Analysis and Risk Study on Landslide Hazard Frequency at Road Corridor of Batu City – Kediri Regency Border

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ABSTRACT

Road corridor of Kota Batu – Kediri Regency Boundary is a provincial road that has a vital function for the economic and tourism movement from and to Batu City in East Java Province. This inter-regency road is historically vulnerable to disaster events such as landslide, Kali Konto flash flood, Kelud Mountain lahar, flood inundation, etc. This research was referred to Regulation of Ministry of Public Work No.22/PRT/M/2007 on Guidelines for Spatial Planning of Landslide Vulnerable Areas and helped with Geographic Information System (GIS). Method comparison was also conducted by Meiliana (2011) with the indicators from the same regulation, and by using Landslide Hazard Assessment (LHA) method that is based on historical data. The landslide risk mapping with LHA method that is combined with analysis result from the vulnerability of moving vehicles is suggested to be the reference in mapping the mass-movement disaster risk on Indonesian road corridors. Analysis on frequency of rainfall that triggered landslide concluded that the probability of landslide occurrence (PLO) on daily rainfall was 126.2 mm, or 3 days-cumulative rainfall of 192.26 mm.

Keywords: road landslide, risk mapping, landslide inventory, frequency analysis

1 BACKGROUND

The Province of East Java has a mountainous and hilly topography that is vulnerable to landslide disaster or flash flood. The disaster events placed East Java Province on the 15th of the 2013 Indonesia Risk Disaster Index level. The landslide disaster event record in East Java showed that there were 357 landslide events on 1998-September 2016, with the total death toll of 96 lives, 4 people missing, 291 people injured, and 3087 people were displaced (Indonesian National Board for Disaster Management, 2016). The administrative areas that became the subject of this research, Malang Regency and Batu City, were ranked 9th on 2013 Indonesia Risk Disaster Index (*Indeks Risiko Bencana Indonesia-IRBI*) of entire Malang Regency, or 2nd in the provincial level.

Landslide disaster in East Java has a negative impact for its financial and economic factor, and also gives damage to its infrastructure. The landslide event record on the road corridor of Batu City – Kediri Regency Boundary took the time span of 8 years, between 2007 up to 2016. The data interpretation result showed 92 points of landslide location with 50 days event, with the peak landslide event was between January and February (82.61%).

Mapping and analysis of landslide disaster risk on road corridor of Batu City – Kediri Regency Boundary was an urgent matter, because the road area has a high landslide risk level in East Java Province. Selecting an appropriate method in mapping the disaster risk was very useful in understanding the landslide character of the landslide-prone segments.

Research on the characteristic of the rainfall that triggered the landslide in the area was also needed in order to increase the disaster resilience capacity of the road users and the policy stakeholder (Faris and Fathani, 2013).

2 LANDSLIDE RISK MITIGATION

2.1 Hazard Map of Landslide Disaster

Landslides, that cause environmental damage and economic losses and death are commonly triggered by rainfall (Laprade, et al., (2000); Salvati, et al., (2010)). The Regulation of Ministry of Public Work No.22/PRT/M/2007 divided the risk aspects into two categories, which are natural physical aspect and human activity aspect, with various accompanying indicators. The indicators on natural physical aspect are 30% for slope angle, 15% for soil condition, 20% for slope-forming rocks, 15% for rainfall, 7% for slope's water system, 3% for seismic factor, and 10% for vegetation. As for vulnerability level indicator on human activities are 10% for cropping pattern, 20% for slope cutting and excavation, 10% for pond, 10% for drainage, 20% for construction work, 20% for population density, and 10% for mitigation effort.

Meiliana (2011) conducted a modification on the indicator used in the Regulation of Ministry of Public Work No.22/PRT/M/2007, with the consideration of the risk indicator that suitable to the road corridor on her research. The research indicators on Meiliana (2011) study were 6 (six) on natural physical aspect: slope angle (30%), soil condition (15%), slope-forming rocks (20%), rainfall (15%), distance from river (7%), and vegetation (13%). The vulnerability indicators on the human activity aspects consisted of 5 indicators as follows: cropping pattern (20%), slope cutting or excavation (20%), pond (25%), population density (15%), and mitigation effort (10%).

Landslide risk mapping using the Regulation of Ministry of Public Work No.22/PRT/M/2007 did not conclude the historical element of past landslide events, even though historical record of landslide event could be used to conduct validation, identification, and mapping the characteristic of landslide distribution on a region.

Risk mapping on road corridor has been conducted by Yivru (2015) at the road corridor of Saint Lucia and Dominica, Northmore (2000) in Jamaica, Gaurav (2009) in Uttarakhand, and Eker (2014) in Turkey, as well as other researches. Yivru (2015) conducted a multi-criteria spatial approach sourced from historical data, which were named as Landslide Hazard Assessment (LHA).

The criteria for the indicators that were used in the method are as follows: (i) weight of the landslide data that was represented with per kilometer landslide density was 50%; (ii) road slope (25%); (iii) road drainage (8%); (iv) slope-forming material (17%), which each was divided into 40% of geological element and 60% soil type. The most important weight on the risk mapping element was the landslide data which was obtained from the landslide inventory data.

The landslide inventory data is very significant in the landslide study, yet it takes a long time in the process of collecting the data (Nayak, et al., 2010). Survey on landslide inventory could be conducted by using satellite imaging or direct field-mapping. Guzzetti (2012) argued that a landslide inventory map could be used for: (i) documenting landslide phenomenon on a range of areas; (ii) initial stage of creating a hazard map; (iii) conducting investigation on distribution, movement pattern, and landslide pattern related to morphology or geological characteristic; and (iv) evolution study from a regional land use.

2.2 Vulnerability on Moving Vehicles

Landslide vulnerability of a road corridor for the road users has different characteristic compared with landslide vulnerability of an area for its occupants. Residents that permanently live on a landslide-prone area have a high level of exposure, while the moving vehicle that moves through a road corridor has relative exposure level based on the length of the track, the velocity of the vehicle, type of the vehicle, and the characteristic of the occurring landslide.

Study of Pierson & van Vickle (1993) which was adopted by Guzzeti (2005), Liu (2006), Gaurav (2009), Nayak (2010), Iswar (2010), Nugroho (2012), Eker (2014) was a detailed research that discussed about the vulnerability of vehicle movement to landslide and debris hazard. Nicolet (2016) compared methods, which resulted to the conclusion that vehicle speed, vehicle distribution, vehicle dimension, velocity, landslide dimension, and track length are main elements in calculating the vehicle vulnerability

Vehicle type basically contributes to the vulnerability of the passenger. For example, the risk of victim caused by a landslide on motorcycle driver is certainly greater than a passenger in a large bus. Buwal (1999) created a method of passenger number estimation related to rock fall, by considering the lethal rate of vehicle type (Prina, et al., 2004).

2.3 Risk Analysis on Landslide-Triggering Rainfall

In general, researches agree that trigger rainfall event is a period of continuous or almost continuous rain, starts from a rain event or sudden intensity increase of a mild rain period, which then ended when the landslide occurred (Berti, 2012; Faris and Fathani, 2013; Faris and Wang, 2014).

Berti (2012) stated that the greatest uncertainty in determining threshold of the rainfall that trigger landslide lies on the determining the initial point of the trigger rain. Aleotti (2004) chose visual approach, while Frattini et al. (2009) used a lot of time frames in determining the initial point of the determinant rain.

Chleborad et al. (2006) suggested a prediction for trigger rain that causes landslide based on the cumulative rainfall threshold (CT) 3 days before the event (P_3) with 15 days of rain before the P_3 that is known as P_{15}. From the study on 577 landslide events in Seattle on year of 1978 to 2003, Chleborad et al. (2006) created a correlation between P_3 and P_{15} that is known as the lower-bound threshold of the landslide-triggering cumulative rainfall.

Huang (2015) conducted a different approach in research at Huangshan, China. Huang (2015) determined the lower-bound threshold of landslide-triggering rainfall through linear regression approach on the lowest points that represent landslide events caused by rain. The abscissa axis is the cumulative rainfall R_t (in millimeter) which is defined as cumulative rainfall for 7 days, while ordinate axis is I_h, rainfall intensity in mm/hour unit.

Huang (2015) determined *PLO*=10% for lower-bound threshold and *PLO*=90% for the upper-bound threshold. The algorithm in the straight line equation follows Equation 1 as follows:

$$R_t + \alpha . Ih = C \quad (1)$$

In which *Rt* is cumulative rainfall (mm), *Ih* = hourly rainfall intensity (mm/hr), and *C* = numeric constant

Equation 1 resulted into two *C* values, which are C_{min}, and C_{max} that each is constant value for lower-bound threshold line and upper-bound threshold line. Relation between *C* value and *PLO* was then followed by Equation 2.

$$\frac{C - C_{min}}{C_{max} - C_{min}} = \left(\frac{PLO-0}{1-0}\right)^2 = PLO^2 \quad (2)$$

By using the Equation 2, the landslide probability for each point that is located between lower-bound threshold and upper-bound threshold could be known. Huang (2015) used short-period rainfall data with certain PLO value span to determine the hazard level classification. However, hourly rainfall data was not available at the research field, therefore making it not possible to create warning status that is based on short-period rainfall data.

3 RESEARCH METHOD

This research compared 3 (three) risk mapping methods, which are: (i) Regulation of Ministry of Public Work No.22/PRT/M/2007; (ii) Regulation of Ministry of Public Work No.22/PRT/M/2007 that was modified by Meiliana (2011); and (iii) LHA method & calculation on the vulnerability of moving vehicle. Further process in the research was to analyze landslide-triggering rainfall frequency based on landslide event record between year 2007 and 2016.

Regulation of Ministry of Public Work No.22/PRT/M/2007 divides hydrogeomorphology condition of an area into 3 (three) zone typologies. The typologies are then divided based on the height span of an area:

a. Zone with high level of landslide potential if the weight value total of the measured aspect is on range of 2.40–3.00
b. Zone with medium level of landslide potential if the weight value total of the measured aspect is on range of 1.70–2.39
c. Zone with low level of landslide potential if the weight value total of the measured aspect is on range of 1.00–1.69.

The assessment on the vulnerability level of entire aspects was next conducted by averaging the measured weight value on the natural physical aspects with the measured weight value on the human activity aspects. The entire of weighting classes is shown in Table 1 and Table 2 of the Regulation of Ministry of Public Work No.22/PRT/M/2007 on the criteria and indicator of vulnerability level for zone with landslide potential type A, B, and C.

The result from Meiliana (2011) and original method from the regulation then was compared with LHA method which has been specifically applied as mapping method on a road corridor that based with historical data. The record of landslide event on the researched road corridor was on the time span of 8 years, between 2007 up to 2016. The data was obtained from the record of Office of Public Works and Highways of East Java Province, Regional Disaster Management Agency, and verified online media. Total recorded event was 92 event points with total days of 50 days. This data then would be correlated with rainfall that triggered landslide, in order to obtain threshold of the rainfall that triggered landslide as conducted by Vennari (2014).

4 RESEARCH RESULT

4.1 Geo-hydro morphology of Research Area

The analysis result from the slope vulnerability division was as shown in Table 1. The type B landslide-prone geo-hydro morphology area is located in the road segment between Km 19+500-53+000 (P26), while type C landslide-prone area is located on road segment of Km 53+000(P26)-63+890 (P36+890).

Table 1. Division of Hydrogeomorphology Classification

Hydrogeomorphology	*L* (km)	Elevation (m asl)	%
Type B Landslide-prone	33.50	500-1183	75.47
Type C Landslide-prone	10.89	196-500	24.53
Total	44.39		100

4.2 Natural Aspect

Indicators that were considered in the calculation of natural physical aspects are as follows.

4.2.1 Slope Angle

Slope angle in this research was the slope gradient that was resulted from survey of landslide inventory. The slope degree was gained by averaging right and left side of the gradient degree, by considering the nature of landslide threat on the road which does not always come from upper side (cliff side), but could also come from slope side of the road (lower side). Classification of the vulnerability of slope angle indicator is shown in Table 2. The recapitulation of vulnerability of slope angle indicator on the studied road corridor is shown in Table 3.

Table 2. Hydrogeomorphology of Type B and Type C Landslide-prone

Sensitivity	Type B gradient	Type C gradient	Weight
High	35%-40%	15%-20%	3
Medium	30%-<35%	8%-<15%	2
Low	21%-<30%	0%-<8%	1

Table 3. Recapitulation of the Vulnerability off Slope Angle Indicator

No	Vulnerability class	*L* (**k**m)	Value	%
1	High	24.80	3	55.86
2	Medium	0	2	0
3	Low	6.44	1	14.51
4	Very Low	13.15	0	29.63
	Total	44.39		100

4.2.2 Soil Type

The condition of surface soil that was passed by the studied road corridor consisted of various type of soils, granular soil, cohesive soil, and cobbles. From the map owned by related institution, data of the road trace based on the soil type is shown in Table 4.

Another method that is better in determining the sensitivity of soil type to landslide is by conducting soil type test through taking sample on the field. However, this method was difficult to be conducted in this research, due to the high number of test sample needed (time limit).

Table 4. Recapitulation of Soil Type Indicator Vulnerability

No	Soil type	*L* (km)	%	Value
1	Inceptisol	3.90	8.79	5
2	Mollisol	0.20	0.45	5
3	Brown and Yellowish Brown Complex Andosol, & Litosol	12.10	27.26	4
4	Association of Grey & Greyish Brown Alluvial	5.80	13.07	1
5	Association of Brown Andosol, Glei Humus	7.30	16.45	4
6	Complex Regosol and Litosol	15.09	33.99	5
	Total	44.39	100.00	

4.2.3 Geology

The geology map of the research area that was obtained from related institution has accuracy degree limited to the rock formation distribution. The analysis result showed data on the road trace at research area, which passed the rock formation of Old Anjasmara Mountain (Qpat) of 30,1 km length (68%), between Km 19+500-49+600. The rest, which was Km 46+600 - 63+890, passed through the rock formation of Young Anjasmara Mountain (Qpva) of 14.29 km length (32%). Because there was no detailed data on the bedrock distribution, the indicator assessment then took three maximum values. This is based on the description of high vulnerability indicator value on bedrock in Regulation of Ministry of Public Work No.22/PRT/M/2007, i.e. slope that is arranged with rocks and has many crack structures.

4.2.4 Rainfall

The Regulation of Ministry of Public Work No.22/PRT/M/2007 put weight value on landslide susceptibility caused by rainfall indicator, which is: (i) vulnerability value 3 (three)/high for yearly rainfall that is more than 2500 mm/year; (ii) value of 2 (two)/medium for yearly rainfall value between 1000-2500 mm/year; and (iii) value of 1 (one)/low for mean yearly rainfall value less than 1000 mm/year. Road segmentation based on vulnerability value caused by rainfall is as shown in Table 5 as follows.

Table 5. Rain station that were affecting the analysis

Rain Station	*L* (km)	Rainfall (mm/year)	Value
Ngaglik	4.20	1788.75	2
Pujon	6.90	2617.28	3
Kedungrejo	6.40	2487.34	2
Ngantang	10.20	4238.75	3
Jombok	8.80	3046.76	3
Kasembon	7.89	2330.82	2
Total	44.39		

4.2.5 Slope's Water System

Regulation of Ministry of Public Work No.22/PRT/M/2007 assessed slope's water system indicator based on the sighting of water or water source on the slope, particularly on the contact area between impermeable rocks with a more permeable soil layer. The observation on the studied road corridor related to slope's water system (primary survey on April 4th 2017) resulted on data which showed that the slopes do not have adequate slope drainage in order to quickly lower the water table at the event of rain. The rainwater that infiltrated into the soil in the hill eventually flowed through the crevices of rock discontinuity or between the soil layer and rocks. In the research of slope's water system indicator weight, its maximum weight to landslide susceptibility is of 3 (three).

4.2.6 Seismic Factor

On the Regulation of Ministry of Public Work No.22/PRT/M/2007, seismic indicator is measured based on frequency of an earthquake event on a certain time span. The weight of the indicator is 3 (three) for earthquake-prone area, value of 2 (two) for area with moderate frequency of earthquake, or 1-2 times in a year; and value of 1 (one) for area with event frequency under 1 (one) time in a year.

According to seismic record in 2016 up to 2017, there were 11 (eleven) earthquake events occurred in the surrounding Malang Raya area (Malang Regency, Batu City, Malang City); with intensity above 4.9 magnitude scale (USGS, 2017); therefore the area could be classified as an earthquake-prone area (seismic indicator value of 3).

4.2.7 Vegetation Type/Land Cover

Data collecting of vegetation type on the studied road corridor was conducted simultaneously with the landslide inventory survey on December 16th 2016 and February 8th 2017.

Table 6. Roadside vegetation type

No	Vegetation type	*L* (m)	%	Weight
1	Heterogenic Forest	8,100	18.25	1
2	Field	6,600	4.51	3
3	Plantation	3,300	7.43	3
4	Riverside vegetation	2,600	5.86	3
5	Pine	1,800	4.05	2
6	Paddy field	1,100	2.48	3
7	Shrubs	500	1.13	3

As shown in Table 6 and Table 7, the data were quite detailed in depicting the actual condition of the existing land use. Several landslide research often use vegetation data based on the interpretation of land cover map or land use map that are obtained from related institution. However in this research, both the land use map and the land cover map did not reflect the actual vegetation condition.

If protected forest area on between Km 20+500-23+500 uses vegetation interpretation based on land use, the vulnerability vegetation value is 1 (one) or in low tendency, because it is a forest area. However from the result of primary survey, the data obtained was that vegetation that dominates the area are pine trees that are categorized as vegetation with moderate level of vulnerability or value of 2 (two) (Regulation of Ministry of Public Work No.22/PRT/M/2007).

4.2.8 Distance from River

About 4.9 km on the left side of the road of Batu City-Kediri Regency Boundary is directly coincided with the flow of Konto River with span of < 10 m, while the right side of the road coincides with the river along 2.6 km of length. Recorded event of disaster on January 13th 2010 has collapse the main bridge, which is Ngeprih Bridge on Km 36+300 (P9+300) which caused traffic lost. Another assessment was also conducted on the stream which cut road trace by giving vulnerability weight of 3 (three).

Table 7. Recapitulation of road distance to river

No	Distance of road centerline to river, j	*L* (m)	%	Value
1	j < 25 m	4,900	11.04	3
2	25 m< j < 50 m	3,600	8.11	2
3	50 m< j < 100 m	8,200	18.47	1
4	j >100 m	27,690	62.38	0
	Total	44,390	100	

4.3 Human Activity Aspect

Main factors that always cause landslide risk are natural factor, human activity factor, or combination of both which further aggravate the landslide disaster event (Highland & Bobrowsky, 2008). Both flood disaster and landslide event geographically have close relationship with human activity (Baioni, 2011). According to Regulation of Ministry of Public Work No.22/PRT/M/2007, risk mapping that involves human activity element consists of 7 (seven) indicators as follows.

4.3.1 Cropping Pattern

The Regulation of Ministry of Public Work No.22/PRT/M/2007 identified the landslide susceptibility caused by cropping pattern through 2 (two) approaches, the approach on vegetation type suitability of the land, and approach on cropping pattern method or season. The interpretation on the vulnerability is shown in Table 8.

Table 8. Vulnerability value on cropping pattern indicator

No	Vulnerability type of cropping pattern	*L* (m)	%	Weight
1	Heterogenic Forest	8,100	18.25	1
2	Field	6,600	4.51	3
3	Plantation	3,300	7.43	3
4	Pines	1,800	4.05	2
5	Paddy Field	1,100	2.48	3
6	Shrub	500	1.13	3

4.3.2 Slope Cutting/Excavation

The primary survey on landslide inventory in December 16th 2016 concluded that the slope collapse events are mostly located at the slope cutting area. The angle of the slope cutting is considered to be fulfilling the technical requirements inadequately, therefore the slope collapse event keeps occurring. This conclusion is in line with the identification of landslide points that was conducted by Purnomo (2010). From the 34 identified points, 64% of them are located in the roadside. Identification on the field of studied road corridor showed that for 17.30 km or 37.8% of the road segment are slope cutting area that was caused by road construction (angle >45 ^{o}). From the assessment on the slope cutting indicator, the slope cutting road segment then was given value of 3 (three)/high vulnerability category.

4.3.3 Pond/Paddy Field

From the landslide inventory survey, there was no pond or paddy field to be found in the upper cliff side of the road corridor. However, the position of pond or paddy field on the studied road corridor was identified to be 800 meter of length (1.8%). The indicator of pond/paddy field forming of the road segment then was given weight of 3 (three).

4.3.4 Drainage

Drainage data on the road corridor was obtained from field survey. The road drainage on the road corridor is divided into 4 (four) categories, which are: (i) drainage with concrete layer or subsurface drainage with value of 1 (one); (ii) stone masonry drainage with value of 2 (two); (iii) soil drainage with value of 3 (three); and (iv) no drainage with vulnerability value of 4 (four). Recapitulation of the existing drainage condition on the studied road corridor is shown in Table 9.

Table 9. Vulnerability value of drainage indicator

Drainage type	*L* (m)	%	Weight
Concrete/subsurface	200	0.45	1
Stone masonry	2,700	6.08	2
Soil	16,200	36.49	3
No drainage	25,290	56.97	4
Total	44,390	100	

4.3.5 Construction Work

In this research, construction work as an indicator was interpreted as settlement building or semi-permanent building that was located along the studied road corridor. The score of the construction work indicator was interpreted from the description in the Regulation of Ministry of Public Work No.22/PRT/M/2007, which is of low value or 1 (one). Location of the built construction along the studied road corridor was interpreted from the location of the settlement area land use, which was 19890 meter (44.81%) from total length of the road corridor.

4.3.6 Population Density

In this research, classification of vulnerability value of the population density followed sub-district administrative level. The description on the Regulation of Ministry of Public Work No.22/PRT/M/2007 put the highest limit of vulnerability level on the population density is > 50 people/ha; medium level of vulnerability is 20-50 people/ha; low level of vulnerability < 20 people/ha.

4.3.7 Mitigation

The method on scoring the mitigation indicator in this research was by giving risk value of 0 (zero) on the road segment that has structural counter measurement, and risk value of 3 (three) on the road segment that does not have structural counter measurement.

4.4 Risk Analysis Result

There was difference on the risk score between the method from Regulation of Ministry of Public Work No.22/PRT/M/2007 and the method from Regulation of Ministry of Public Work No.22/PRT/M/2007 that has been modified by Meiliana (2011). Due to the removal of seismic factor indicator and slope's water system indicator, risk mapping method by modified Regulation of Ministry of Public Work No.22/PRT/M/2007 (Meiliana, 2011) gave a lower risk score result on its natural physical aspect (Table 13 and Table 14).

As for the landslide risk based on human activity aspect, the risk score resulted from method from Regulation of Ministry of Public Work No.22/PRT/M/2007 and the modified Regulation of Ministry of Public Work No.22/PRT/M/2007 by Meiliana (2011) gave an identical risk map. However, due to removal of construction work and drainage as indicators, the risk score result from the modified method by Meiliana (2011) gave higher risk score. This was because by removing those indicators, the percentage of the remaining indicators was increased (Table 13 and Table 14). From the assessment of risk mapping result from the abovementioned methods (Figure 3 and Figure 4), the resulted risk score did not depict landslide event based on historical record or landslide inventory mapping.

4.5 Landslide Hazard Assessment (LHA) Method

From the aforementioned risk scoring study, initial conclusion was that the Regulation of Ministry of Public Work No.22/PRT/M/2007 does not suitable to be used for mapping landslide risk of road with lengthwise typical (wide-scale mapping). A more appropriate approach would be landslide hazard assessment through spatial based multi-criteria evaluation. Yivru (2015) conducted the approach with criteria: (i) landslide density per kilometer with 50% weight; (ii) road slope (25%); (iii) road drainage (8%);

(iv) slope-forming material (17%); which each was divided by 40% of geological material and 60% of soil.

4.5.1 Landslide density

Landslide density is the segmentation effort from landslide distribution based on total event divided by certain units. Landslide density in this indicator was the result from analysis of landslide inventory survey on Table 1, in which then yields the landslide density value as shown in Table 10.

Table 10. Landslide density on road corridor

Road segment	Initial km	End km	*L* (km)	n	n/km
Segment 1	20+400	24+100	3.7	37	10.00
Segment 2	24+100	29+400	5.3	0	0.00
Segment 3	29+400	42+000	12.6	66	5.24
Segment 4	42+000	48+000	6.0	8	1.33
Segment 5	48+000	59+000	11.0	40	3.64
Segment 6	59+000	63+890	4.89	0	0.00

4.5.2 Slope Angle Indicator in LHA

Slope angle indicator in this research followed research from Yivru (2015). Slope angle classification is as shown in Table 11.

Table 11. Slope angle classification in LHA Method

No	Gradient (°)	*L* (m)	%	Value
1	0-5	17,390	39.18	0.50
2	5-10	2,100	4.73	1.00
3	10-20	100	0.23	1.5
4	20-30	4,400	9.91	2.00
5	30-45	4,900	11.04	2.5
6	>45	15,500	34.92	3.00
	Total	44,390	100	

4.5.3 Other Indicators in LHA

Slope-forming material indicator in LHA method used classification as shown in Table 4. As for road drainage in this method follows classification in Table 10.

4.5.4 Result of Landslide Hazard Assessment based on LHA Method

Analysis on weighting of indicators in LHA method generated an identical result of vulnerability distribution with the analysis result of landslide risk that used method from Regulation of Ministry of Public Work No.22/PRT/M/2007. Recapitulation from the LHA method is as shown in Table 12. While the LA map is shown in Figure 5.

Table 12. Classification of mapping hazard with LHA method

No	Threat level	*L* (m)	%
1	Very Low	0	0.00
2	Low	8,490	19.13
3	Moderate	9,400	21.18
4	High	8,100	18.25
5	Very High	18,400	41.45
	Total	44,390	100.00

Data in Table 12 shows that road risk mapping with LHA method produced a more detailed score span compared with method from Regulation of Ministry of Public Work No.22/PRT/M/2007. Factors of uncertainty such as river distance, vegetation, cropping pattern, slope cutting, and land use, were in fact also calculated into the analysis through the historical record data of landslide event.

4.6 Threshold of Landslide-Triggering Rainfall

According to the research of Chleborad et al. (2006) and Huang (2015), determination of the landslide-triggering rainfall was applied on the road corridor of Batu City-Kediri Regency Boundary. Both of the methods could not be applied entirely because of the limited data of the short period rain distribution in the research field. The drawing of lower-bound threshold of the landslide-triggering rainfall in this research followed the method of Huang (2015), which was by pulling regression from lowest points of the rainfall data which was considered to be representative; this is as shown in Figure 1, in which then would create linear equation that followed Equation 2. Further then, the line of *PLO* 90% was created by leaving 3 (three) rain events that were considered not a trigger for landslide. This was considered to be quite representative, since the total of sample data that was used in this analysis was 3324 days, whereas the total of *PLO* 90% events that were exceeded was well below 1%. Figure 2 shows the threshold of landslide-triggering rainfall correlation of P_0 and P_7.

As for the analysis on landslide-triggering rainfall that was described by Huang (2015), result of frequency analysis generated lower-bound threshold value equation (Probability of Landslide Occurrence, PLO 10%) $P_0 = -0{,}2524P_7 + 14{,}238$, and upper-bound equation (*PLO 90%)* $P_0 = -0.2524P_7 + 126.2$. Probability of landslide event was close to 90% on daily rainfall of 126.2 mm.

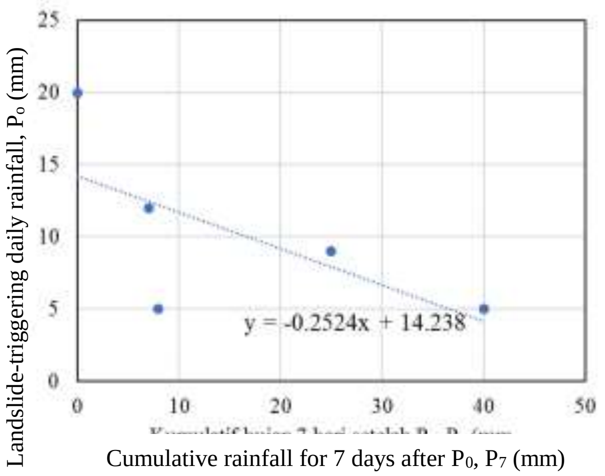

Figure 1. The withdrawing of lower-bound threshold gradient of landslide-triggering rainfall (*PLO* 10%).

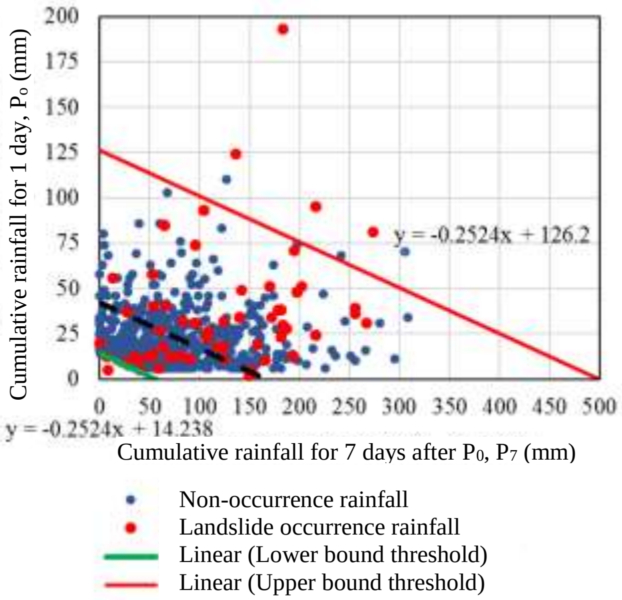

Figure 2. Threshold of landslide-triggering rainfall correlation of P_0 and P_7.

Table 13. Result recapitulation of the landslide disaster risk mapping with method from Regulation of Ministry of Public Work No.22/PRT/M/2007

No	Risk level	Natural aspect		Human activity aspect		Last risk	
		Length (m)	%	Length (m)	%	Length (m)	%
1	High	24,300	54.74	0.00	0.00	400	0.90
2	Medium	8,890	20.03	12,600	28.38	21,100	47.53
3	Low	11,200	25.23	31,790	71.62	22,890	51.57
	Total	44,390	100.00	44,390	100.00	44,390	100.00

Table 14. Result recapitulation of the landslide disaster risk mapping with method from modified Regulation of Ministry of Public Work No.22/PRT/M/2007 (Meiliana, 2011)

No	Risk level	Natural aspect		Human activity aspect		Risk	
		Length (m)	%	Length (m)	%	Length (m)	%
1	High	20,300	45.73	1,000	2.25	2,000	4.51
2	Medium	8,100	18.25	11,700	26.36	17,400	39.20
3	Low	15,990	36.02	31,690	71.39	24,990	56.30
	Total	44,390	100.00	44,390	100.00	44,390	100.00

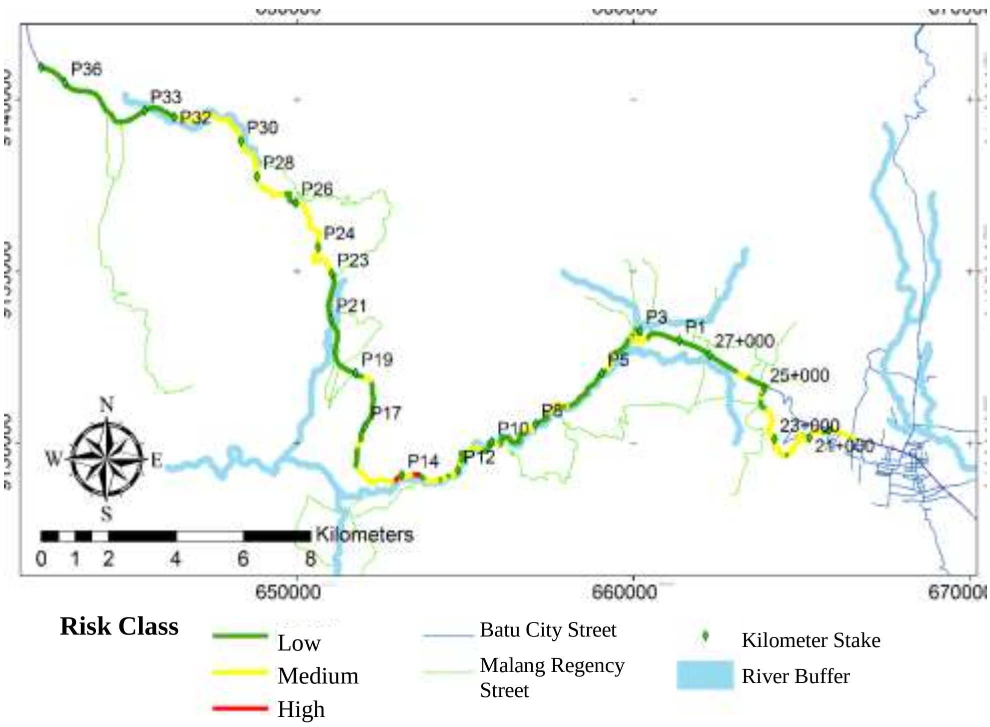

Figure 3. Landslide risk map with Regulation of Ministry of Public Work No.22/PRT/M/2007.

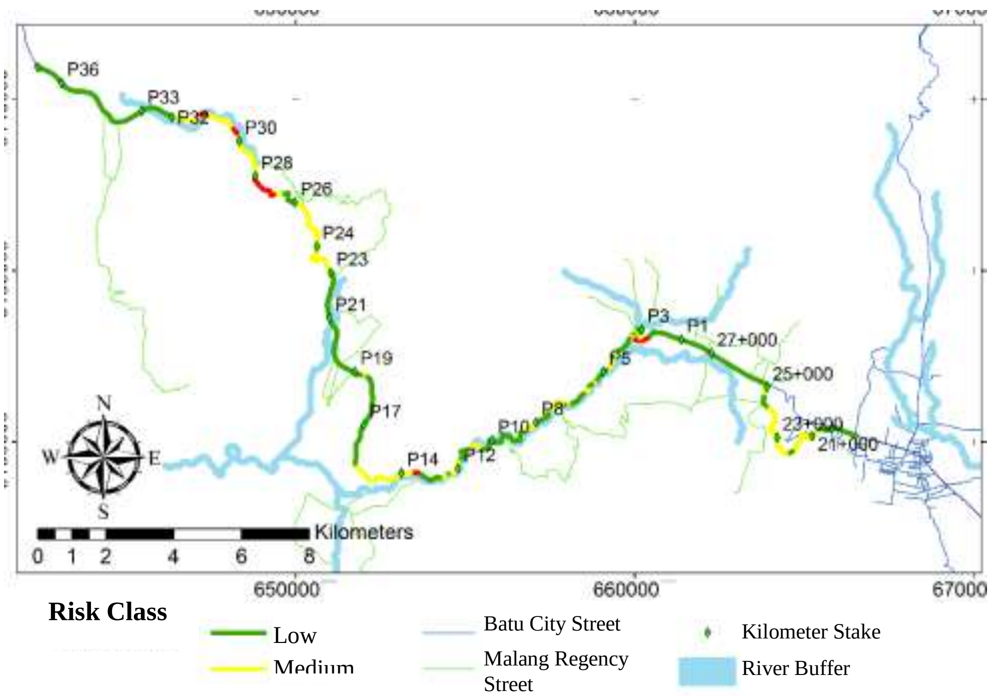

Figure 4. Landslide risk map with Regulation of Ministry of Public Work No.22/PRT/M/2007 modified by Meiliana (2011).

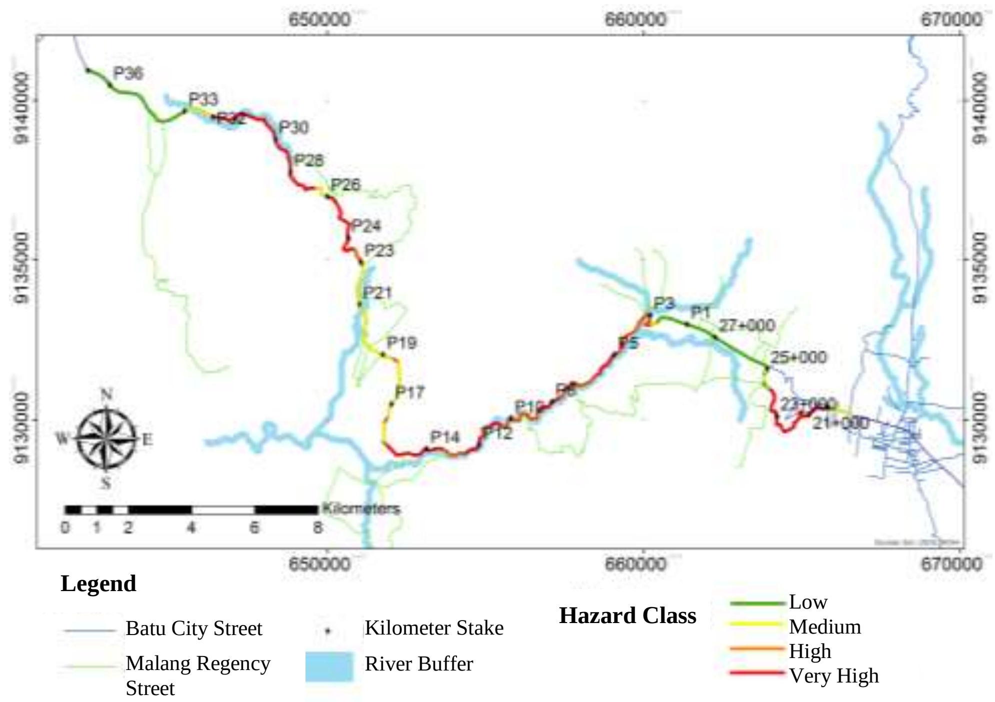

Figure 5. Landslide Hazard Assessment (LHA) map.

5 CONCLUSION

Risk mapping with method from Regulation of Ministry of Public Work No.22/PRT/M/2007 is more appropriate to be used in a region that does not have adequate record of landslide event. However, if the record of landslide event is available, historical data-based mapping would result risk value that is close to reality.

Landslide risk mapping on a road corridor would be more detailed and close to reality if it is conducted with LHA method that is combined with assessment on vehicle movement vulnerability. Historical record of landslide event on a road corridor could be used to assess financial risk on road users, including the probability of the event occurrence on certain time.

On the studied road corridor, the probability of landslide event was close to 90% on daily rainfall of 126.2 mm. The availability of gauge station for short period rainfall on landslide-prone road corridor is urgently required. This is intended to reduce landslide disaster risk through capacity building, development of early-warning system, and improving the safety of the road users.

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