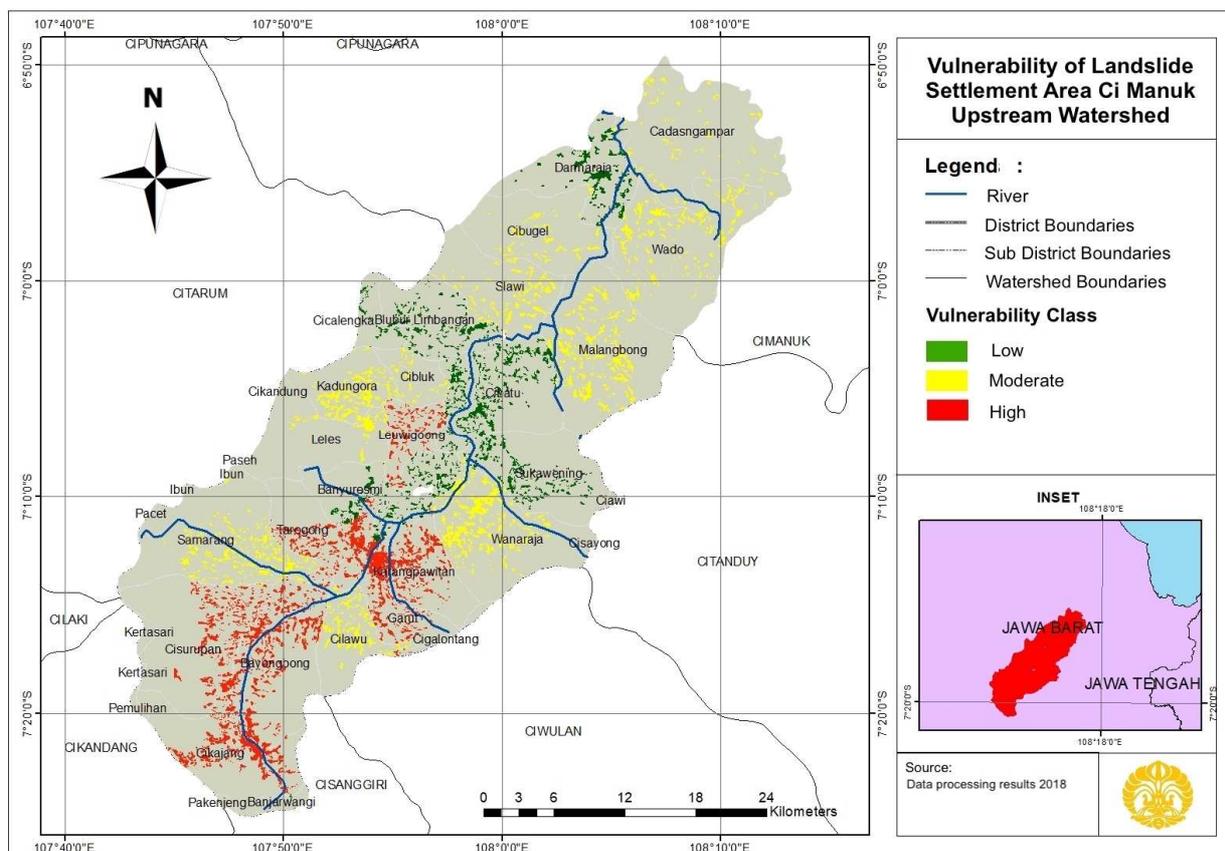
Fig. 6 Vulnerability of Landslide Settlement Area Ci Manuk Upstream Watershed

The area of landslide vulnerabilities is presented in Table 6.

TABLE VI
AREA AND PERCENTAGE OF VULNERABILITY LANDSLIDE SETTLEMENT
AREAS IN CI MANUK UPSTREAM WATERSHED

No.	Landslide Vulnerability Class	Area (km²)	Percentage (%)
1	Low	18.22	27.32
2	Moderate	27.93	41.88
3	High	20.54	30.80
Total		66.70	100.00

Distribution of landslide vulnerable settlement areas of Ci Manuk Upstream per village that is (1) Low: Pamekarsari, Sukaraja, Sukahaji, Sukasenang, Pananjung, Bagendit, Sukaratu, Kertajaya, Cibatu, Wanakerta, Sukawening, Sindangsuka; (2) Moderate: Cisaat, Cikembulan, Mekarbati, Hegarsari, Telagasari, Cangkuang, Mangkurakyat, Sukahati, Mekarmukti, Sukamukti, Margalaksana, Cintarasa, Cihuni, Wanaraja, Cinunuk, Sukahurip, Karangsari; (3) High: Girijaya, Cikajang, Padasuka, Cigedug, Sirnajaya, Cipaganti, Mekarjaya, Sukajaya, Bayongbong, Cibodas, Salakuray, Kotawetan, Suci, Jati, Sukajadi, Cimurah, Situgede, Karanganyar. Description of area with high landslide vulnerability level is captured by using Google Earth *software* in Cisurupan, Cipaganti Village which can be seen in Fig 7.

Fig. 7 High Landslide Vulnerability Area in Cisurupan, Cipaganti Village from Google Earth

IV. CONCLUSIONS

Based on the modeling of SINMAP (Stability Index Mapping), indicating that 43.88% of the total area of the Ci Manuk Upstream watershed area is a potential landslide area. The results of landslide potential validation in Ci Manuk Upstream of 38 mudslide incidents that have occurred before, 31 occurrences are in the territory of potential landslides by the modeling of SINMAP. SINMAP modeling in Ci Manuk Upstream has an accuracy of 81.57%.

The settlements area prone to high landslides in Ci Manuk Upstream watershed amounted to 19.04% or an area of 12.70 km². The north or downstream of the basin, dominated by the area of vulnerable landslides with the class of high avalanche-prone, while in the south or upstream the watershed is dominated by landslide-prone areas with low

prone type. The factors that make the region have a high level of prone because settlements are in the area of potential landslides.

30.80% or 20.54 km² is the vulnerability of the settlement areas in the high landslide area. Susceptible levels of landslides tend to increase from downstream to the upstream watershed. These levels are because the population in the downstream of the basin tends to be lower in density, so the low vulnerable level and the quality of buildings in downstream areas have the high quality of buildings.

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