Landslide risk assessment and Cost Benefit Analysis on Mitigation Measures in Bili/bili Watershed, South Sulawesi - Indonesia

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Dissertation Abstract

This dissertation proposes a new approach where the whole framework is related to find the optimal result in sediment related disaster integrated with economic analysis. Begin with evaluating the most influential factors to trigger the landslide, generate the optimal landslide susceptibility map, then continued to zoning the vegetation recovery area from the most prioritize to less priority to reduce the sediment related disaster probability, then final stage is optimization in economic terms associated with natural disaster risk.

Chapter 1. Introduction

Indonesia is situated in one of the most active disaster hot spots where several types of disaster such as earthquake, tsunami, volcanic eruption, flood, landslide, drought and forest fires frequently occur. According to a global risk analysis by the World Bank, Indonesia is among the top 35 countries that have high mortality risks from multiple hazards with about 40 percent population living in areas at risk. For a country that has more than 230 million population, this percentage gives a very large nominal number of more than 90 million population potentially at risk creating a major humanitarian catastrophe in case large disasters occur. Besides human losses, economic damage effect by disasters during the period 1980-2008 is also huge. The country suffers an annual economic damage of US $ 731,705,000 caused by disaster, with a total of US $ 21,219,450,000. This means that we need to have good strategies for predicting the likelihood of disasters and this information needs to be available for decision making when undertaking engineering projects.

Landslide is third most frequent disaster in Indonesia. Frequently, landslides occur in connection with other phenomena. For example, an earthquake can set off a landslide, which leads to a river blockage or natural dam that is vulnerable to collapse which can cause a flood downstream (Marui and Nadim, 2009: 435). Rainfall energy is the prime cause of erosion from tilled or bare land, occurring when the soil lacks protective vegetative cover. Plants shelter and fix the soil with their roots (Gysselsetal., 2005; de Baets et al., 2007a, b) reduce the energy of raindrops with their canopy (Bochet et al., 1998; Durán et al., 2007). Also, vegetation can act as a physical barrier, altering sediment flow at the soil surface (Van Dijk et al., 1996; Lee et al., 2000; Martínez et al., 2006).

The objectives of this research are (1) To evaluate the importance of each causative factors in landslide susceptibility assessments and to compare landslide susceptibility models using certainty factor and weight of evidence in Jeneberang watershed, Indonesia. For this, the occurrence of landslide was detected in the study area by field surveys and satellite imagery derived from Google Earth. (2) To comparatively evaluate the usage of certainty factor and weight of evidence to optimize causative factors in landslide susceptibility assessment in Jeneberang watershed, Indonesia. (3) To develop an improved landslide susceptibility in purpose of vegetation recovery to reduce the sediment rate in Bili bili Dam. (4) To proposed optimization procedure in economic point of view by compare all the mitigation plan for Bili bili Dam by utilize cost benefit analysis.

Chapter 2. Study Area

The study area is located in Jeneberang sub-watershed, Gowa regency, Southern part of South Sulawesi island, Indonesia. An area covered 384.81 km^2 with total population 747.753. This area was chosen because of its frequent landslides history over the past view years. In March 2004, this area experienced the gigantic collapsed of Bawakaraeng Kaldera with a volume about 235 million m^3 (width about 1600 m and length about 750 m). Sediment and debris from the landslide covered the Jeneberang river and causing many unstable slopes along the river. The climate of South Sulawesi island is tropical with two seasons within a year. Rainy season between November and May and a dry season from June to October. The temperature in the study area can reach 34°C, and average annual precipitation is from 2864 mm to 3039 mm.

<u>Part 1 : Optimization to generate a landslide map</u>

Chapter 3. The Evaluation of Influencial Factors Toward the Effective Landslide Susceptibility Map

This chapter demonstrates the usefulness of the certainty factor and weight of evidence to identifying the better-fitted conditioning factors to generate effective landslide susceptibility map. Sixteen conditioning factors has evaluated. Based on the Certainty factor (CF), eleven conditional factors (profile curvature, curvature, slope, TPI, rainfall, elevation, distance to fault, land use, distance to river, drainage density, plan curvature) have a high correlation to landslide occurrence. Meanwhile weight of evidence (WoE) applied the conditional independent test to assess the independence of each factor and produce a combination of elevation, plan curvature, lithology, distance to river, soil, SPI, and TPI as a combination with a significant correlation to trigger a landslide. Both models have a high accuracy, but the CF models has slightly higher ROC result (AUC = 90.3%, prediction = 90.2%) than WoE (AUC = 90.1%, prediction = 89.9%).

SCENARIO	FACTORS	AUC	PREDICTION ACCURACY (%)
1	ELEVATION,ASPECT,PROF CURVATURE,SPI,TPI	0.86	0.856
2	SLOPE,LUSE,SOIL	0.897	0.885
3	ELEVATION,ASPECT,PROF CURVATURE,PLAN CURVATURE,FAULT	0.825	0.798
4	CURVATURE,LITHO,LUSE,DISRIV,FAULT,SOIL,TPI	0.894	0.897
5	ELEVATION,ASPECT,PROF CURVATURE,LUSE,DISRIV,FAULT,RAIN	0.882	0.874
6	**ASPECT,PLAN CURVATURE,LITHO,LUSE,DISRIV,SOIL,SPI,TPI**	**0.901**	**0.903**
7	CURVATURE,PLAN CURVATURE,LITHO,SPI	0.87	0.866
8	PROF CURVATURE,RAIN	0	0
9	SLOPE,CURVATURE,PROF CURVATURE,PLAN CURVATURE,LUSE,TWI	0.808	0.787
10	DRAINDEN,TWI	0	0
11	CURVATURE,PROF CURVATURE,PLAN CURVATURE,DISRIV,SPI,TPI,TWI	0.835	0.881
12	ASPECT,CURVATURE,PROF CURVATURE,FAULT,TPI,TWI	0.794	0.797
13	SLOPE,CURVATURE,PLAN CURVATURE,SOIL,SPI	0.894	0.855
14	**ELEVATION,PLAN CURVATURE,LITHO,DISRIV,SOIL,SPI,TPI**	**0.901**	**0.899**
15	ELEVATION,CURVATURE,PLAN CURVATURE,DISRIV,FAULT,SPI,TPI	0.877	0.887
16	LUSE,DRAINDEN,DISRIV,FAULT,TWI	0.803	0.794

MODEL	AUC	PREDICTION ACCURACY
10 CAUSATIVE FACTOR	0.901	0.904
11 CAUSATIVE FACTOR	0.903	0.902
12 CAUSATIVE FACTOR	0.901	0.9

<u>Part 2 : Optimization in zoning a targeted area for rehabilitation</u>

Chapter 4. Improved landslide susceptibility map integrating with critical land map for revegetation priority in Jeneberang Watershed area.

This chapter shows an efforts to improve the function of the landslide susceptibility map not only to detects landslide-prone areas but also can be used as one of the supporting maps to zoning the most priority area for rehabilitation in order to reduce the erosion rate and

LS CLASS	CRITICAL LAND CLASS	Sum of Area_m2	CLASS PRIORITY
VERY LOW	1	265,397,422.63	
	UNCRITICAL	14,447,544.79	3
	POTENTIALLY CRITICAL	94,739,244.55	3
	MEDIUM CRITICAL	111,361,883.40	3
	CRITICAL	44,848,749.89	3
LOW	2	40,484,288.80	
	UNCRITICAL	8,132,643.73	3
	POTENTIALLY CRITICAL	16,284,374.83	3
	MEDIUM CRITICAL	9,290,567.55	3
	CRITICAL	6,774,592.74	3
	VERY CRITICAL	2,109.94	3
MEDIUM	3	18,332,036.46	
	UNCRITICAL	5,123,649.23	3
	POTENTIALLY CRITICAL	6,646,981.85	3
	MEDIUM CRITICAL	3,908,933.76	3
	CRITICAL	2,634,235.23	2
	VERY CRITICAL	18,236.39	2
HIGH	4	17,990,316.58	
	UNCRITICAL	5,844,235.67	3
	POTENTIALLY CRITICAL	6,049,211.92	2
	MEDIUM CRITICAL	3,814,296.45	2
	CRITICAL	2,171,792.09	1
	VERY CRITICAL	110,780.45	1
VERY HIGH	5	42,611,086.77	
	UNCRITICAL	14,188,897.24	3
	POTENTIALLY CRITICAL	7,984,025.70	2
	MEDIUM CRITICAL	12,864,476.05	2
	CRITICAL	3,557,663.96	1
	VERY CRITICAL	4,016,023.82	1
Grand Total		384,815,151.24	

susceptibility of landslides. The new map is generate by integrating an optimized landslide susceptibility map and the critical land map to zoning the area for revegetation recovery. Critical land map that employed in this study has been verified and validated by Ministry of Public Work and Pompengan Jeneberang Watershed Agency. Coding for the revegetation recovery map using the matrix relationship method. The zoning area is divided into 3 classes; first priority, second priority and third priority. First and second priority is the targeted area that need an immediate treatment for revegetation recovery plan, and third priority area is classified as an area that can be treated later after first and second priority area has implemented.

<u>Part 3 : Optimization in Economic sector</u>

Chapter 5. Investigation of flood and landslide in the Jeneberang catchment area, Indonesia in 2019.

This chapter shows the impact of reduction of bili bili dam effectivity as a flood control. On January 22, 2019, ten regencies in the province of South Sulawesi experienced an extreme flood. The Jeneberang River is one of the major rivers and has the most extensive impact on flooding. Bili-bili Dam is a multipurpose dam located on Jeneberang River, Gowa regency. The heavy rainfall that occurred on January 22 was marked by heavy rainfall from January 21 to January 23. The peak rainfall recorded at three measuring stations including 329 mm at Lengkese station, 308 mm at Bawakaraeng station, and 328 mm at Limbungan station. The flood downstream was a result of the river basin not being able to accommodate the water discharge from the spillway dam which related to decreasing of dam capacity caused by siltation in dam. Landslides in some area also occurred and caused a flash flood in the sub-watershed of Kampala and destroyed a bridge downstream. Landslides with extensive impacts occurred in the settlement area and buried half of the village in Pattalikang. Total of damage cost by flood and landslide for 3 regencies (directly impacted by Bili bili Dam) is 611 billion rupiah.

Chapter 6. Application of Cost Benefit Analysis related to natural disaster for Selecting the Optimal risk reduction scenario

This chapter shows an optimization in economic terms associated with natural disaster risk. It starts with the calculation of the lifetime of the reservoir using dead storage volume approach then the cost benefit analysis (CBA) was utilized to compare the costs and benefits of proposed three scenarios. The differences between conventional CBA is the "risk reduction" is count as the value of benefits. There are three scenarios are considerable to reduce the sediment level in Bili-bili dam;

1. **Scenario 1 (Dredging work vol 82.000 m^3/year – existing condition)**
2. **Scenario 2 (Dredging work vol. 246.000 m^3/year)**
3. **Scenario 3 (Dredging work vol 82.000 m^3/year and aerial bomb seeding)**

All benefits and costs should be expressed in discounted present values. Costs and benefits have to be compared in order to be able to derive at a decision (BCR). Scenario with a benefit-cost ratio greater than 1 have greater benefits than costs, hence they have positive net benefits. The higher the ratio, the greater the benefits relative to the costs. The result of the calculation of service time and effectivity, scenario 3 (existing dredging + revegetation) shows an increase in dam effectiveness and reduced sedimentation rates in the dam.

While all scenarios provide a net positive outcome, the NPV and BCR methods provide slightly different outcomes. Using NPV suggests project scenario 2 provides the best outcome as the NPV of ¥ 16,692,837,000 is greater than the NPV of scenarios 1 and 3. However, when using the BCR method, scenario 3 has the highest a BCR of 16.9.

In this case, the overall result of the cost–benefit analysis may be determined by considering the costs involved in scenario 2, which are much greater, or may be determined by considering the much greater overall benefits (in monetary terms) obtained by choosing scenario 2. So in my humble opinion, I considered to choose the scenario 3 as a best option. Because In this case, the decision maker is a government, not a private sector. So their final decision is not only considering about the benefit in economic aspect but also the benefit for the society. The CBA result shows the every scenario offer a positive outcome, but the scenario 3 has an additional value, benefit in environment aspect which not calculated in CBA but we can see the positive trend from the effectivity calculation.

Variable	Without dredging	Scenario 1	Scenario 2	Scenario 3		
				2%	5%	10%
Remaining service life	17.82	22	25	34	35	37
Additional service life		3.92	7.02	12.34	17.34	19.29
Effectivity		18%	28%	36%	49%	52%
Finish Operating	2,048	2,052	2,055	2,064	2,065	2,067

Scenario			Present Value		Risk Reduction Benefit	BC Ratio	B-C
Alternatives	Efective age	Interest Rate	Cost	Benefit			
Scenario 1	22	4	¥ 589,519,070	¥ 8,250,567,695		14.0	¥ 7,661,048,625
Vol. 82.000 m3		5	¥ 725,880,023	¥ 7,521,491,208		10.4	¥ 6,795,611,185
		6	¥ 892,021,369	¥ 6,885,934,494		7.7	¥ 5,993,913,125
		7	¥ 1,094,070,194	¥ 6,329,652,307		5.8	¥ 5,235,582,113
		8	¥ 1,339,338,232	¥ 5,840,813,400		4.4	¥ 4,501,475,168
		9	¥ 1,636,536,524	¥ 5,409,558,789		3.3	¥ 3,773,022,265
		10	¥ 1,996,026,409	¥ 5,027,645,878		2.5	¥ 3,031,619,468
Scenario 2	25	4	¥ 1,701,632,781	¥ 18,394,469,781	¥ 1,683,333,846	11.8	¥ 16,692,837,000
Vol. 246.000 m3		5	¥ 2,158,305,557	¥ 16,603,223,104	¥ 1,683,333,846	8.5	¥ 14,444,917,547
		6	¥ 2,731,375,154	¥ 15,065,796,164	¥ 1,683,333,846	6.1	¥ 12,334,421,010
		7	¥ 3,448,970,652	¥ 13,739,530,564	¥ 1,683,333,846	4.5	¥ 10,290,559,912
		8	¥ 4,345,654,834	¥ 12,589,724,412	¥ 1,683,333,846	3.3	¥ 8,244,069,577
		9	¥ 5,463,814,104	¥ 11,588,034,387	¥ 1,683,333,846	2.4	¥ 6,124,220,284
		10	¥ 6,855,331,404	¥ 10,711,217,724	¥ 1,683,333,846	1.8	¥ 3,855,886,320
Scenario 3	34	4	¥ 1,076,986,003	¥ 16,370,899,861	¥ 1,796,061,538	16.9	¥ 15,293,913,857
Existing + Veg2%		5	¥ 1,492,295,118	¥ 14,395,397,454	¥ 1,796,061,538	10.9	¥ 12,903,102,336
		6	¥ 2,061,373,808	¥ 12,770,937,154	¥ 1,796,061,538	7.1	¥ 10,709,563,346
		7	¥ 2,838,843,029	¥ 11,423,444,319	¥ 1,796,061,538	4.7	¥ 8,584,601,290
		8	¥ 3,897,921,658	¥ 10,296,141,061	¥ 1,796,061,538	3.1	¥ 6,398,219,402
		9	¥ 5,336,490,824	¥ 9,345,217,272	¥ 1,796,061,538	2.1	¥ 4,008,726,448
		10	¥ 7,285,050,074	¥ 8,536,643,165	¥ 1,796,061,538	1.4	¥ 1,251,593,091