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Landslide Susceptibility Mapping (LSM) in Kelud Volcano Using Spatial Multi-Criteria Evaluation

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Abstract. Mount Kelud eruption on February 2014 has a tremendous impact on the surrounding physical environment which ejected more than 200x106m3 of material. Thus, triggered secondary hazard such as landslides in the surrounding area. The purpose of this study is to map landslides susceptibility using Spatial Multi-Criteria Evaluation (SMCE) approach in Kelud mountainous area in particular within KRB 1 and 2. The identification of landslide occurrence was conducted based on remote sensing data and field observation along with four considerations criteria; topography, hydrology, soil, and environmental characteristics. Each factor then reduced into several sub-criteria such as slope, aspect, topographic position index, topographic wetness index, stream power index, rainfall, soil texture, soil structure, COLE index and land use. The SMCE method was also engaged with expert judgment provided by academic university' view and the BPBD agencies. The result showed that the river channel and surrounding areas categorized as landslide high prone area. Furthermore, eruption material found as the sources of landslides occurrences.

Keywords: Kelud Volcano, Landslides, Spatial Multi-Criteria Evaluation, Disaster

1. Introduction

Mount Kelud eruption on February 2014 with VEI 4 has a tremendous impact on the surrounding physical environment and affects the condition of agriculture, livestock, and fisheries. This physical environmental impacts are triggered by eruption material which ejected by Mount Kelud. The material such as ballistic bombs, volcanic ash, and pumice material reached more than 200x106m3 of material [1]. Thus, triggered secondary hazard such as landslides in the surrounding area.

Landslides are described as mass movement of soil or rock that shear displacement along one or may be several slip surfaces [2-3]. Over the last two decades, researcher have investigated landslide hazard and construct maps portraying their spatial distribution [4]. Mapping landslide susceptibility is essential for proper land use planning and disaster management [5]. Different techniques and methods have been developed and applied in landslide susceptibility mapping using both the quantitative or qualitative approach [6] such as probabilistic models [7–12], the logistic regression model [13–17], and multi-criteria analysis [18–21,5]. In this study, the landslide susceptibility assessment employed spatial multi criteria model as a method. Four considerations criteria such as topography, hydrology, soil, and environmental characteristics were used. Each factor then reduced into several sub-criteria such as slope, aspect, topographic position index, topographic wetness index, stream power index, rainfall, soil texture, soil structure, COLE index, land use, and distance from river. The SMCE method was also engaged with expert judgment provided by academic university’ view and the BPBD agencies.

2. Study Area

Mount Kelud is located at $7^0$56’00” South Latitude and $112^0$18’30” East Longitude with elevation level of 1731 . Administratively Mount Kelud distributed within three districts in East Java, namely Blitar, Kediri, and Malang. It is categorized as high intensity of volcanic activity in Indonesia. The eruption characteristic of Kelud is explosive along with phreatic eruption [22]. It is characterized by spilling water that contained of mixed mud and material. In addition, freatomagmatic eruption of Mount Kelud produces ash-lapilli precipitate in the form of fall, then can be followed by flow of fall of pyroclastic material. The eruption period of Mount Kelud is relatively short with the eruption cycle in 20 years. In Fig. 1 shows the location of Mount Kelud.

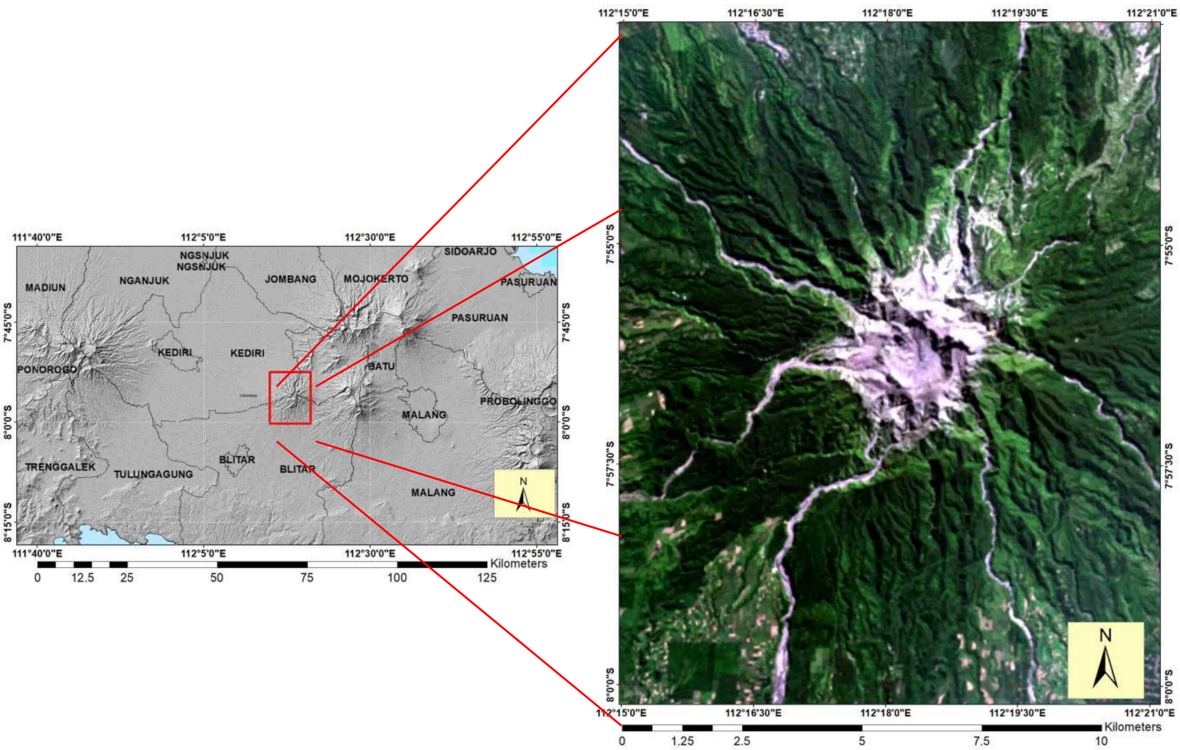

Figure 1. Location of The Study Area Showing Mount Kelud, East Java Province, Indonesia

3. Methodology

3.1. Input Data

This study used nine different GIS layers data to produce Landslide Susceptibility Map. All raster images (30m x 30m) were projected using Datum Universal Transverse Mercator (UTM), with WGS 84 zones. Then, each data layer is classified into several classes using Natural Breaks (Jenks) method.

Natural breaks class based on natural grouping attached to the data. It identifies the points of reference by choosing the class that breaks to the best group of value, same value and maximize the differences between classes [5]. Details of layers data used in this study are described as follows.

3.1.1 Altitude

A digital elevation model (DEM) is a digital model representing an earth's surface. It is one of the important input in modelling dynamic natural phenomena such as landslides, mass-movement, and soil erosion. DEM describes information about morphological relief of earth's surface on a digital format raster that height value on each pixel. To produce this parameter which controlled by several geologic and geomorphological processes [7,21,23,24], ASTER Global-DEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer) data was used. Figure 2 showed the spatial information related to the altitude/ elevation within research area.

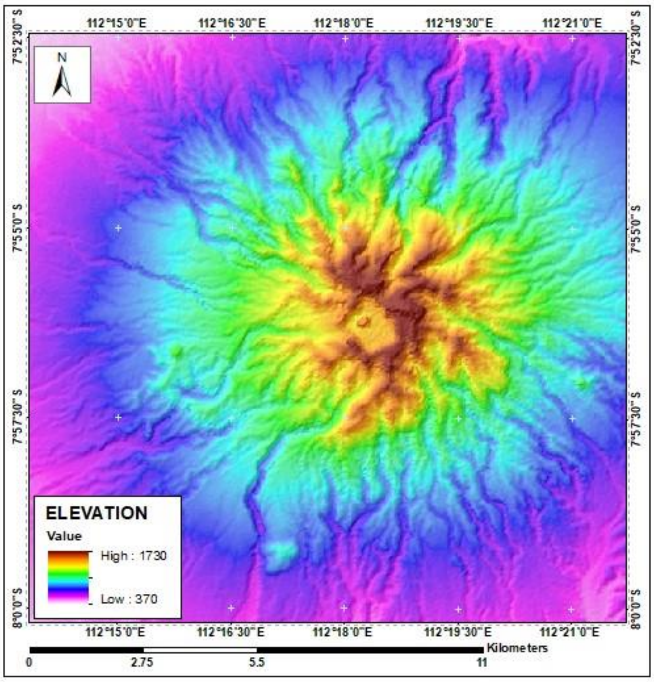

Figure 2. The elevation map.

3.1.2 Slope

The most important parameter in the slope stability analysis is the slope (Lee and Min, 2001). The slope gradient is one primary geomorphometric parameter that figure of geomorphological process of earth's surface. The slope is directly related and affected to the landslides and it is frequently used in preparing susceptibility maps [25–28]. Based on the ASTER GDEM data, the slope map was produced. Below figure showed the spatial distribution of slope gradient.

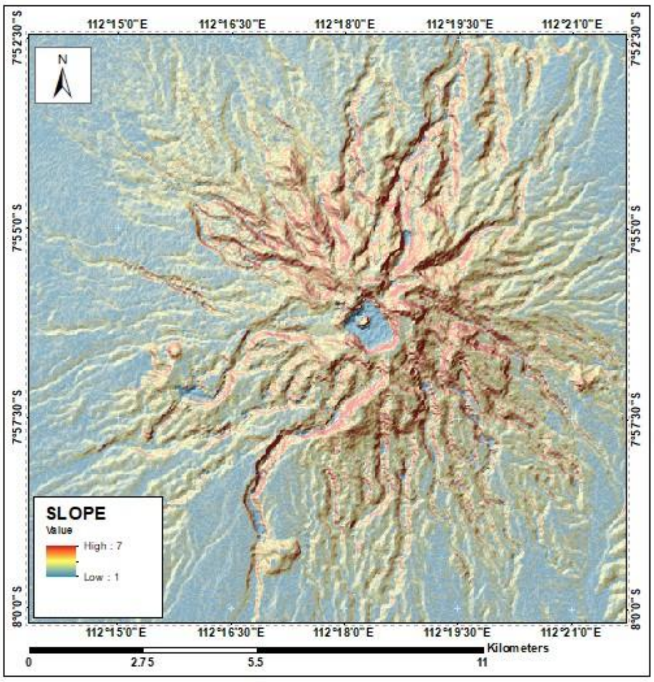

Figure 3. The slope gradient map.

3.1.3 *Topographic Position Index (TPI)*

The Topographic Position Index (TPI) is calculated as the difference the cell elevation and the mean elevation of neighbouring cells [28]. Applied specific thresholds for TPI values allows for the identification of different topographic landforms, such as ridge, slope, and valley. Since the landslide scarps occur mostly on the ridges, the TPI index may be seen as one of landslide conditioning factor, and used for landslide susceptibility map [29,30]. TPI was calculated using Jennes, et al. (2013) implementation. The result of calculated TPI can be seen in figure 4.

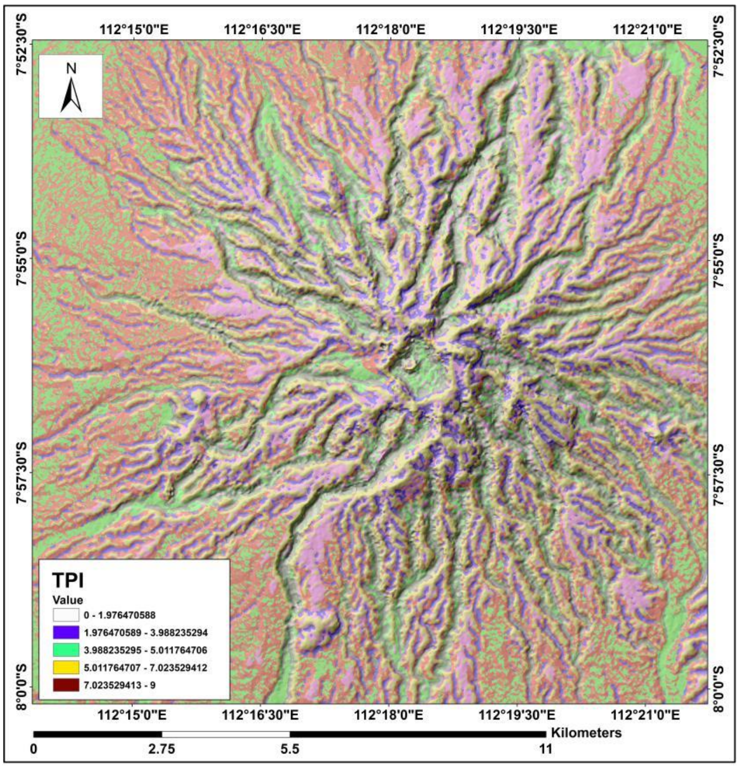

Figure 4. The Topographic Position Index (TPI) Map.

3.1.4 Stream Power Index (SPI)

The massive soil erosion describe the geomorphological process, and it's have direct affect to potential landslide in an area. The Stream Power Index (SPI) used in this study (Fig. 5). This index is used to visualization potential flow erosion and related with landscape processes [31]. The SPI describes potential for flow erosion at the given point of the surface, and controls potential erosive power of water flow [28,31]. The SPI is calculated from following formula:

$$SPI = As * tan\beta \quad (1)$$

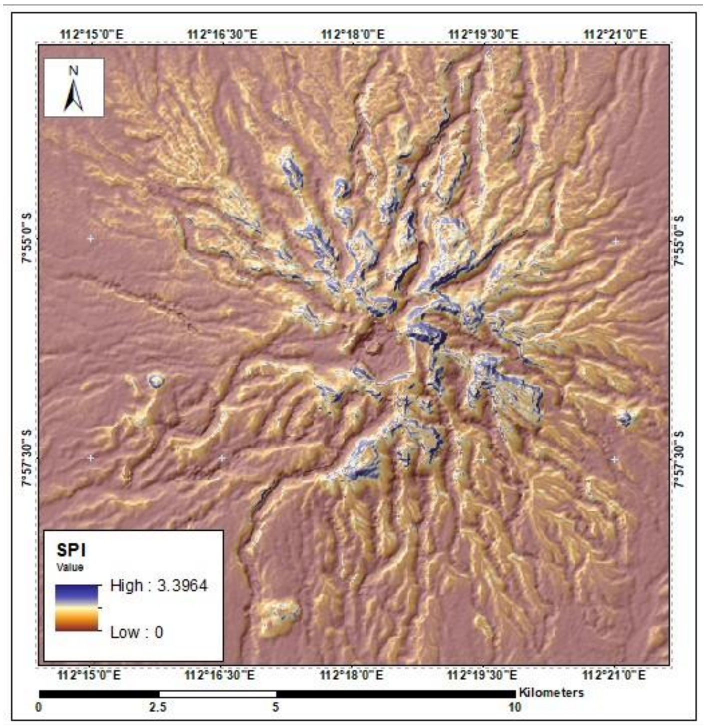

Figure 5. The Stream Power Index (SPI) Map.

3.1.5 Rainfall

We used rainfall data with the duration three years periods from Malang, Kediri, Blitar, Blitar City, Malang City, and Batu City rainfall station in processing landslide susceptibility map. Rainfall data can figure the accumulation of water that can transporting materials and soil, and also triggering the landslides. Spatial distribution of average of three annual rainfall data, we visualized in figure 6.

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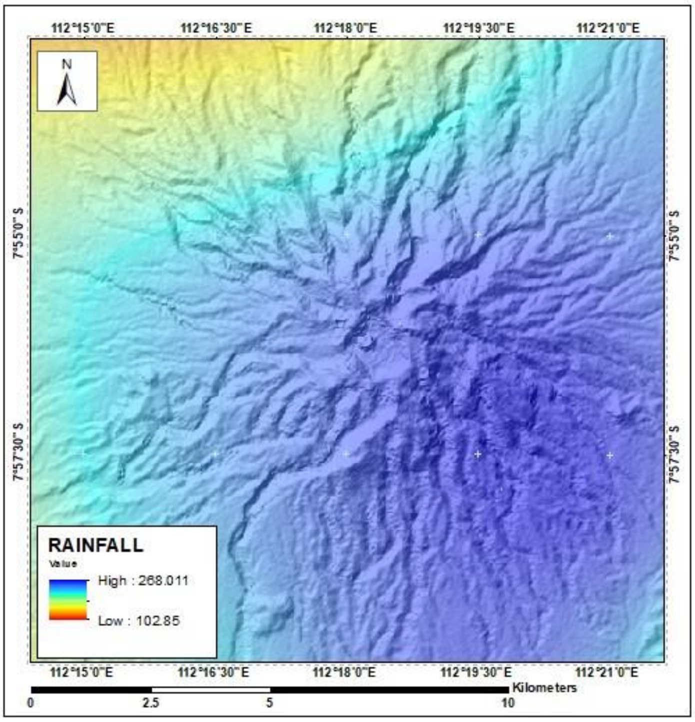

Figure 6. The Rainfall Map

3.1.6 Topographic Wetness Index (TWI)

The Topographic Wetness Index (TWI) model is one of the criteria that indicate hydrological process, related to the accumulation of water flow based on the control of slope factor in an area [28–30]. The slope control of the hydrological process will be highly visible in areas with high relief configurations. Especially at the Mount Kelud area, the high slope configuration encourages control of hydrological processes, which relate to the process of accumulation of water flows. In Figure 7, its show the accumulation of water flows.

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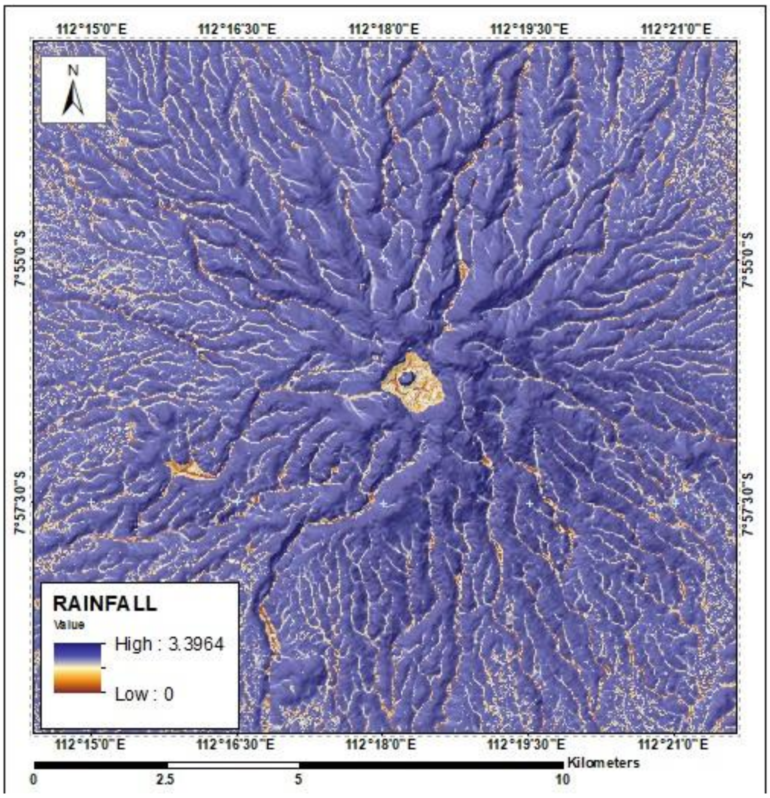

Figure 7. The Topographic Wetness Index (TWI) Map.

3.1.7 Soil Texture

Soil texture describe the materials and physical characteristic in each soil profile. After catastrophic event, in 2014 Kelud eruption ejecting the amount of material, is important to make spatial distribution of soil texture. Soil texture data extracted from the laboratory analyses. The average percentage of soil texture in the study area were 70% sand, 20% silt, and 10% clay. Figure 8 contain the distribution of soil texture in the Kelud area.

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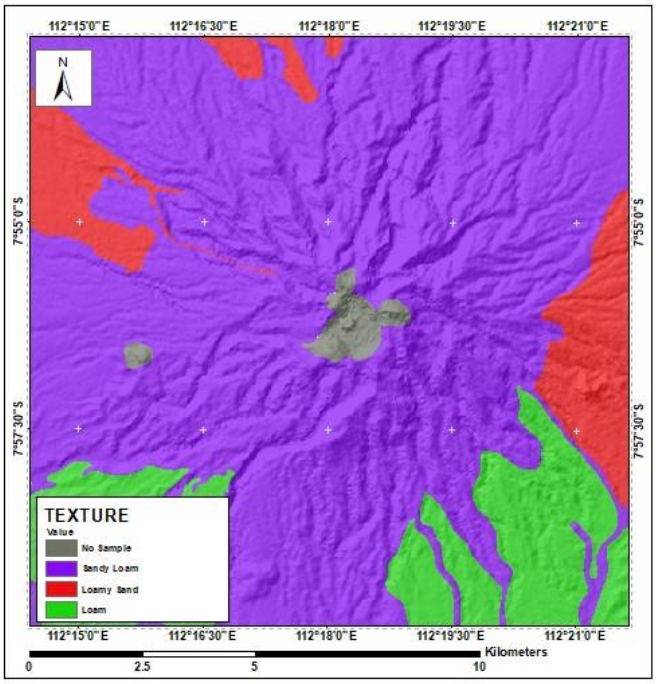

Figure 8. The Soil Texture Map.

3.1.8 COLE Index

The low percentage content of montmorillonite clay fraction causes a low of COLE index in this study area. The low COLE index will have an effect on low soil ability to retain water and soil ability to form aggregates. Figure 9 contain the information of distribution COLE index in research area.

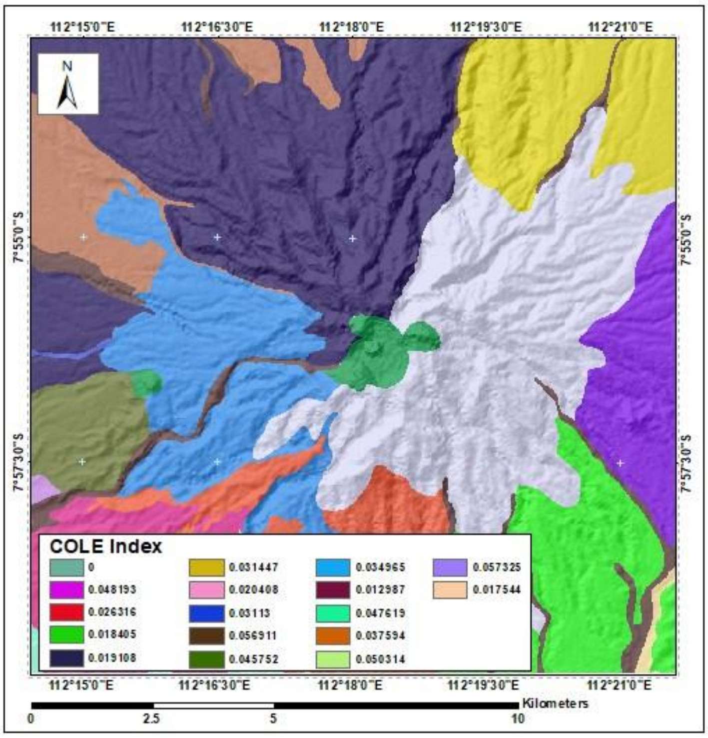

Figure 9. The COLE Index Map.

3.1.9 Land-Use

In this study, land use map was produced from the LANDSAT 8 OLI/TIRS satellite image, and applying a object-based classification scheme. There are eight types of land use are identified in the study area. In the landslides susceptibility modelling, land use map is important to produce information of human induce and environment condition in research area.

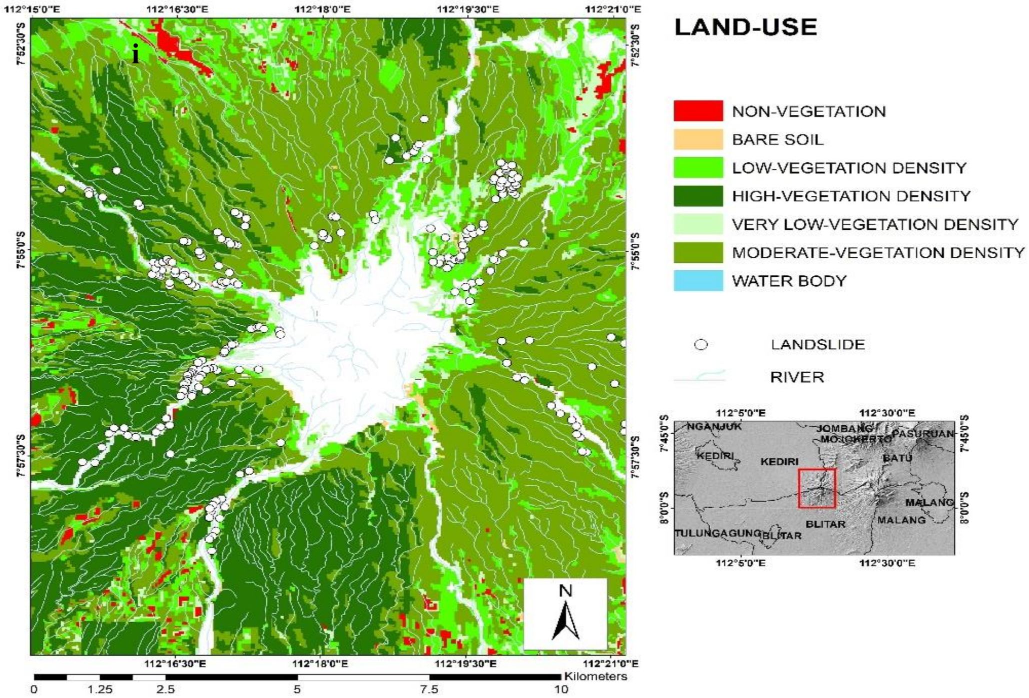

Figure 10. Human-Induced Parameter Land-Use Map.

3.2. Research Proses

3.2.1 Landslide Inventory Map

Creation of landslide inventory maps is an important step in the process of determining and assessing the level of susceptibility. The landslides inventory map (see Fig. 11) can document the occurrence of landslide in an area [32]. The location of the incident, the volume and impact of a landslide can be represented and visualized through landslide inventory map [19]. A landslide inventory map is prepared for several scopes such as (i) documenting the occurrence of landslides in an area, (ii) as a first step towards the assessment of landslide susceptibility, and (iii) to investigate the distribution, type and pattern of landslides that occur [33].

Landslide inventory maps can be done with different techniques. The determination of the techniques used depends on the objectives of the landslide inventory process, the extent of the study area, the time available in the data collection process, the data sources used, and the experience of the researcher [32,34,35]. The selection of manufacturing techniques becomes very important, because it affects the processes and effort undertaken to produce landslide inventory maps that have a high degree of reliability.

The landslide delineation is carryout by visual interpretation using remote sensed data. Applied Google Earth for visual interpretation. In addition, Google Earth provides high-resolution of imagery, the ability to display 3D earth surface has provided the ease and opportunity to detect and mapping landslide distribution in study area. Figure 11 showed the landslide interpretation that we digitized and marked where landslide occurred in this research area. The result of interpretation process, we used this information to validated, captured, and measured the materials of landslides in field observation process.

Figure 11. Interpretation Landslide Based on 3D Visualization in Google Earth.

Field observation process is needed to know the landslide characteristic. Through field observation information will be obtained specifically related to the type and visual characteristics of landslide [34], as well as to determine the validation of landslide inventory maps that have been made. In the process of field observation, we observed the landslide event, and took a picture for every landslide that we found, showed in figure (a). In addition, we took the material of landslide (see figure b and c) , and we classified the type of every landslide events that we found.

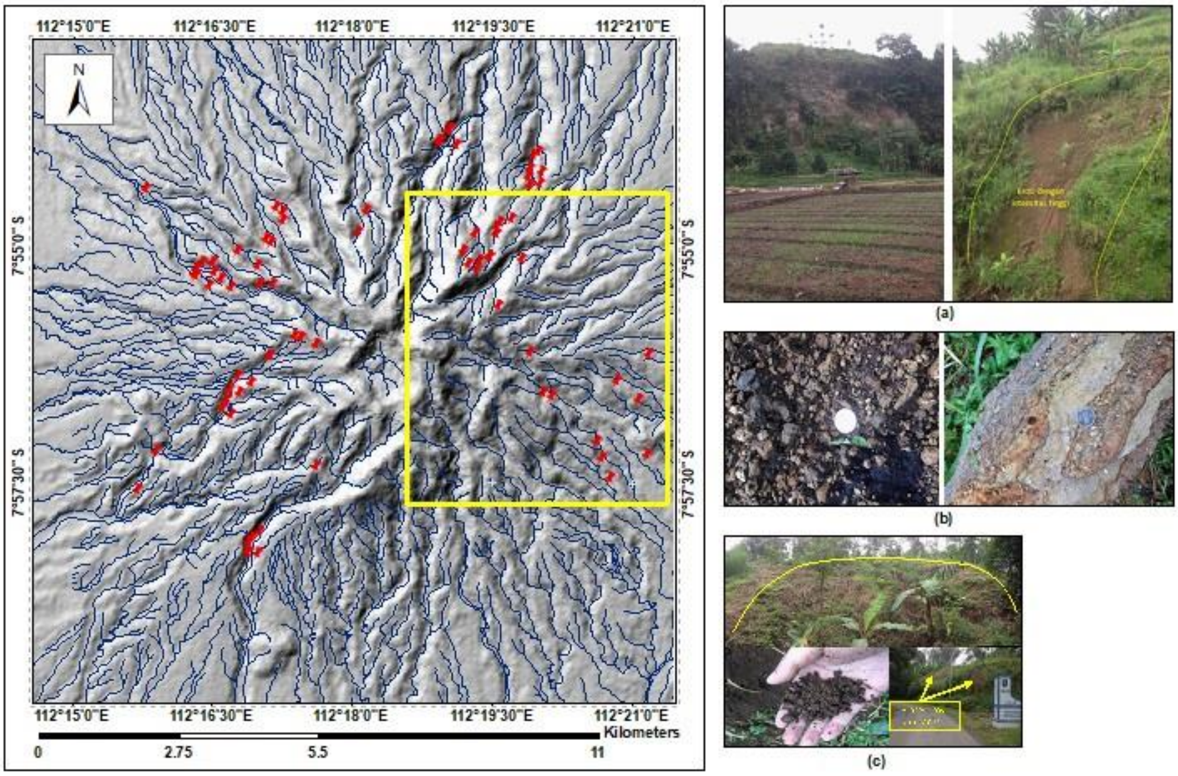

Figure 12. Landslide Inventory Mapping and Field Observatory

3.2.2 LSM Using SMCE

To solve spatial-based problems such as landslide phenomenon, GIS-based Spatial Multi-criteria Evaluation (SMCE) have been used. SMCE is a way of producing policy-relevant information about spatial decision problems for decision makers [21]. The basic steps is to divide the decision problem into small, understandable parts, analyse each of them, and integrate these parts in a logical manner to produce a meaningful solution [36]. SMCE process can be visualized in Figure 12 [21,37].

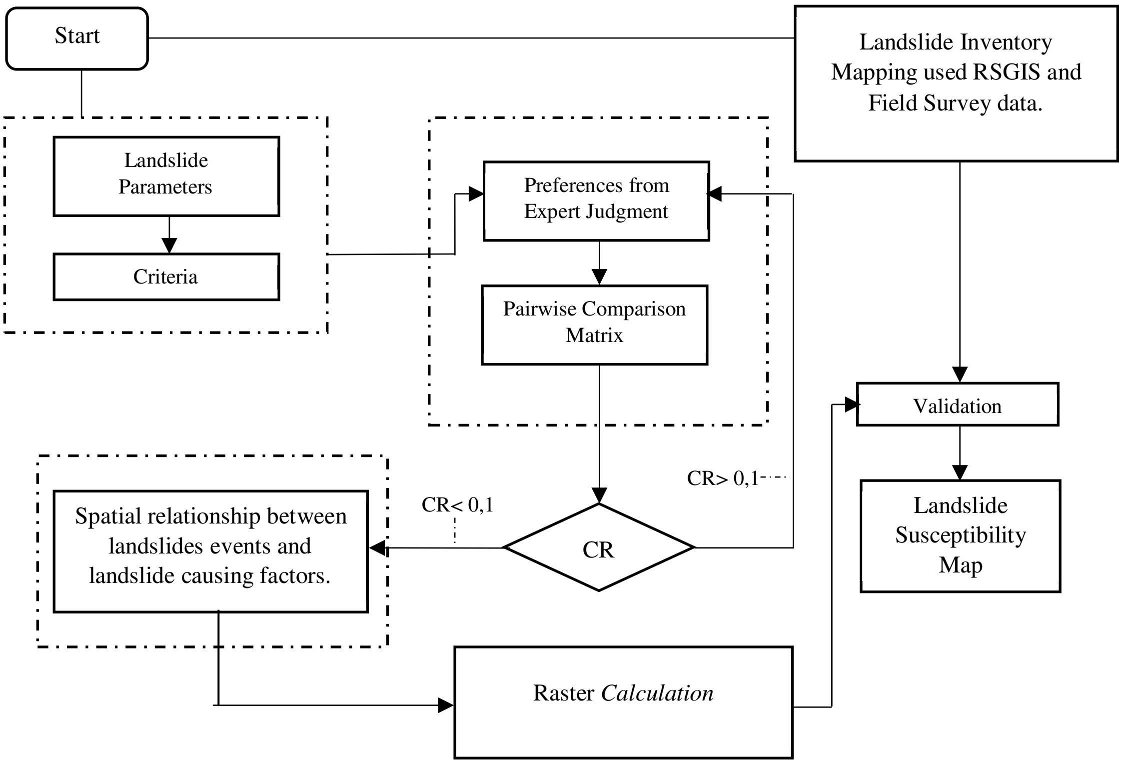

Figure 13. Landslide Susceptibility Process Using Spatial Multi-Criteria Evaluation (SMCE).

SMCE method in this study was also engaged with expert judgment provided by academic university's view and the BPBD agencies. For these method, a pair-wise comparison based weighting was used. Pair-wise comparison method was established by Saaty (1987) in the context of the Analytical Hierarchy Process (AHP), showing in Table 1. According to Pourghasemi, et al., (2012) the AHP consists of three main steps; (1) generating the pari-wise comparison matrix, (2) computing the weigts of the criterion, and (3) estimating the consistency ratio. In making comparison matrix, the AHP method uses a scale with a range of values 0 – 9 to assess relatve preferences for two criteria. The range value can be shown in table as followed:

Table 1. The Range Value in AHP.

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominace demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

Source: Pourghasemi *et al*, 2014

3.2.3 Landslide Parameters

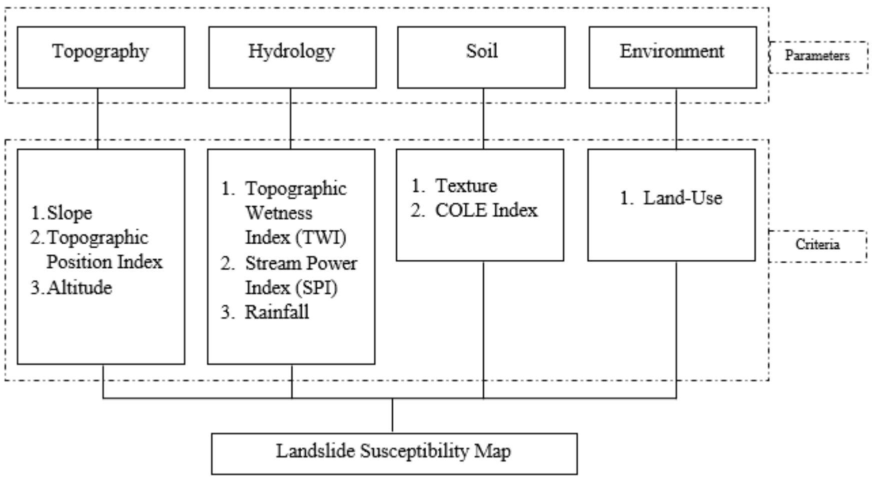

Figure 14. The flowchart of the research

In the diagram above shows the landslide parameters of this research. In the process of assessment of landslide susceptibility have been used several parameters covering topography, hydrology, soil, and environment. Then, each parameters is reduced to several criteria including slope, TPI, altitude, TWI, SPI, rainfall, soil texture, soil COLE index, and Land Use. The layers from each data is then integrated in attempt to build a landslide susceptibility maps.

3.2.4 Pairwise Comparison Matrix

Table 2. Pairwise Matrix for Landslide Susceptibility Mapping.

LSM Parameters

Parameters	(1)	(2)	(3)	(4)	Eigen Value
Topography (1)	1	1/2	3	3	0.308
Hydrology (2)		1	3	3	0.433
Soil (3)			1	3	0.165
Land-Use (4)				1	0.094

Consistency Ration: 0.08

Topography's Criteria

Elevation

Factors	(1)	(2)	(3)	(4)	(5)	(6)	Eigen Value
0 – 550 (1)	1	½	1/2	1/2	½	½	0.085
551 – 700 (2)		1	1/2	1/2	½	½	0.107
701 – 850 (3)			1	1/2	½	½	0.135
851 – 1000 (4)				1	½	½	0.169
1001 – 1250 (5)					1	1/3	0.204
1251 – 1730 (6)						1	0.300

Consistency Ration: 0.06

Slope

Factors	(1)	(2)	(3)	(4)	(5)	(6)	Eigen Value
0 – 5 (1)	1	½	1/3	1/3	1/3	1/3	0.059
6 – 15 (2)		1	1/3	1/3	1/3	1/3	0.074
16 – 30 (3)			1	1/3	1/3	1/3	0.117
31 – 50 (4)				1	1/3	1/3	0.171
51 – 70 (5)					1	1/2	0.258
> 70 (6)						1	0.322

Consistency Ration: 0.08

Topographic Position Index (TPI)

Factors		(1)	(2)	(3)	(4)	(5)	(6)	Eigen Value
0	(1)	1	2	2	2	2	2	0.275
2	(2)		1	2	2	2	2	0.218
4	(3)			1	2	2	2	0.173
5	(4)				1	2	2	0.138
7	(5)					1	2	0.109
9	(6)						1	0.087
Consistency Ration: 0.04								

Hydrology's Criteria

Stream Power Index (SPI)

Factors		(1)	(2)	(3)	(4)	(5)	(6)	Eigen Value
0 – 20	(1)	1	3	3	3	3	3	0.350
20 – 40	(2)		1	3	3	3	3	0.241
40 – 60	(3)			1	3	3	3	0.166
60 – 80	(4)				1	3	2	0.107
80 – 100	(5)					1	2	0.074
>100	(6)						1	0.062
Consistency Ration: 0.09								

Rainfall

Factors		(1)	(2)	(3)	(4)	(5)	Eigen Value
175	(1)	1	1/3	1/3	1/3	1/3	0.070
200	(2)		1	1/3	1/3	1/3	0.110
225	(3)			1	1/3	1/3	0.172
245	(4)				1	1/2	0.281
270	(5)					1	0.367
Consistency Ration: 0.09							

Topographic Wetness Index (TWI)

Factors		(1)	(2)	(3)	(4)	(5)	Eigen Value
0 – 4	(1)	1	1/3	3	3	3	0.261
0 – 7	(2)		1	3	2	3	0.412

7 – 11 (3)			1	2	2	0.140
11 – 15 (4)				1	2	0.106
15 – 18 (5)					1	0.081

Consistency Ration: 0.06

Soil's Criteria

Texture

Factors	(1)	(2)	(3)	Eigen Value
Loam (1)	1	½	1/3	0.157
Loamy Sand (2)		1	1/3	0.249
Sandy Loam (3)			1	0.594

Consistency Ration: 0.05

Factors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Eigen Value
0.01299 (1)	1	1/2	2	2	2	2	2	2	2	2	2	0.128
0.01841 (2)		1	2	2	2	2	2	2	2	22	2	0.143
0.01911 (3)			1	2	2	2	2	2	2	1/2	2	0.108
0.02041 (4)				1	2	2	2	2	2	2	2	0.102
0.02632 (5)					1	2	2	2	2	2	2	0.091
0.03110 (6)						1	2	2	2	2	2	0.082
0.03145 (7)							1	2	2	2	2	0.073
0.37594 (8)								1	2	2	2	0.065
0.04575 (9)									1	2	2	0.058
0.04762 (10)										1	2	0.052
0.04819 (11)											1	0.058

Consistency Ration: 0.06

Land-Use's Criterion

Factors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Eigen Value
Lahars	1	2	2	2	2	2	2	0.232

Non-Vegetation		1	2	2	2	2	2	0.192
Bare Soil			1	2	2	2	1/2	0.141
Very Low-Veg.				1	2	2	2	0.134
Low-Veg.					1	2	2	0.110
Moderate-Veg.						1	2	0.091
High-Veg.							1	0.100

Consistency Ration: 0.08

3.2.5 *Data Standardization*

Table 3. Spatial Relationship between Landslides and Landslide Causing Factors.

Factor	Class	No.of pixels in domain	Percentage of domain	No. of landslide	Percentage of landslide	FR		a	b	c	d
Elevation	550	389135	21.88	2	2.35	0.11	0.085	0.0091	0.249	0.308	0.0007
	700	564495	31.74	3	3.53	0.11	0.107	0.0119	0.249	0.308	0.0009
	850	374988	21.09	20	23.53	1.12	0.135	0.1506	0.249	0.308	0.0116
	1000	226558	12.74	32	37.65	2.96	0.169	0.4994	0.249	0.308	0.0383
	1250	153265	8.62	21	24.71	2.87	0.204	0.5848	0.249	0.308	0.0449
	1730	69955	3.93	7	8.97	2.28	0.3	0.6844	0.249	0.308	0.0525
Slope (deg)	0 - 5	504856	28.41	2	2.35	0.08	0.59	0.0489	0.594	0.308	0.0089
	6 - 15	459015	25.83	4	4.71	0.18	0.074	0.0135	0.594	0.308	0.0025
	16 - 30	336505	18.93	11	12.94	0.68	0.117	0.0800	0.594	0.308	0.0146
	31 - 50	204188	11.49	10	11.76	1.02	0.171	0.1750	0.594	0.308	0.0320
	51 - 70	138069	7.77	25	29.41	3.79	0.258	0.9767	0.594	0.308	0.1787
	> 70	134527	7.57	33	38.82	5.13	0.322	1.6514	0.594	0.308	0.3021
TPI	0	179733	10.11	17	20.00	1.98	0.275	0.5442	0.157	0.308	0.0263
	2	162564	9.14	16	18.82	2.06	0.218	0.4490	0.157	0.308	0.0217
	4	429951	24.18	10	11.76	0.49	0.173	0.0842	0.157	0.308	0.0041

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	5	540320	30.38	10	11.76	0.39	0.138	0.0534	0.157	0.308	0.00
	7	139962	7.87	8	9.41	1.20	0.109	0.1304	0.157	0.308	0.00
	9	325866	18.32	24	28.24	1.54	0.087	0.1341	0.157	0.308	0.00
SPI	0-20	1129999	63.54	16	18.82	0.30	0.35	0.1037	0.249	0.433	0.01
	20-40	369601	20.78	18	21.18	1.02	0.241	0.2456	0.249	0.433	0.02
	40-60	178372	10.03	27	31.76	3.17	0.166	0.5258	0.249	0.433	0.05
	60-80	75223	4.23	20	23.53	5.56	0.107	0.5952	0.249	0.433	0.06
	80-100	23104	1.30	3	3.53	2.72	0.074	0.2010	0.249	0.433	0.02
	>100	2097	0.12	1	1.18	9.98	0.062	0.6186	0.249	0.433	0.06

Table 4. (*continued*).

Factor	Class	No.of pixels in domain	Percentage of domain	No. of landslide	Percentage of landslide	FR		a	b	c	d
Rainfall	175	132116	11.67	2	2.35	0.20	0.7	0.1412	0.594	0.433	0.03
	200	186247	16.45	10	11.76	0.72	0.11	0.0787	0.594	0.433	0.02
	225	237631	20.98	17	20.00	0.95	0.172	0.1639	0.594	0.433	0.04
	245	243707	21.52	33	38.82	1.80	0.281	0.5070	0.594	0.433	0.13
	270	332822	29.39	23	27.06	0.92	0.367	0.3379	0.594	0.433	0.08
TWI	0-4	757470	43.02	22	25.88	0.60	0.261	0.1570	0.0157	0.433	0.00

	0-7	564669	32.07	36	42.35	1.32	0.412	0.5441	0.0157	0.433	0.00
	7-11	253185	14.38	16	18.82	1.31	0.14	0.1833	0.0157	0.433	0.00
	11-15	137012	7.78	7	8.24	1.06	0.106	0.1122	0.0157	0.433	0.00
	15-18	48489	2.75	4	4.71	1.71	0.081	0.1384	0.0157	0.433	0.00
Texture	Loam	48415	16.41	5	5.88	0.36	0.157	0.0563	0.75	0.165	0.00
	Loamy Sand	41837	14.18	9	10.59	0.75	0.249	0.1859	0.75	0.165	0.02
	Sandy Loam	204820	69.41	71	83.53	1.20	0.594	0.7148	0.75	0.165	0.08
Cole	0.01299	79561	6.87	16	18.82	2.74	0.128	0.3507	0.25	0.165	0.01
	0.01841	143539	12.39	14	16.47	1.33	0.143	0.1900	0.25	0.165	0.00
	0.01911	65241	5.63	7	8.24	1.46	0.108	0.1579	0.25	0.165	0.00
	0.02041	42961	3.71	6	7.06	1.90	0.102	0.1941	0.25	0.165	0.00
	0.02632	79114	6.83	2	2.35	0.34	0.091	0.0313	0.25	0.165	0.00
	0.03110	37431	3.23	4	4.71	1.46	0.082	0.1194	0.25	0.165	0.00
	0.03145	73728	6.37	3	3.53	0.55	0.073	0.0405	0.25	0.165	0.00
	0.37594	28311	2.44	1	1.18	0.48	0.065	0.0313	0.25	0.165	0.00
	0.04575	112169	9.69	2	2.35	0.24	0.058	0.0141	0.25	0.165	0.00
	0.04762	111689	9.64	3	3.53	0.37	0.052	0.0190	0.25	0.165	0.00
	0.04819	256884	22.18	23	27.06	1.22	0.058	0.0708	0.25	0.165	0.00

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Table 5. (*continued*).

Factor	Class	No.of pixels in domain	Percentage of domain	No. of landslide	Percentage of landslide	FR		a	b	c	d
Landuse	Lahar	86320	7.01	11	12.94	1.85	0.232	0.4282	0.094		0.04025
	Non-Vegetation	55602	4.52	6	7.06	1.56	0.192	0.3001	0.094		0.02820
	Bare Soil	7014	0.57	12	14.12	24.78	0.141	3.4936	0.094		0.32839
	Very Low Vegetation	65521	5.32	3	3.53	0.66	0.134	0.0889	0.094		0.00835
	Low Vegetation	192981	15.68	21	24.71	1.58	0.11	0.1734	0.094		0.01630
	Moderate Vegetation	526222	42.75	24	28.24	0.66	0.091	0.0601	0.094		0.00565
	High Vegetation	297322	24.15	8	9.41	0.39	0.01	0.0039	0.094		0.00037

Domain: pixels in study area, domain (%): (domain/total pixels in study area)*100, landslide: number of landslide occurrences, landslide (%): (landslide/ total number of landslide occurrences)* 100, frequency ratio: landslide (%)/ domain (%).

[a] Normalized value.

[b] Parameter's value.

[c] Group's value.

[d] Final weight.

4. Result and Discussion

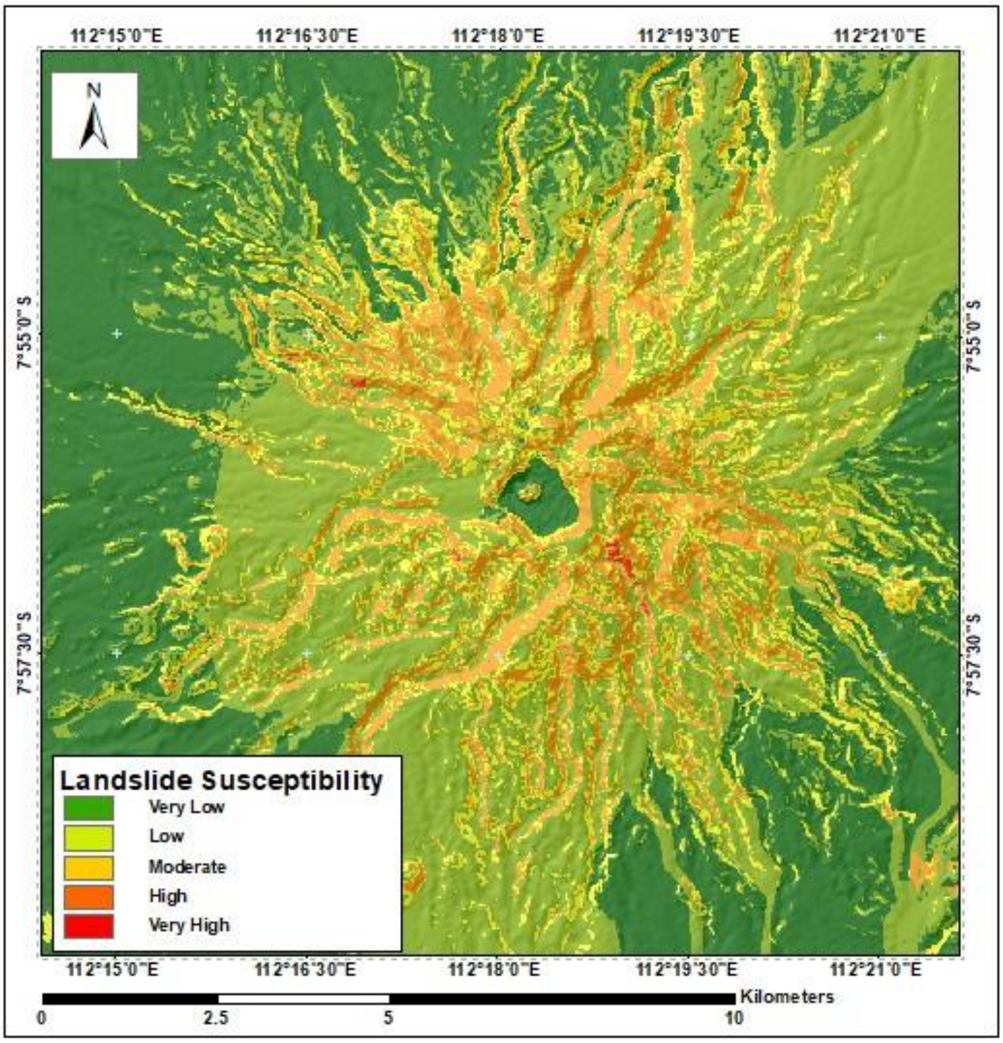

Figure 15. Landslide Susceptibility Map

This study produce landslide susceptibility map which applied AHP method for determine the weight value of each parameters and criterion. The standardization stage of each criterion is based on frequency ratio calculation, where the percentage of landslide points in each class is divided by number of pixels domains from each class within each criterion. We applied Natural Break (Jenks) classification to divide the susceptibility into several class. The class of landslide susceptibility consists of “Very Low’, “Low”, “Moderate”, “High”, and “Very High”.

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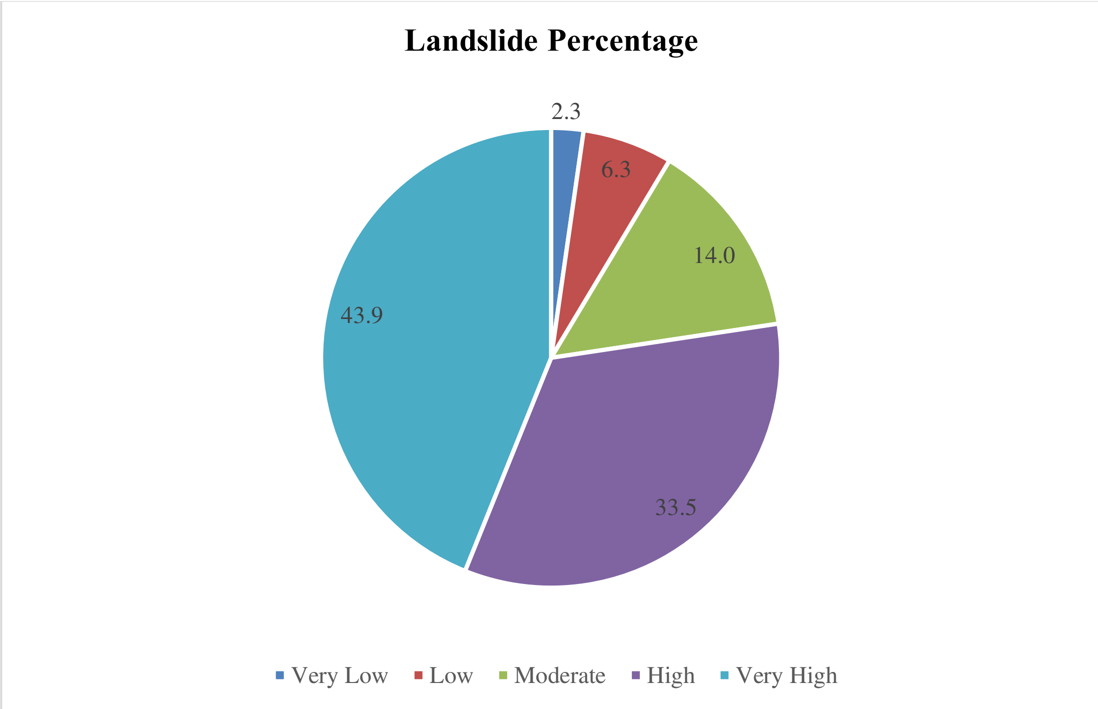

Figure 16. The Pie Diagram of Percentage Landslide Occurrences

Total number of landslide point used in this study is 121, with landslide characteristic has area >100m2. Number of landslide in each class of susceptibility can be seen in the above figure. Based on the graph it is known that the area with very high level of susceptibility has a percentage of landslide incidence of 24, 977%, then high susceptibility class is 27, 957%, moderate susceptibility class is 27, 660%, low susceptibility class is 15,288%, and very low class is 4,116%.

5. Conclusion

The phenomenon of landslide becomes a serious threat post eruption of Mount Kelud in 2014. This is in line with the mapping of landslide susceptibility that has been done. The area around Mount Kelud has a high landslide potential level. Based on research results of 24.977% of the area included into the class of very high susceptibility, and 27.957% including into high susceptibility class. The information generated from this research becomes important to reduce the impact of losses that can be caused by landslides.

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