Landslide Susceptibility Mapping in Padang Pariaman District, West Sumatera Province, Indonesia: A Preliminary Study

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Abstract
Earthquakes are one of the typical natural triggering mechanisms for landslides disaster, which result in severe human casualties, property losses and environmental degradation. For example, the 7.9 Richter Scale (SR) earthquake struck Padang Pariaman District, West Sumatera Province, Indonesia on Wednesday, 30 September 2009 whereby 375 people were died. Considering geographical condition of West Sumatera Province that normally triggered by the earthquake, as well as topography of this region that mountainous where the hills are easily fell down especially after earthquake and heavy rain, there is a need to generate a comprehensive 'Landslide Susceptibility Map - LSM' of the landslide proned areas. The goal of the LSM is to assess the landslide hazards in order to reduce the risks to people, urban areas, infrastructures. Over many years, Geographical Information Systems (GIS) and Remote Sensing have become integral tools for the evaluation of natural hazard phenomena. The role of remote sensing is mainly to map the distribution of existing landslides location and the factors that affect the landslide occurrences. While, the GIS are used for database construction and management, data displays, data analysis of LSM production. This paper highlights the method that has been implemented to generate GIS based landslide susceptibility maps for Padang Pariaman District, West Sumatera, Indonesia. In this study, numerical rating system was applied to various factors that contributed to slope instability. Remote sensing data were used to map existing landslide locations and factors that are important in landslide initiation, such as slope, slope aspect, elevation, land use/land cover, and vegetation mass. Preliminary results are presented and discussed.

Keywords: Landslide susceptibility, Geographic information system (GIS), Remote Sensing, Slope analysis

1.Introduction

The Indonesian archipelago sits on the junction of 3 (three) plates the world's great Indo-Australian plate, Eurasia and the Pacific. In the area meeting took place between the plate subduction zone which resulted in the formation of volcanic island arc with moderate to steep slope. Volcanic eruption of the material has high porosity and less compact and scattered in an area with a slope steep, if disturbed hydrological balance, the area will be prone to landslides. These conditions resulted in areas that are in island arc are prone to landslides (Sutikno, 2001). Landslides are a natural event at this frequency incidence is increasing. .Landslides are caused when the victim either of fatalities and property loss and the human culture. Territory of Indonesia in general and the Province of West Sumatra in particular a most of there is located on the hills and mountains, causing this region prone to landslides. Frequent rain with high intensity and an earthquake happens, it will naturally be able to trigger landslides.

The 7.9 Richter Scale (SR) earthquake struck West Sumatra and its surrounding area on Wednesday, 30 September 2009, at 17.16 pm. Epicenter of this earthquake was located at Latitute 0º.84[1] South , Longitute 99º.65[1] East, or 57 miles southwest of the city of Pariaman, with depth 71 km (Indonesia Meteorologi and Geophysics Body (BMKG),2009)

Impact of the earthquake, at various levels, leads to destruction and damage to many district/towns in West Sumatra Province especially in Padang Pariaman district that the area with largest number of died casualties (666), and Padang (383). (Satkorlak Disaster of West Sumatra 2009).Major destructions on building and Man-made construction were found in the both cities Padang and Padang-Pariaman. There were 488 people died in these cities due to collapsed of the buildings. Specific to Padang Pariaman, other than death due to collapsed building, 375 people were death and buried caused by the landslide which was triggered by the earthquake.

Other than in Padang Pariaman, there are number of areas that landslide will potentially occur if heavy rain fall such as Road of the Anai Valley that link Padang to Bukittinggi; the two biggest cities in the province, as well as Sitinjau Laut, another major national road that link Padang to Solok. These areas often experienced landslide and caused causalities such as death and destruction of on road and passing vehicles.

Earthquakes in the West Sumatera Province are caused by a fault called as Semangko fault (fault). This fault starts from Semangko Gulf in South of Sumatra up to Gulf of Andaman in Nicobar Islands in the Indian Ocean. In addition, there is a great continental tectonic plate meeting (tectonic plate of Eurasian and tectonics plate of Indo-Australia) established in this area specifically neat to the islands called as Mentawai islands (See Figure 1). The tectonic plate is seismically active. According to experts, this tectonic plate creates big earthquake every 200 years. The new 200 years cycle has predictably came in recent years.(Zachariassen et al,1999; Natawidjaya et al,2006) in Natawidjaya, 2007.

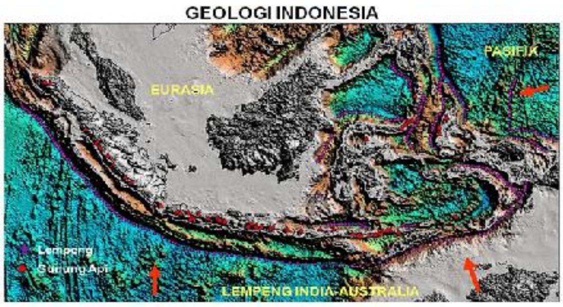

Figure 1. Tectonic Plate of Indonesia

In addition to Semangko fault and meeting point between two tectonic plates, the land of West Sumatra is also composed by intermingle highlands; start from Province of Aceh in the north to the Province of Lampung in the south. The intermingle highland is created by intermingle igneous volcanic (especially tuft, sediment stones and andesite) and metamorphic rock (especially sikis). Some of volcanic mountain in this highland is still active. The constituent rocks in this highland also truncated – cut by fissures – rock cracks, and brittle. If it is jiggled by the earthquake, it will experience landslide. In the earthquake of September 30, 2009, there are lots of debris and most of debris were happened in due to the rocks on the slopes glide row of mountains in the fault lines (Dwikorita Karnawati, 2009).

Based on a review of the location of the landslide in Padang Pariaman District, specificly in Sub District Patamuan,, Nagari Tandikek, Jorong Cumanak, Jorong Lubuk Laweh, Jorong Pulau Air, the location of landslide is estimated to be in the line of the fault. The slope of the Hill before the landslide was ranging between 300 to 400 which is composed by tuft and pumice rides range above andesitic rocks. These rocks appear to undergone a change so that make a cover form of land consist of porous clays that is thick (more or less 20 meters). This characteristic unfortunately is found in 80% of the area of the West Sumatera Province. Only a small part of this province that is plains and these areas is generally located on the edge of the sea (more or less 5 km). Therefore, this province is very prone to catastrophic landslides.

Due to this reason, it is important to build map of susceptibility landslide in West Sumatra, particularly in Padang Pariaman. Mapping susceptibility landslide is very important to be done as soon as possible to predict future catastrophic landslide. Remote sensing and GIS useful for landslide susceptibility mapping and can help identify the area best suited for development activities (Guzzetti et al, 1999; Van westen 2000; Dai et al, 2001; Van Westen et al, 2003; Sarkar and Kanungo 2004; Saha 2005; Van Westen et al 2008; Gupta et al, 2008).

The objective of this paper was to generate a landslide susceptibility map of the Padang Pariaman District to assist Government and community to minimize impact of next earthquake.

2. Study Area

Study area is in Padang Pariaman District the Geographical position is located between Latitute 0 ^{0}, 11 0 ^{0}, 49; South and Longitute 98 ^{0}, 36 °-100 ° 28 ^{0} East , with landmass of 1,328.79 Km2 with long coastlines 84.50 km. In total, land area of Padang Pariaman is equivalent to 3.15% of the land area of the West Sumatra Province. The capital city of Padang Pariaman is Pariaman city which is approximately 55 km from Padang, the capital city of West Sumatra.(BPS Satatistic of Padang Pariaman District).

Topography of Padang Pariaman consists of land located on the Mainland Sumatra and six of small islands. Forty percent of the region is located in the low area near to the beach, with an average width of approximately 1-2 miles from the beach with an elevation of 0 – 10 meters above sea level. The rest 60% of this region is located in the East specifically in hilly undulating hills a with an elevation of 10 – 1000 meter above the sea level.(Figure 2)

Padang Pariaman has a tropical climate with a short dry season specifically for the beaches area. This area also heavily affected by the sea breeze. Temperatures range between 24.4 ^{0} C – 25.78 ^{0} C. The maximum temperature in general is 31,08 ^{0} C while the minimum is 21,34 ^{0}C. Relative humidity for this area is 87.25%. The hottest temperature occurs in May and lowest temperature occurs in September1.

The average rainfall in 2010 in this area is of 427,7 mm with an average rainy days as many as 22 days per month.(Source : Climatological Station, Sicincin, 2011)

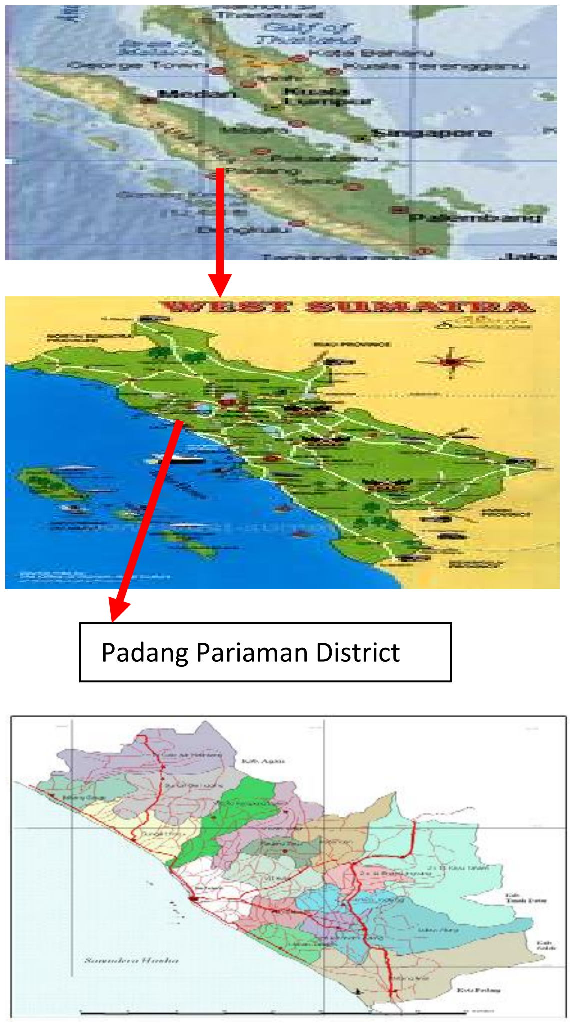

Figure 2. Location Area of Study

3 Materials and methods

The data required for this study is the slope angle, slope aspect, elevation, land use / land cover and vegetation mass (NDVI). The data was gathered from various sources, such as topographic maps scale 1: 50,000, Landsat satellite imagery dated March 1, 2009 and May 24, 2010; and contour maps and field survey. Field survey conducted to determine the actual condition of the landscape, by combining the DEM (Digital Elevation Model) of the contour map

Landslide susceptibility map can be prepared by several methods such as statistical methods, deterministic and heuristic. All of these methods generally begin with an inventory of landslide mapping as a basis to obtain landslide susceptibility maps. In this paper, the landslide susceptibility mapping using the heuristic method with value-weighting methods; values and weights are determined based on expert opinion that states the amount of influence the types of parameters to the occurrence of landslides.

Parameter weights and high value illustrates the high influence of these parameters on the occurrence of landslides. Numeric ranking system is applied to the five parameters used in the analysis of landslide susceptibility, namely: slope, slope aspect, elevation, land use / land cover and vegetation mass (NDVI). Each thematic map was assigned a weight depending on its influence on landslide hazard based on multiple criteria decision making techniques. GIS is an ideal tool to Analyse and solve multiple criteria problems (Belton and Stewart 2002). The relative score of each thematic unit in a theme was calculated by multiplying the weight of the theme with the rank of thematic units.The weight and rank of each layer is given in table 1.

Table 1 Thematic maps, weight and ranking for landslide susceptibility zonation study

No	Theme	Weight	Features	Fixels	Rank
1	Slope	5	0 - 4.20 4.20 - 12.30 12.30 – 20.40 20.11 – 27.52 27.52 – 34.93 34.93 – 42.69 42.69 – 51.51 51.51 – 70.21 70.21 - 90	280,529 67,294 56,990 48,943 42,462 34,007 24,072 8,826 2,374	1 2 3 4 5 6 7 8 9
2	Elevation	4	0 – 19 19-32 32- 52 52-81 81-125 125-192 192-292 292-443 443-670 670-1011 1011-1521 1521-2299	286,909 370,790 270,160 229,384 274,817 280,504 291,339 224,144 209,546 201,337 80,262 3,488	1 2 3 4 5 6 7 8 9 10 11 12
3	Land use/ Land cover	3	Emplasmen Primary - forest Secondary – forests village Pplantation mining housing Rice field bush Land baring	2094153 401174113 70934889 3269986 6984676 174291 46427404 229104144 1760289 202907	5 1 2 5 4 9 5 5 8 9
4	NDVI	2	-1 – 0.2 0.2- 0.4 0.4-0.6 0.6-0.8 0.8-1	383.729 550.795 637.900 15 146	5 4 3 2 1
5	Slope Aspect	1	Flat North North east East South east South South west West North west	86.892 10.221 5.677 7.092 14.346 29.380 52.944 26.831 18.208	1 7 8 9 6 4 3 2 5

The scored maps were overlaid using the spatial analysis tool of ArcGIS 10 to generated a Landslide susceptibility mapping (LSM). The resultant map was classified into very high, high, medium, and low zones. The Methodology adopted in this study is shown as a follow chart in Figure 3.

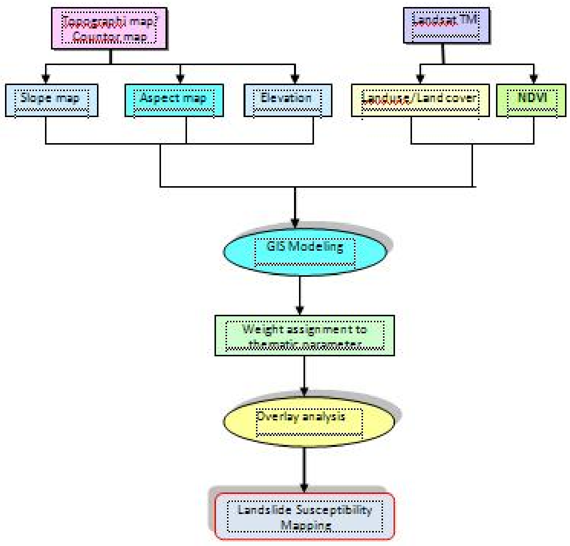

Figure 3. Flow chart depicting the methodology adopted for Landslide Susceptibilty Mapping

3. **Result and discussion**

Determination of weight and value for each parameter are described in Table 1 with the description as follows:

a. slopes angle

In the analysis of slope stability, slope angle is one of the main factors that influence it, a large angle of slope will increase the shear stress and reduced shear strength. This means the possibility of very large landslides will be occurred in the large slope angle(Saha et al, 2002; Cepik and Topal, 2003;; Lee, 2005;) (figure 4)

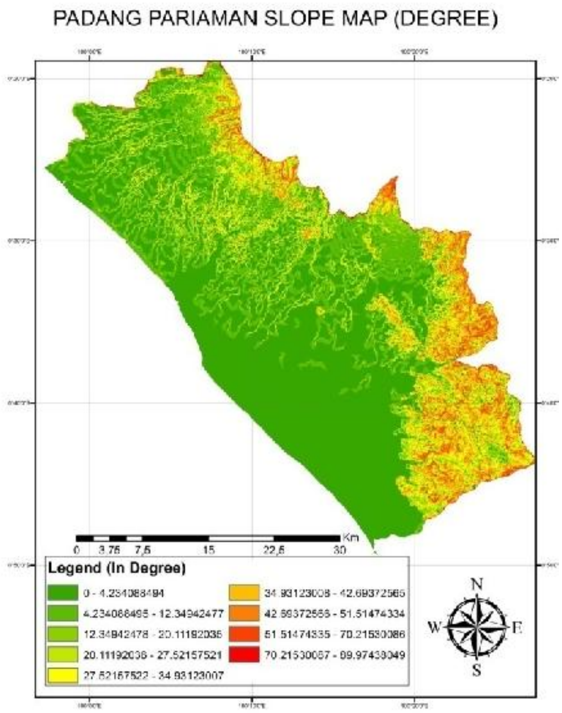

Figure 4 Slope Map

b.Elevation

The rain comes from water vapor in the atmosphere, so that the shape and number of affected by climatological factors such as wind, temperature and atmospheric pressure. Water vapor into the atmosphere would be so cool and there was condensation into grains - grains of water that eventually falls as rain. The cooling process due to the decrease in temperature with increasing altitude. JACoe et al, 2004 states that the area that are at high elevations will more receive much rain than the lower elevation areas, and therefore has a high elevation areas are very vulnerable to landslides (figure 5)

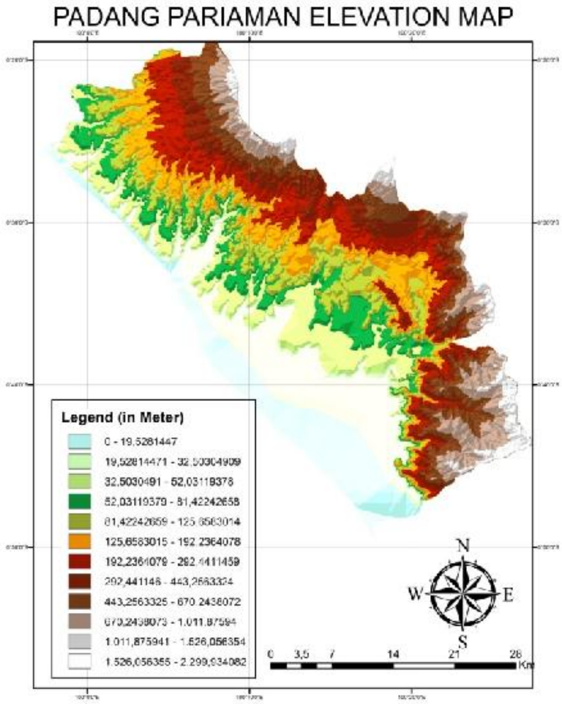

Figure 5. Elevation

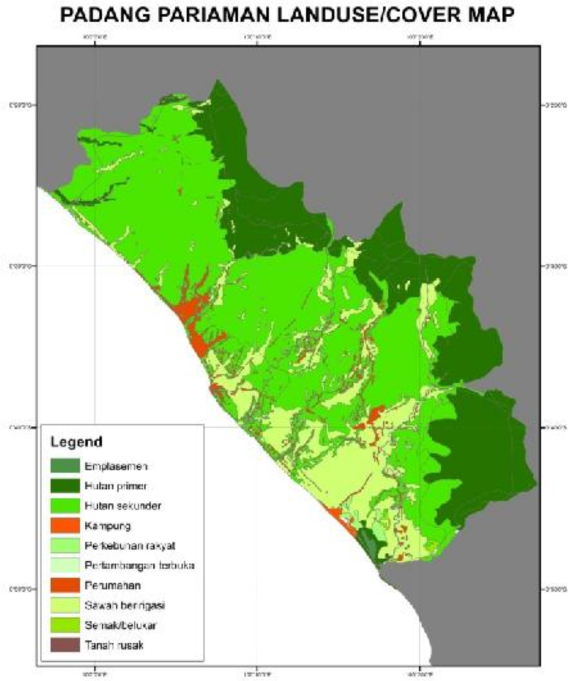

Figure 6. Landuse/Landcover map

C. Land Use / Land Cover

Lillesand and Kiefer (1977) states that the land use associated with human activity on a particular land area, whereas land cover (land cover) associated with the type of appearance which is on the surface of the earth. Land use is part of human activity, in general land use that can cause landslides is the construction of infrastructure such as cutting slopes to change angle of slope, this will also alter the flow of surface water and groundwater. Deforestatiom and land use that do not pay attention to ecosystems can also trigger landslides. Factors of land use and land use can be analyzed through the variable type and land use activities that occur in the study area. Based on Landsat TM in 2009 and 2010, the study area are classified into ten categories such as: Emplasment, Primary forest, secondary forest, village, People's Plantations, Open mining, Housing, irrigated rice field, bush/ shrub, land bare (figure 6)

d. NDVI

The presence of vegetation on the land can be used as one indicator of the criticality of the land. To obtain the density of vegetation that covers the land created an image that memperesentasikan presence of vegetation with NDVI (Normalized Difference Vegetation Index). For monitoring vegetation, made the comparison between the brightness of the red light channel and the channel near-infrared light. The phenomenon of red light absorption by chlorophyll and the reflectance of near infrared light by mesophyll tissue contained in the leaves will make the brightness value received by satellite sensors in the canals will be much different. In the non-vegetation land, including territorial waters, residential, vacant land is open, and the area with degraded vegetation conditions, will not show a high resiki value (minimum). In contrast to the vegetated area is very tight, with good health, a comparison of both channels will be very high (maximum). NDVI = (NIR - RED) / (NIR + RED). NDVI has a value ranging from - 1 (non vegetation) to 1 (of vegetation).(figure 7 and 8)

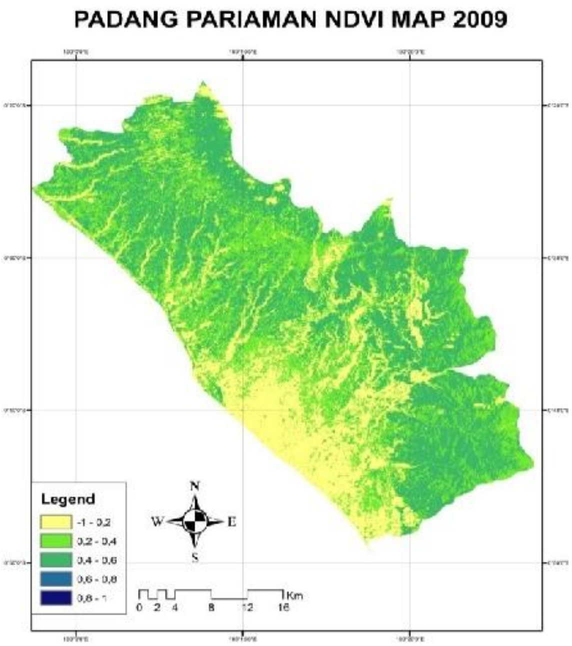

Figure 7 NDVI Map 2009

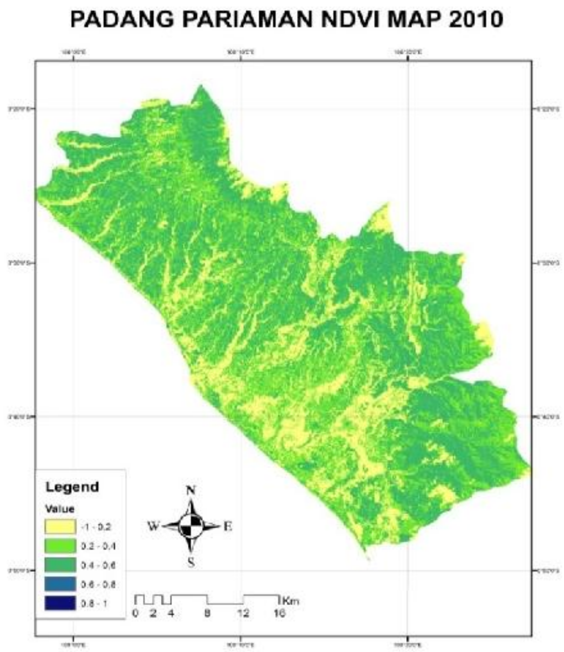

Figure 8 NDVI Map 2010

e.Aspek slopes

Slope aspect, or surface relative orientation of slope to the movement of the sun, is one factor that may affect the slopes stability. Slope look out to the sunrise and sunset will receive more radiation from the surface facing slope towards the other. The amount of solar radiation effect on the weathering of the soil (Guzzetti et al, 1999; Saha et al, 2002; Cepik and Topal, 2003).(figure 9).

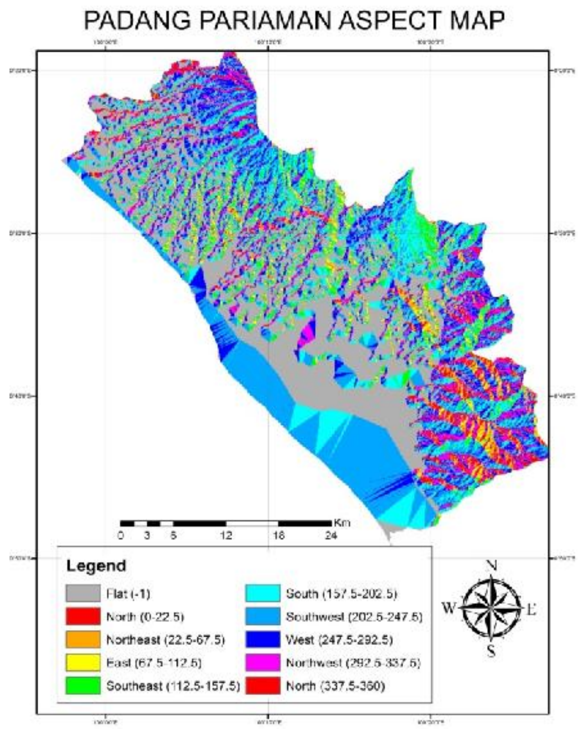

Figure 9 Slope aspect

4.Conclusions

Remote sensing and GIS technology is very useful for the integration of the data to generate Numerous landslide susceptibility maps. By using the five data of thematic layers in this study, namely, Slope, Elevation, Landuse / landcover, NDVI and Slope Aspect, The landslide susceptibility maps were produced divides the area into very high (14:28%), high (17:45%), medium (10:49 %), and low (57.78%) susceptibility zones, (Figure 10)

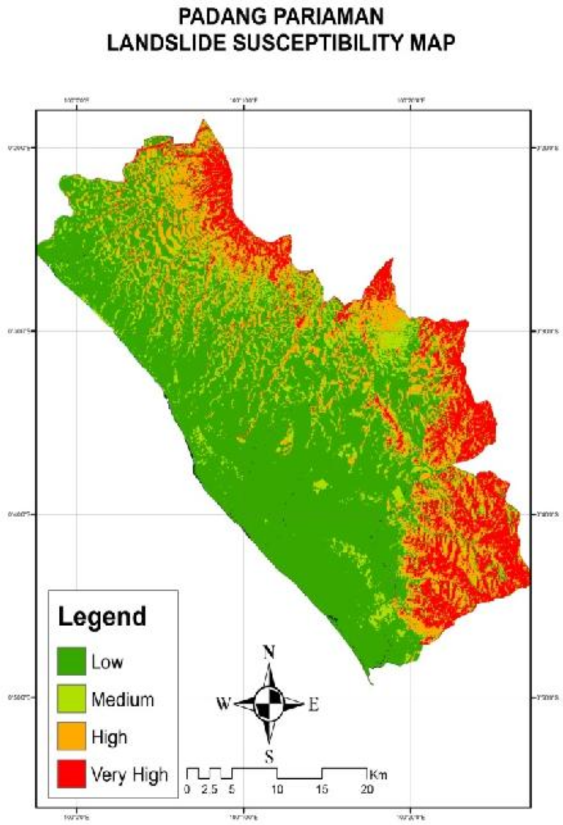

Figure 10 Landslide Susceptibility Map

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