THESIS

ANALYZING AND ESTIMATING LANDSLIDE RISK IMPACT TO ROAD

A CASE STUDY IN SAMIGALUH DISTRICT, KULON PROGO REGENCY, YOGYAKARTA PROVINCE

Thesis submitted to the Double Degree M.Sc. Programme,
Gadjah Mada University and Faculty of Geo-Information Science and Earth Observation, University of Twente in partial fulfillment of the requirement for the degree of Master of Science in Geo-Information for Spatial Planning and Risk Management

UGM

ITC

By :

Eko Setya Nugroho
GMU : 10/307100/PMU/06743
ITC : 27679 AES

Supervisors :
Dr. Danang Sri Hadmoko, M.Sc (GMU)

Dr. C.J. (Cees) Van Westen (ITC)

Drs. N.C. (Nanette) Kingma (ITC)

GRADUATE SCHOOL
GADJAH MADA UNIVERSITY
FACULTY OF GEO-INFORMATION AND EARTH OBSERVATION
UNIVERSITY OF TWENTE
2012

THESIS

ANALYZING AND ESTIMATING LANDSLIDE RISK IMPACT TO ROAD
A CASE STUDY IN SAMIGALUH DISTRICT, KULON PROGO REGENCY, YOGYAKARTA PROVINCE

Prepared by
Eko Setya Nugroho
GMU : 10/307100/PMU/06743
ITC : 27679 AES

was defended before the Board of Examiner
on the date 6th March 2012

Board of Examiners

Supervisor 1

Dr. Danang Sri Hadmoko, M.Sc
Supervisor UGM

Supervisor 2

Dr. C.J. (Cees) Van Westen
Supervisor ITC

Supervisor 3

Drs. N.C. (Nanette) Kingma
Supervisor ITC

ITC Examiner

Dr. M. (Mark) van der Meijde

External Examiner

Prof. Dr. Junun Sartohadi, M.Sc

This thesis was declared acceptable
to obtain the master degree
Date ...13 MAR 2012

Program Director of Geo-Information for
Spatial Planning and Risk Management

Prof. Dr. H.A. Sudibyakto, M.S.
NIP. 19560805 198303 1 004

Approved by
Vice Director for Academic Affairs,
Development and Cooperation

Prof. Ir. Suryo Purwono, MA.Sc., Ph.D.
NIP. 19611119 198601 1 001

DEDICATED TO……

- *My lovely wife: **E**lna **M**ulti **A**stuti*
- *My two sweet daughters:*

***T**sabita **A**ulia **Z**ahra & **T**saqifa **A**ulia **N**aura*

DISCLAIMER

This document describe work undertaken as part of a program of study at the Double Degree International Program of Geo-Information for Spatial Planning and Risk Management, a Joint Educational Program of Gadjah Mada University, Indonesia and Faculty of Geo-Information Science and Earth Observation, University of Twente, the Netherlands. All views and opinion expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Yogyakarta,   March 2012

Eko Setya Nugroho

ANALYZING AND ESTIMATING LANDSLIDE RISK IMPACT TO ROAD IN SAMIGALUH DISTRICT, KULON PROGO REGENCY

Eko Setya Nugroho[1], Danang Sri Hadmoko[2], Cees van Westen[2], Nanette Kingma[2]

ABSTRACT

Due to many factors favoring the occurrence of landslides: steep slopes, high rainfall, breccia rock, and landuse type (low vegetation density and the dominance of shallow-fiber root vegetation system), road segment 174 has the highest of landslide susceptibility among 21 road segments in Samigaluh. This research aims to analyze and estimate the impact of landslide risk to road in Samigaluh District. The impact of landslide both direct and indirect impact were analyzed in the road segment 174. In this study, direct risk assessment was developed for various scenarios on the basis of hazard (e.g. spatial probability, temporal probability and magnitude class), vulnerability and estimating cost of road damage. Indirect risk assessment was derived from traffic interruption. It was used network analysis and community perception to determine the optimal road which was chosen by commuter

The research results show the highest direct impact of debris slide type of magnitude I located in the 20th mapping unit which is Rp. 89,586.69, Rp. 243,995.46 and Rp. 370,414.67 for return period 1 yr, 3 yr and 5 yr respectively. The lowest direct impact of debris slide type of magnitude I can be founded in the 18th mapping unit having Rp. 0.04, Rp. 0.11 and Rp. 0.17 for return period 1 yr, 3 yr and 5 yr respectively. The direct impact of rock fall type of magnitude I which is located in the 6th mapping unit is Rp. 3,976.34, Rp. 9,897.32 and Rp. 13,866.27 for return period 1 yr, 3 yr and 5 yr respectively. Meanwhile, indirect impact which was caused by road blockage is Rp. 4,593,607.20 and Rp. 4,692,794.40 by using network analysis and community perception methods respectively. After class classification, road segment 174 is dominated by very low hazard, very low vulnerability and very low direct impact. This condition compatible with the Jaiswal's Landslide Magnitude Classification that magnitude I have less hazard probability occurrence and cause minor damage

Key Words: road segment, landslide hazard, road vulnerability, direct impact, indirect impact.

1) Geo-Information for Spatial Planning and Risk Management Student 2010/2011

2) Supervisor

ACKNOWLEDGEMENT

First of all, author admires and thanks to Alloh SWT in which author can complete a thesis. This research had been supported by many people and institution. Herewith, I gratefully acknowledge and thank to people and institution which give important contribution.

To Rector of Gadjah Mada University, for supporting and giving opportunities to study in Gadjah Mada University.

To Director of Graduate School and Dean of the Geography Faculty Gadjah Mada University, for the opportunities to follow the master program and all facilities to support my study.

To Bappenas, Pusbindiklatren and Neso, for giving scholarship to achieve higher education in Gadjah Mada University, Indonesia and Faculty of Geo-Information Science and Earth Observation (ITC), Twente University, The Netherlands.

To Local Government of Kulon Progo Regency, especially Agriculture and Forestry Office Kulon Progo Regency, for giving permission to continue my study.

To Director of Geo-Info Program, Prof.Dr. Sudibyakto, M.S, thank for his advice and direction.

To my GMU and ITC supervisors, Dr. Danang Sri Hadmoko, M.Sc (GMU), Dr. C.J. (Cees) Van Westen (ITC) and Drs. N.C. (Nanette) Kingma (ITC), thank for their attention, comment and direction.

To all lecturer and staff in Gadjah Mada University and ITC-Twente University, especially Prof. Dr. Junun Sartohadi, Drs. R Voskuil, Dr. David G Rossiter, Drs. Tom Loran, Drs. Michiel Damen and all lecturer and staff that I couldn't mention one by one.

To all staff of Geoinfo Program and Graduate School Program, especially Mbak Indri, Mbak Tutik, Mas Wawan, and Mbak Wiwin, for their helping and information. Also, to all my friends "Batch VI", thank for supporting my study and togetherness in love and grief.

To DPU, Bappeda, Kesbanglinmas, BPBD, Kebonharjo Village Office and citizens of Kebonharjo Village, for giving information and data related with my study.

To my parents and parents in law, for their praying to make me smoothly in my education. To my lovely wife, Elna Multi Astuti and also my two sweet daughters, Tsabita Aulia Zahra and Tsaqifa Aulia Naura, who are a source of my inspiration and passion for author in completing this thesis.

Yogyakarta, March 2012

Eko Setya Nugroho

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS

BPS	Badan Pusat Statistik (Central Statistical Agency)
DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Geographic Position System
USGS	United States Geological Survey
AGSO	Australian Geological Survey Organisation
UNDRO	United Nations Disaster Relief Organization
BAKOSURTANAL	Badan Koordinasi Survei dan Pemetaan Nasional (National Coordinating Agency for Survey and Mapping)
BAPPEDA	Badan Perencanaan dan Pembangunan Daerah (Local Agency for Planning and Development)
BMKG	Badan Meteorologi Klimatologi dan Geofisika (The Meteorology, Climatology and Geophysics Agency)
KESBANG LINMAS	Kesatuan Bangsa dan Perlindungan Masyarakat (Agency for National Unity and Community Protection)
Desa	Village
Balai Desa	Village Office
Dusun	Sub Village
SDN	Sekolah Dasar Negeri (Sate Elementary School)
MU	Mapping Unit
KORAMIL	Komando Rayon Militer (Military Command at the District Level)

I. INTRODUCTION

1.1 Background

Indonesia is an area that lies at the meeting of the Eurasian and Indo Australian plate and is in the ring of fire, making the area prone to disaster Indonesian volcanoes, earthquakes and tsunamis. Due to its climatic setting as humid tropical areas, Indonesia has high intensity and frequency of rainfall, making Indonesia as the prone area for landslide. Landslide is one disaster that often occurs in Indonesia, which claimed many lives, destroyed buildings and infrastructure, and caused economic and environmental loss.

Actually, Samigaluh District is situated on the Menoreh Limestone Mountain, which is susceptible to landslide. This is caused by several factors such as: steep slopes, humid climate, earthquakes occurrence and human activity (mining, heavy development, agriculture) (Hadmoko et.al, 2010). Landslides occur from year to year and dominate natural disaster in Kulon Progo Regency. Based on the percentage of catastrophic events in 2009, it can be known that landslide of 59.1%, flooding of 4.5% and hurricanes as much as 36.4%, respectively. (Data obtained from the Kesbang Linmas Office Kulon Progo).

Landslides in Samigaluh generate a large amount of damage and even loss of life. The damage and loss are in form of material damage to houses, farmland, public facilities, and a large number of the main economic activities. Landslides also cause damage to the road network. According to (ANTARA News, May 31 th,2010) at least three houses were damaged and hundreds of people were isolated after a landslide destroyed the main road in Sidoharjo, Samigaluh, Kulonprogo, Yogyakarta, Sunday morning May 30th, 2010. Landslides closed the access road connecting among Kalibawang, Samigaluh, Muntilan and Wates. Villagers have to turn to move to another village at a distance of 10 kilometers. Heavy rain which flushed the last few days caused landslides in Balong, Banjarsari Gunung Kucir, Samigaluh. As a result of this landslide caused the road damage.(Kedaulatan Rakyat News, September 24th, 2010).

Road network is as a vital infrastructure to support local development. Road will support transportation and provide benefits in the wider community, economic development and ease of mobility of people, goods and services resulting in increased regional competitiveness and success of development. The availability of road network has a very strong relationship with regional growth rates among others, marked by economic growth and prosperity. Samigaluh District located in the furthest distant from the center of government and economic center of Kulon Progo Regency. It really needs the existence of the road network to support regional development and open access to the surrounding area.

Generally, many road networks were built by cutting slope. This condition caused the reducing of slope stability. Many landslide occurrences were caused by cutting slopes for roads, railways and housing (Hardiyatmo, 2006). Vibration due to transportation (especially vehicles carrying heavy loads) can trigger landslide occurrence on the streets. Based on data recorded from Kantor Kesbang Linmas Kulon Progo Regency in 2010, the most of landslide hit road which are 26 events (54.17%) are located in Samigaluh District. Based on those facts above, this research was focused on landslide risk impact to road in Samigaluh District.

1.2. Research Problem

Actually, road networks in Samigaluh District were susceptible to landslide. In 2010, several roads have been destroyed by landslide (Table 1.1 and Figure 1.1). Roads damage due to landslides caused losses both direct and indirect impacts. The direct impacts are cost in road reconstruction, cost for removing mass movement on the road. Indirect impacts affected the disruption of economic activity, social, educational, delay in travel time which can cause the disruption of regional development. Commonly, indirect impacts would result in greater losses than the direct impact.

Table 1.1: Road damaged due to landslide in Samigaluh District in 2010

NO	Date of Occurrences	Sub Village	Village	Road Affected
1	**2**	**3**	**4**	**5**
1	Jan 25th 2010	Pengos	Gerbosari	Village Road
2	March 7th 2010	Ngroto	Gerbosari	Village Road
3	March 7th 2010	Manggis	Gerbosari	Village Road
4	March 7th 2010	Jeruk	Gerbosari	Village Road
5	March 7th 2010	Clumprit	Gerbosari	Village Road
6	March 7th 2010	Ketaon	Gerbosari	Village Road
7	March 7th 2010	Kaliapak	Banjarsari	Village Road
8	March 7th 2010	Balong I	Banjarsari	Village Road
9	March 7th 2010	Waru X	Banjarsari	Village Road
10	March 7th 2010	Ngaran	Banjarsari	Regency Road
11	March 7th 2010	Kleben	Kebonharjo	Regency Road
12	March 7th 2010	Pringtali	Kebonharjo	Regency Road
13	March 7th 2010	Pelem	Kebonharjo	Regency Road
14	March 7th 2010	Pringtali Rt 15/06	Kebonharjo	Regency Road
15	March 7th 2010	Kleben Rt 24/10	Kebonharjo	Regency Road
16	March 7th 2010	Kaliduren Rt 09/03	Kebonharjo	Village Road
17	March 7th 2010	Dangsambuh Rt 20/09	Kebonharjo	Regency Road
18	March 7th 2010	Jarakan Rt 04/02	Kebonharjo	Regency Road
19	March 7th 2010	Gebang 19/09	Sidoharjo	Regency Road
20	March 7th 2010	Jeringan Rt 12/05	Gerbosari	Village Road
21	May 16th 2010	Trayu	Ngargosari	Regency Road

Table 1.1: Continue

1	2	3	4	5
22	May 30th 2010	Gn Kendil	Sidoharjo	Regency Road
23	May 30th 2010	Puncak Suroloyo	Gerbosari	Regency Road
24	May 30th 2010	Sidoharjo	Sidoharjo	Regency Road
25	Sept 6th 2010	Keceme	Gerbosari	Regency Road
26	Sept 8th 2010	Balong V	Banjarsari	Regency Road

(Source: Kesbang Linmas Office Kulon Progo)

Figure 1.1: Road damaged due to landslide in Samigaluh District. A) Landslide covered Suroloyo road, Gerbosari in 2011, B) Suroloyo road, Gerbosari damaged due to landslide in 2011, C) Road damaged due to landslide in Balong, Banjarsari Samigaluh in 2010. (Source: KRjogja.com), D) Landslide type of rock fall that hit the regency road in Kebonharjo, Samigaluh in 2011. (A, B, D Source: Eko Setya N, 2011)

In this study, the estimation of landslide impact to road considers the comprehensive estimation including the direct impact and indirect impact estimation as well. Besides that, the assessment of landslide impact used quantitative method which quantifies landslide probabilities (spatial probabilities & temporal probabilities). (Abella, 2008) stated quantitative method based on probabilities or percentage of losses expected. The assessment of landslide impact to road using this method is very limited in Indonesia, especially in Kulon Progo Regency. By using this method, the comprehensive estimations of landslide impact to road can be assessed and predicted. Due to this reason, it was necessary to estimate the impact of landslide risk to road in Samigaluh District, Kulon Progo Regency.

1.3. Research Objective

The general objective of the research is to estimate the landslide risk impact to road in Samigaluh District. More detailed objectives are as follows:

- To assess level of landslide hazard to road network.
- To assess landslide vulnerability of road network.
- To estimate the landslide risk direct impact to road.
- To estimate the landslide risk indirect impact to road.

1.4. Research Question

Table 1.2: Research objective and research question

No	Research objectives	Research questions
1	2	3
1.	To assess level of landslide hazard to road.	a. What factors lead to hazard? b. How is spatial probability distributed on the road network? c. How is temporal probability distributed on the road network? d. Which level of landslide hazard is on the road network?

Table 1.2: Continue

1	2	3
2.	To assess landslide vulnerability to road network	a. How is spatial characteristic vulnerability of road network? b. Which level of vulnerability is on the road network?
3.	To estimate the landslide risk direct impact to road	a. How hazard and vulnerability can be combined for direct risk assessment? b. How much the direct risk value can be estimated on road network? c. Which level of landslide direct impact is on the road network?
4.	To estimate the landslide risk indirect impact to road	a. What kind of vehicles type can influence the indirect risk value? b. How much the indirect risk value due to road blockage?

1.5. Scope of Research

The assessment of road damage due to landslides is focused on regency roads and provincial roads, because these roads have an important role as access and facilities to support the development and its distribution. Damage which affects these road types will cause big loss and negative impact on regional development. The impact of landslide to road is focused on road having the highest landslide density (susceptibility). In this road, it will be analyzed the direct and indirect impact of landslide.

II. LITERATURE REVIEW

2.1. Landslide

Landslide is mass movement on slope involving rock fall, debris flow, topples, and sliding (Vernes et al, 1984). Gravity is the main driving force behind mass wasting processes. Gravity will pull on material and force to downhill (Kusky, 2008). Those two definitions stated that landslide deal with mass movement which includes rock fall, topples, debris flow and sliding. It which occurs on slope is influenced by gravitation. Landslide occurs as result of the presence of saturated clay materials on the impermeable layer on steep slopes (Arsyad, 1989). The presence of soil moisture leads the increasing of the pore water pressure and lessens the material stability.

Landslide is one of the most natural disasters occurring in the mountainous area in the wet tropics and climate. Damage is caused by the movement not only direct damage, but also the indirect damage that cripples economic activity and development (Hardiyatmo, 2006). This definition stated that landslide frequently occurs in tropic zone in which high both of quantity and quality of rainfall deal with the increasing of landslide events. Besides that, landslide causes several damages which include direct damage and indirect damage (impact).

According to (Highland et al, 2008), there are 5 (five) main types of landslides, namely:

1. Falls

It is the movement of rock or soil or both of them on a very steep slope to ramp slope, or the free fall movement of rock or soil with little contact on the surface.

Figure 2.1: Shematic view rock fall ((Highland et al, 2008) and photo of rack fall in Samigaluh Disrtict in 2011(Eko Setya N, 2011)

Landslide fall type has a very fast motion and free fall. The material moves generally in the form of rocks, boulders and rock fragments. Characteristics that appear on the type of fall are a large rock slid down the slope, the bottom of the rock slide is a material which is less compact or easily decomposed (*Figure 2.1*).

2. Topples

It is the movement of rock or soil or both of them, on a very steep slope to ramps slope, or rock or soil movement in free fall with a major mass movement that involves the rotation to the front of the rock mass.

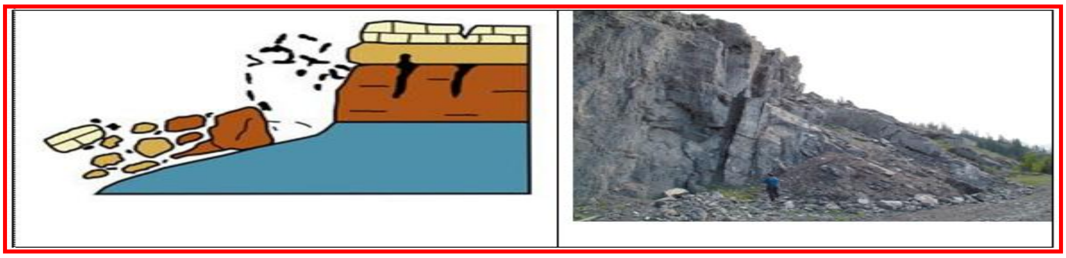


Figure 2.2. Shematic view and photo of topples in Canada (Highland et al, 2008)

Topples has the same type with the type of fall that has very fast movement, but topples has fall rotation. The material moves generally in the form of rocks, boulders and rock fragments. Characteristics which appear on the type of fall are a large rock slid down the slope, the bottom of the rock slide is a material which is less compact or easily decomposed (Figure 2.2).

3. Slide

This type represents ground movement, debris, or rock which move very fast, so that there is soil or rock mass transfer along the surface. Type of slide is divided into two categories:

a. Rotational slide

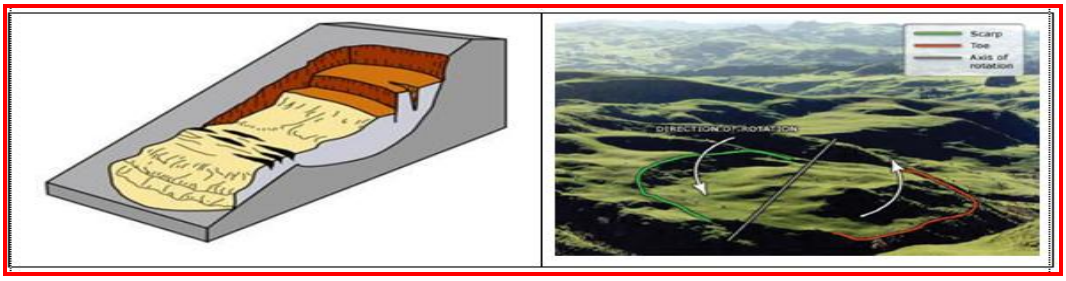


Figure 2.3. Shematic view and photo of rotational slide in New Zeland (Highland et al, 2008)

b. Translational slide

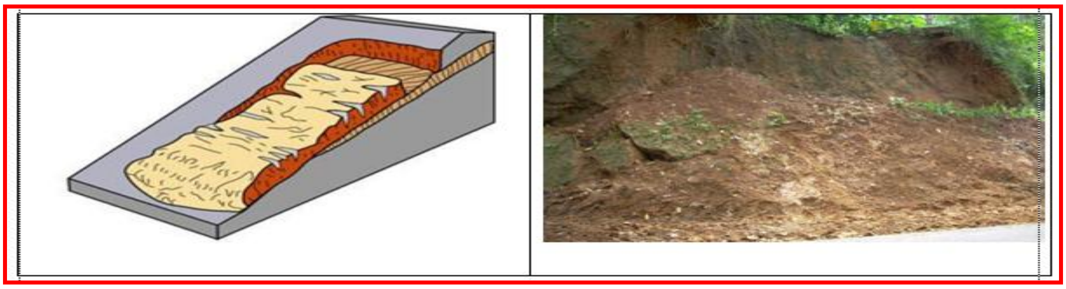


Figure 2.4. Shematic view of translational slide (Highland et al, 2008) and photo of translational slide in Samigaluh in 2011 (Eko Setya N, 2011)

Characteristics of landslides as shown in (Figure 2.3 and 2.4), there is the fault on a hilltop, the appearance of seepage or springs between weathered and water-resistant material, landslide soil mass in the form of soil material mixed with clay loam, there usually is crack under fault, and density of vegetation and terrace is not perfect.

4. Spread

It is the mass movement of soil or rock caused by the saturation of material below (Figure 2.5).

Figure 2.5. Shematic view and photo of spread in California, USA in 1989 (Highland et al, 2008)

5. Creep

The movement of soil or rock material down to a slope that is very slow and difficult to identify. Characteristics for this creep type are the emergence of cracks in the construction of roads or houses, railway embankments, destroyed bridges on the road or railroad embankments (Figure 2.6).

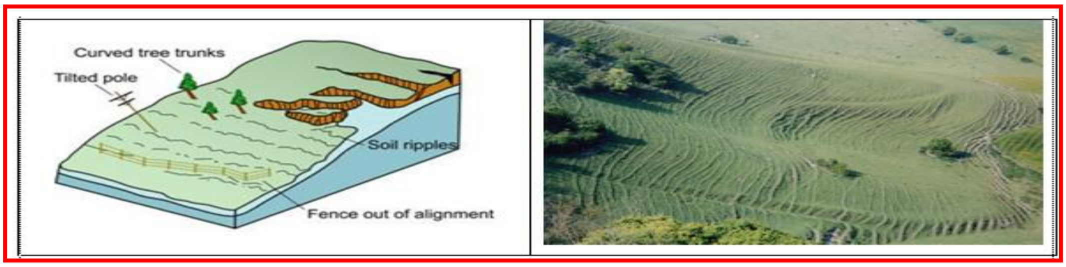


Figure 2.6. Shematic view and photo of creep in UK (Highland et al, 2008)

Many factors, such as geological and hydrological conditions, topography, climate and weather changes, may affect the stability of the slope in a landslide. Landslide occurs rarely for one reason alone. The causes of landslides were categorized into geological causes, morphological causes and human causes by (USGS, 2004) in (Table 2.1):

Table 2.1: The various causes of landslides (USGS, 2004)

Geological Causes	**Morphological Causes**	**Human Causes**
1	2	3
a. Weak or sensitive materials.	a. Tectonic or volcanic uplift.	a. Excavation of slope or its toe
b. Weathered materials.	b. Glacial rebound.	b. Loading of slope or its crest.
c. Sheared, jointed, or fissured materials.	c. Fluvial, wave, or glacial erosion of slope toe or lateral margins.	c. Drawdown (of reservoirs).
d. Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth).	d. Subterranean erosion (solution, piping).	d. Deforestation.
e. Contrast in permeability and/or stiffness of materials	e. Deposition loading slope or its crest.	e. Irrigation.
	f. Vegetation removal (by fire, drought).	f. Mining.
	g. Thawing.	g. Artificial vibration.
	h. Freeze-and-thaw weathering.	h. Water leakage from utilities
	i. Shrink-and-swell weathering	

Source: USGS, 2004

2.2. Hazard, Vulnerability and Risk

2.2.1. Hazard

Hazard is a potentially physical damage, human activity which can cause death or injury and damage of property, social, economic, and environmental. This event has an occurrence probability in a specified period and in certain areas, and intensity (Van Westen et al, 2009). (Coppola, 2007) stated hazard is a source of potential damage to a community which includes population, private & public property, infrastructure, environment and businesses. These definitions stated that hazard is a threat to people and the things value (property, infrastructure, facilities etc). In this study, roads were categorized as infrastructure and the landslide hazard threaten the existence of road. In this case, the landslide hazard arises from human activity which cut the contour to build roads. This activity can cause the reducing of slope stability. Hazard has 3 components which are probability within specified period (temporal probability), probability within certain areas (spatial probability), and an intensity (magnitude). In other definition, (Chakraborty, 2008) stated hazard includes parameters which are location related to question “where”, time related to “when” and the size to “how”. This definition explains that spatial probability (location) can answer the place of occurrence (where?), temporal probability (time) is used in order to answer the time of occurrence (when?) and magnitude (size) can answer (how?). According to (Varnes, 1984) landslide hazard consists of two major elements, namely landslide spatial probability and landslide temporal probability which is related to the magnitude, return period of the triggering event and the occurrence of landslides

2.2.1.1. Spatial Probability

(Chakraborty, 2008) distinguished the landslide spatial probability methods which were classified as direct method and indirect method. The direct method uses geomorphological mapping deal with past and present landslide events and then zonation is created in area in which failure frequently occur. Otherwise, indirect method can be divided as two methods, namely heuristic method (knowledge driven) and statistic method (data driven). Heuristic method considers landslide influencing factor such as, slope, rock type, landform and landuse and then is ranked or weighted based on the influence of causing mass movement. In statistical method, spatial probability is determined based on the relationship with the past/present landslide distribution (Carara et.al, 1991). To compose landslide hazard map in Menoreh Limestone was used five parameter maps, namely slope map, landuse map, geological map, soil map and landform map (Hadmoko et al, 2010). In this study, author uses heuristic method and considers several factors to create mapping unit, namely; slope, and landuse in which those factors will influence landslide event.

2.2.1.2. Temporal Probability

Temporal probability is the probability of occurrence of landslide event in a particular time steps (Chakraborty, 2008). Temporal probability can be derived from several methods. (Jaiswal et al, 2009) distinguished temporal probability method which are physically threshold based model and empirical rainfall threshold methods. In the physical threshold-based model, it uses certain features of the local terrain (e.g. slope, gradient, soil depth, lithology) based on a dynamic hydrological model where the most important variable is rainfall. Otherwise, empirical rainfall threshold method is method to measure temporal probability based on the calculation of rainfall threshold causing landslides. The other method is gumbel extreme value distribution which uses maximum annual rainfall. By using this method, it can be known the relationship between the temporal probability and time periods. This method was used by (Wahono, 2010) to determine landslide temporal probability in Wadaslintang, Central Java. Temporal probability can be determined by using poisson probability model, this method was used by (Chakraborty, 2008) and (Nayak, 2010) to calculate temporal probability of landslide in India. The poisson probability model is a continuous-time model consisting of random-point events that occur independently in ordinary time, which is considered naturally continuous (Nayak, 2010)

2.2.1.3. Magnitude

Magnitude deal with the amount of energy released during the hazardous event, or it shows the hazard size. By using a scale, consisting of classes, and related to a (logarithmic) increase of energy, magnitude can be indicated (Van Westen et al, 2009). Landslides magnitude which is as a factor to determine the amount of damage on each element in the risk of landslides within a specified time is the most important element in assessing the risk of landslides. Magnitude can be determined by several methods. One of the methods was proposed by (Malamud et al, 2004). He calculated magnitude based on some equation which used several variables (events number, total volume of landslide, and landslide total area). The other method was proposed by Jaiswal, (Nayak, 2010). In this method, he tried to quantify landslide magnitude for each types of landslide which was used to determine landslide magnitude on road corridor. The magnitude class was classified based on volume, type and characteristics of landslides (location, potential for damage, human perception and field investigations).

2.2.2. Vulnerability

Vulnerability is the degree of loss of certain elements at risk which is caused by the natural phenomena of a given certain size (magnitude) and shown in a scale from 0 (= no damage) to 1 (= total loss). -UNDRO. (Thywissen, 2006). This definition tries to quantify vulnerability by giving scale from 0 to 1 based on the level of damage. (Coppala, 2007) stated transportation systems (roads, highway, railroad, publict transportation) which are affacted by hazard, can be categorized as physical vulnerability. According to (Dai et al 2002) landslide vulnerability concept mainly depends on run out distance, volume of landslide, sliding velocity, the element at risk, the nature of the element at risk type and proximity to a slide. This concept explains several factors that influence landslide vulnerability. Based on (Berdica, 2002), the vulnerability of the road transport system relates to the incident, which may reduce the functionality of the road network. This means the failure of the service function road in operating condition at given time (non-reliability)**.** This definition stated road transport vulnerability is associated with decreased the road service function because of certain incident.

Several methods were used to determine road vulnerability, (Abella, 2008) used vulnerability values from 0.5 to 1 which were assigned to each road type. These values represent a financial loss when a landslide hit the road. This means that the high cost of road construction (such as high way) have a vulnerability value of 0.5, because these roads will have a stronger construction to protect landslide event. In other hand, the low cost road construction (such as trail, path) have vulnerability value 1, because both of the road type have worst construction to face landslide. AGSO 2001 make vulnerability scale from 0.3 to 1 based on slope. High vulnerability (score 1), if road lies on slope > 25^o. And low vulnerability (score 0.3), if road lies on slope < 25^o. This concept based on previous research in Cairn, Queensland that roads on slope > 25^o will totally damage due to landslide event given score 1. Otherwise, roads on slope < 25^o show that every 5 km road length will damage 1-2 km due to landslide and given value 0.3. (Ebta, 2008)

2.2.3. Risk

Risk which consists of three elements, namely, vulnerability, hazard and exposure is the possibility of damage or loss. Element of risk associated with each other, when one of the elements increases, the risk will increase, and vice versa (Thywissen, 2006). (Coppola, 2007) stated risk is the likelihood of an event multiplied by the consequence of that event. The term of “likelihood” can be given as a probability or a frequency. (Vernes et al, 1984) explained risk is the expected degree of loss which can be caused particular natural phenomenon. It is showed by the product of hazard times vulnerability. These definitions above explain risk elements, which will influence the risk value.

Several methods propose to determine landslide risk. (Abella, 2008) distinguished risk based on the level of quantification; there are the landslide risk assessment methods in qualitative, semi quantitative and quantitative. Qualitative methods based on risk classes which are categorized by expert judgment. Risk classes: high, moderate and low; Semi-quantitative based on ranking weighted by given criteria. Risk index: ranked value (0-1, 0-10 or 0-100);. Quantitative based on probabilities or percentage of losses expected. Risk value: probabilistic values (0-1) over certain amount of monetary or human loss. According to (Coppala, 2007) qualitative analysis uses definition to describe and determine risk. Quantitative analysis uses mathematical and/or statistical data to calculate risk. (Van Westen, 2006) explained some expert have made consensus about classification of landslide risk approach, there are four approaches which are landslide inventory-based probabilistic approach, heuristic approach, statistical and deterministic approach. Landslide inventory-based probabilistic approach, it can be determined by using landslide historical events which can be used as the main input in hazard assessment. Heuristic approach can be divided into 2 methods, namely: direct method based on the experience of experts by considering geomorphologic mapping, and indirect methods using combination with a heuristic approach. Statistical approach can be divided into 2 methods which are bivariate statistical analysis based on weights of evidence modeling by testing the factors of landslide susceptibility, and multivariate statistics. Deterministic approach based on slope stability models which can be used to determine safety factors.

2.3. Road Network, Road Classification, and Road Network Analysis

2.3.1. Road Network

According to (Indonesian Republic Laws of the road no. 38, 2004) the road network system is an integral link that connects to each other growth centers and deal with a territory which is under the influence of a hierarchical relationship. This definition stated that the road is a means of land transportation as well as all the equipment to support a traffic transportation, which includes both the transport in the surface or underground. Rail way and cable transportation aren’t included in this definition. The road network is a unitary relationship road that has a role in supporting development, particularly in linking the development of growth centers with each other (Indonesian Republic Laws of the road no. 38, 2004).

Roads as the transportation infrastructure is one of the pulses of public life have an important role in the development of regime. Within this framework, the road has a role to realize the goals of development such as distribution of development and its results, economic growth, and realization of social justice for all Indonesian people. (Indonesian Republic Laws of the road no. 38, 2004).

2.3.2. Road Classification

According to (Indonesian Republic Laws of the road no. 38, 2004) roads are distinguished by considering function and status. According to their functions roads are grouped into arterial roads, collector roads, local roads, and environment road;

a. Arterial road is public roads with the main function to serve the major transportation which has characteristics such as; travel distance, high average speed, and limited number of entrance in the most efficient.
b. Collector road is public roads which has function to serve freight collector or deal with the characteristics of medium-range travel, medium average speed, and the limited number of driveway.
c. Local road is public roads having function to serve local transportation with the characteristics of travel a short distance, low average speed, and the number of entry is not restricted.
d. Environment road is public roads having function to serve transport environment with close distance travel characteristics, and low average speed.

According to their status are grouped into national roads, provincial roads, district roads, urban roads and rural roads.

a. National road is the arterial roads and collector roads in the primary road network system linking the provincial capital, and the national strategic roads and highways.

b. Provincial roads are collector roads in the primary road network system connecting the provincial capital with regency capital, or between the capital of regency, and provincial strategic road.
c. Regency roads connecting the capital of regency with the capital of district, between the capitals of district, the capital of regency with local activity centers, inter-local activity centers, as well as public roads in the secondary road network system in the regency, and regency strategic roads.
d. The city roads are public roads in the secondary road network system which connects the service centers in the city, connecting with a Persil service center, connecting between the Persil, and the relationship between the central settlements within the city.
e. Village roads are public roads which connect the region and / or between the settlements in the villages, and road environment.

2.3.3. Road Network Analysis

Actually, landslide can cause road network blockage in which vehicles or commuters can't pass this road segment. As a result, vehicles or commuters will find the optimal alternative way to achieve their destination. In this case, landslide was assumed as barrier/constraint which closed travel to across the road network. In order to determine optimal route, it can be done by using network analysis. Network analysis, as in transportation or project scheduling, is a mathematical method of analyzing complex problems, which will represent the problem as a network of lines and nodes (http://dictionary.reference.com). In the other definition, network analysis is the mathematical analysis of complex working procedures in terms of a network of related activities (http://oxforddictionaries.com).

In the last decade, GIS is widely used to analyze network in term of routing and allocation applications. Routing aims to find the optimal path between two nodes in the network and to minimize the travel costs involved in transporting goods / people from one location to another whether in terms of trips required or distance or a combination of these (Nijagunappa et al, 2007).

(Curtin, 2007) stated that in GIS software, there are four fundamental operations deal with network analysis, such as : finding a route between point locations, determining the service area for a facility, finding the closest facility across the network and creating an origin–destination matrix. (Vinod et al, 2003) used GIS to analyze the characteristics of transport network in Kasaragod Taluk, Kasaragod district of Northern Kerala, India. Network application (analysis) requires a network that is vector basis and topologically connected. Network analysis can assist in solving location allocation and transportation planning such as shortest path analysis, closest facility, allocation (service area), location-allocation, urban transportation planning model. Some applications are directly accessible through command in a GIS package (Kang et al, 2010). In this study, optimal route can be found by using GIS deal with network analysis tools. Optimal route deal with optimal condition (shortest distance, fastest speed and lowest cost) obtained by passengers who pass the road segment.

2.4. Landslide Risk to Road

Landslides risk to road can be divided into direct and indirect impact. (Smith, 1992) stated that direct loss (impact) is the first order consequences which occurs after an event, such as death, injuries, cost of repair building, cleanup cost,. Meanwhile indirect loss (impact) is consequence occurring later to the event, such as: loss of income, reduction in business, mental illness, bereavement. These impacts related with the cost of each element at risk. Among the attributes of the element at risk are the cost associated with each element in disaster as the total value, cost recovery and cost of service interruptions. In other definition, (Abella, 2008) distinguished the impact of the landslides risk to the road become a direct impact such as road repair costs, and indirect impacts related to disruption of transport disruption (road service). (Coburn et al, 1994) have classified the costs become tangible cost and intangible cost depend on their possibility to be quantified. (Zezere et al, 2007) stated direct impacts included the cost of replacement, repair of reconstruction, and maintenance of property or infrastructure damaged by landslides. Otherwise, indirect impacts deal with the disruption of transportation systems, business, loss of tax revenues, reduced property values, loss of productivity, loss of tourism losses and litigation. (Nayak, 2010) consider road and vehicle type on the road to calculate direct risk impact. Meanwhile indirect risk impact was calculated based on time during for road blockage and profit for particular type of shop. In this study, the landslide risk direct impact to road was done in term of road construction cost and cost of removing landslide mass. And the landslide risk indirect impact to road was calculated by considering costs of fuel purchases due to road blockage.

III. STUDY AREA

3.1. Administrative Location

Samigaluh District which lies between 110° 7' 00"E - 110° 13' 00" E and 7° 38' 40"S - 7° 43' 15" S, is one of the most northern districts in Kulon Progo Regency, Yogyakarta Special Region. Administratively, Samigaluh District has boundary such as (Figure 3.1):

- Southern : Girimulyo District and Kalibawang District, Kulon Progo Regency, Yogyakarta
- Eastern : Kalibawang District, Kulon Progo Regency, Yogyakarta
- Northern : Salaman District, Borobudur District Magelang Regency, Central Java.
- Western : Bener District, Kaligesing District and Loano District, Purworejo Regency, Central Java.

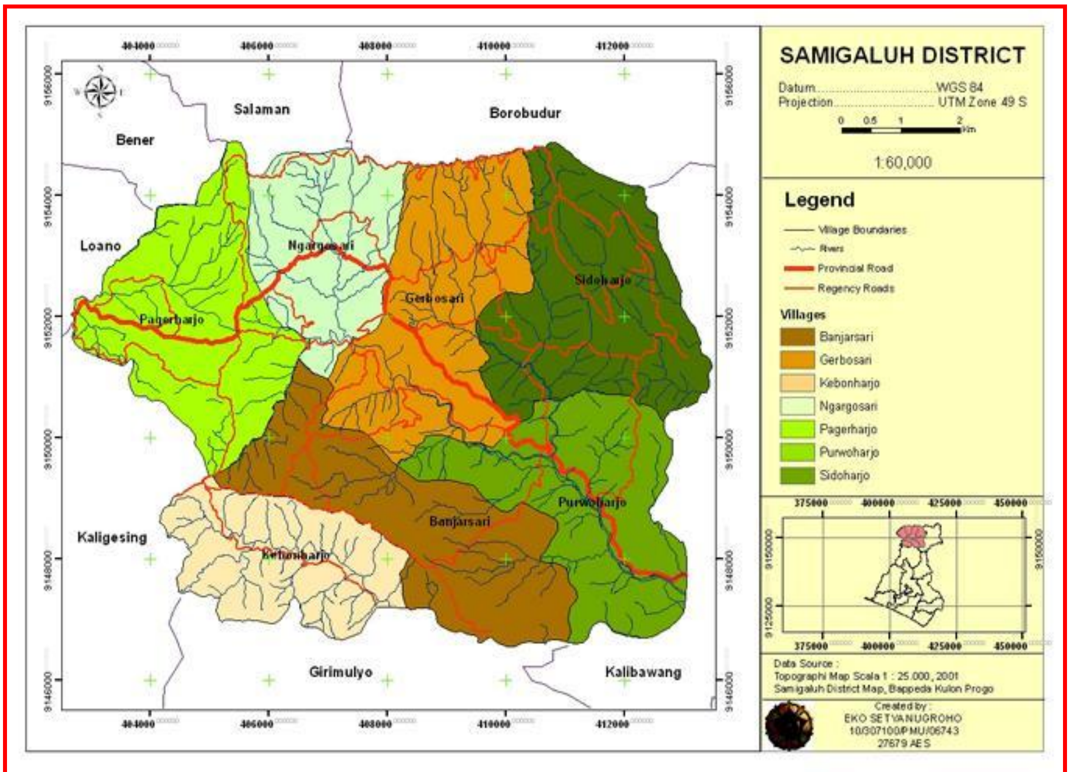


Figure 3.1: Samigaluh District Map (Source: BAKOSURTANAL)

Samigaluh District has a total area of 6,736.78 Ha which consists of 7 villages (e.g. Pagerharjo 1,055.98 Ha, Ngargosari 715.48 Ha, Gerbosari 1,093.65 Ha, Banjarsari 1,043.04 Ha, Sidoharjo 1,115.84 Ha, Purwoharjo 1,003.61 Ha and Kebonharjo 709.18 Ha). (Source: Data Analysis). Samigaluh is very strategic location, because it is located at the cross roads of trade traffic between Yogyakarta Province and Central Java Province.

3.2. Road Networks

Samigaluh road networks consist of provincial roads, district roads and village roads. In this study, road networks were restricted on provincial roads and regency roads only. Map of Samigaluh road networks can be seen in (Figure 3.2)

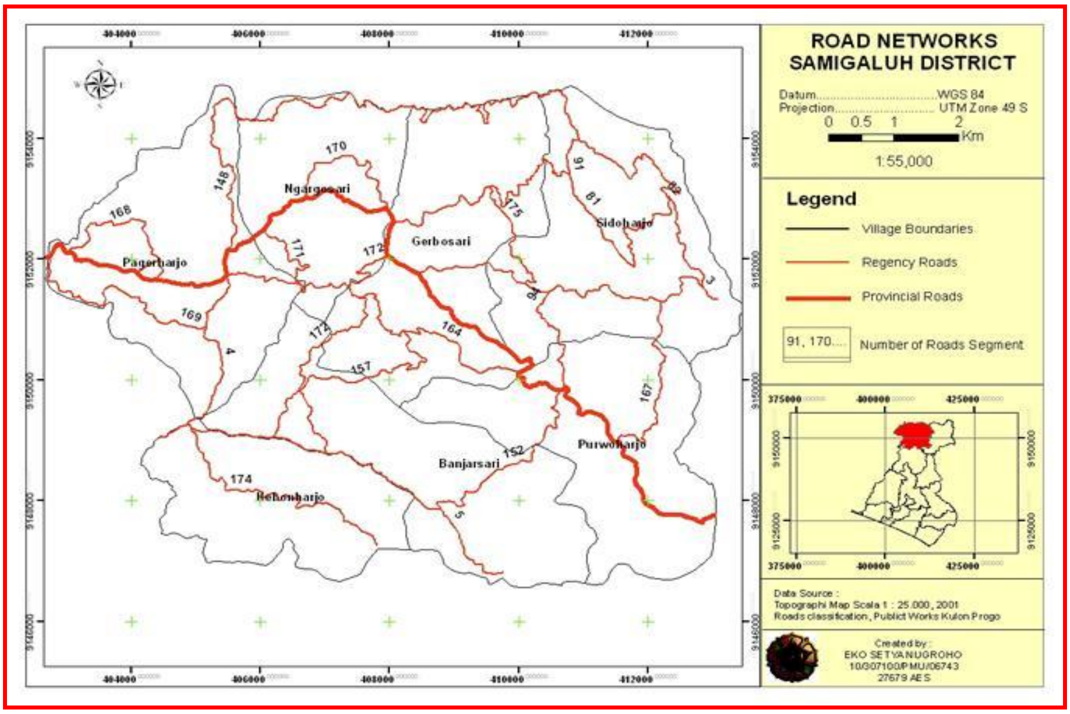


Figure 3.2: Roads network Samigaluh District map (Source: Public Works Office Kulon Progo Regency)

Based on the road network map above, road tracking was done to ensure and measure the actual road network in the field. The results of tracking and the length of each road segments were known through Arc GIS 9.3, it can be known the road length for each type and shown in (Table. 3.1)

Table 3.1: Road network in Samigaluh District

Road Type	Segment	Connecting	Length (Km)
1	2	3	4
Provincial Road		Kulon Progo - Purworejo	15.82
Regency Road	5	Simpang Ngori-Nogosari	6.73
Regency Road	4	Serguyu-Ngori	3.06
Regency Road	164	Pengos-Serguyu	6.48
Regency Road	152	Balong-Keji	3.70
Regency Road	169	Kalirejo Selatan-Kaliancar	3.92
Regency Road	3	Gerbosari-Boro	6.02
Regency Road	94	Keji-Sulur	2.06
Regency Road	170	Ktr Pos Samigaluh- BD Ngargosari	2.69
Regency Road	91	Ngaliyan-Nglambur	6.54
Regency Road	168	Pasar Plono-Sinogo	2.90
Regency Road	28	Ngaglik-Pagerharjo	0.43
Regency Road	148	Nglambur-Ps Plono	11.33
Regency Road	82	Nglambur-Munggang Wetan	5.98
Regency Road	171	Pucung-Petet	1.81
Regency Road	157	Ngroto-SD Bendo	4.95
Regency Road	172	Clumprit-Pasar Bendo	4.46
Regency Road	174	Pringtali-Jarakan	4.85
Regency Road	175	Sulur-Manggermalang	2.26
Regency Road	81	Nglambur-Madigondo	3.01
Regency Road	167	Munggang Wetan-Tukharjo	3.43
Total Length			**102.42**

Source: Data Analysis

3.3. Slope

Slope classifications based on score which shows the influence level on the landslide hazard. The higher score the higher level of influence on the landslide hazard. (Hadmoko et.al, 2010) used this slope classification to determine landslide hazard in Menoreh Limestone Mountain. The slope composition and classification can be seen in (Table 3.2). In study area, slope class is dominated by > 45 % covering 29.76 % from total area. This class spreads almost on all of village. The least slope class is 8 % – 15 % which covers

13.82 % from total area. The slope classes of 8 % – 15 % and < 8 % cover on the south east of Samigaluh District. (Figure 3.3) describes spatially slope distribution in Samigaluh District.

Table 3.2: Slope composition and classification in Samigaluh District

No	Slope Classes	Score	Area (Ha)	Percentage (%)
1	2	3	4	5
1.	< 8 %	1	1,326.49	19.68
2.	8-15 %	2	930.78	13.82
3.	15-25 %	3	1,062.26	15.77
4.	25-45 %	4	1,412.66	20.97
5.	> 45 %	5	2,004.59	29.76
Total			**6,736.78**	**100.00**

Source: Data Analysis

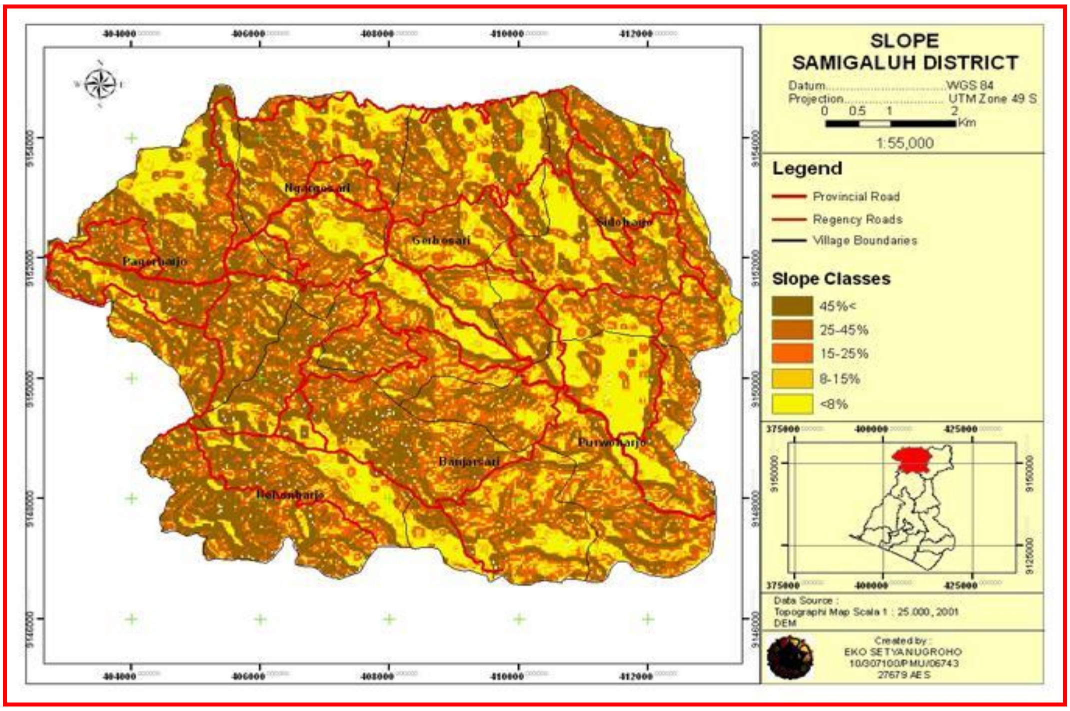


Figure 3.3: Slope Samigaluh District map (Source: DEM)

3.4. Rainfall

Rainfall is the climatic variables which affect the level of landslide susceptibility areas. Rainfall data in the study area was determined based on the four rain stations namely: Samigaluh rain station (Samigaluh District), Singkung rain station (Girimulyo District), and Gejakan rain station (Kalibawang District) and Maron rain station (Loano, Purworejo). Data used were rainfall data from year 2001 to year 2010. (Figure 3.4) is the average monthly rainfall and annual rainfall of Samigaluh District which was obtained from four rain stations. Samigaluh rain station is the only station that lies within Samigaluh District. From those stations, we can know that the average monthly rainfall in Samigaluh District can reach 262.62 mm/month.

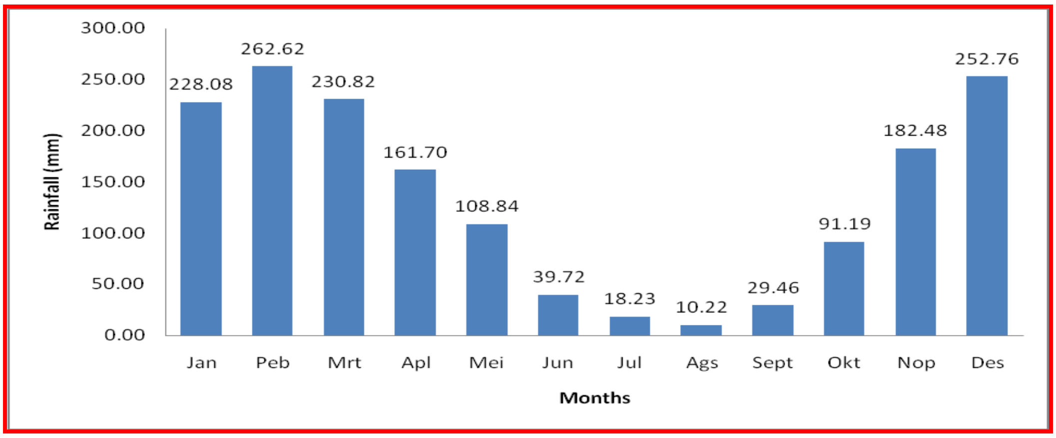


Figure 3.4: Average monthly rainfall of Samigaluh District (2001-2010)

Especially, the landslides occurred during five rainy months (January, February, March, November, and December). This is because the rainfall that falls on the last five months has ranges of average precipitation between 182 until 262 mm / month.

Isohyets method was used to illustrate the condition of rainfall in the study area. Isohyets method is good method which can be used to depict the study area, because topography can be accommodated. Isohyets method is a line in the map which connects places having the same amount of rainfall during a certain period. Isohyets line can be obtained by using cumulative maximum 3 antecedent days of rainfall during 10 years (2001 – 2010) which is considered as rainfall inducing landslide. Isohyets map in Samigaluh District and the distribution of 4 rain stations can be seen in (Figure 3.5). (Jaiswal et al, 2009) used 3 antecedent days of rainfall to determine shallow landslides hazard in India.

Serayu Opak Progo Watershed Bureau which is technical implementation unit of Indonesian Ministry of Forestry has used a Standard Operational Procedure (SOP) to determine landslide hazard. One of the parameters used are the cumulative daily rainfall of three consecutive days. Then, the cumulative daily rainfall of three consecutive days was classified as the (Table 3.3):

Table 3.3: Rainfall classification

No	Ranging (mm)	Classes Description
1	**2**	**3**
1	< 50	Low
2	50 - 99	Almost Low
3	100 - 199	Moderate
4	200 - 300	Almost High
5	> 300	High

Source: SOP of Serayu Opak Progo Watershed Bureau

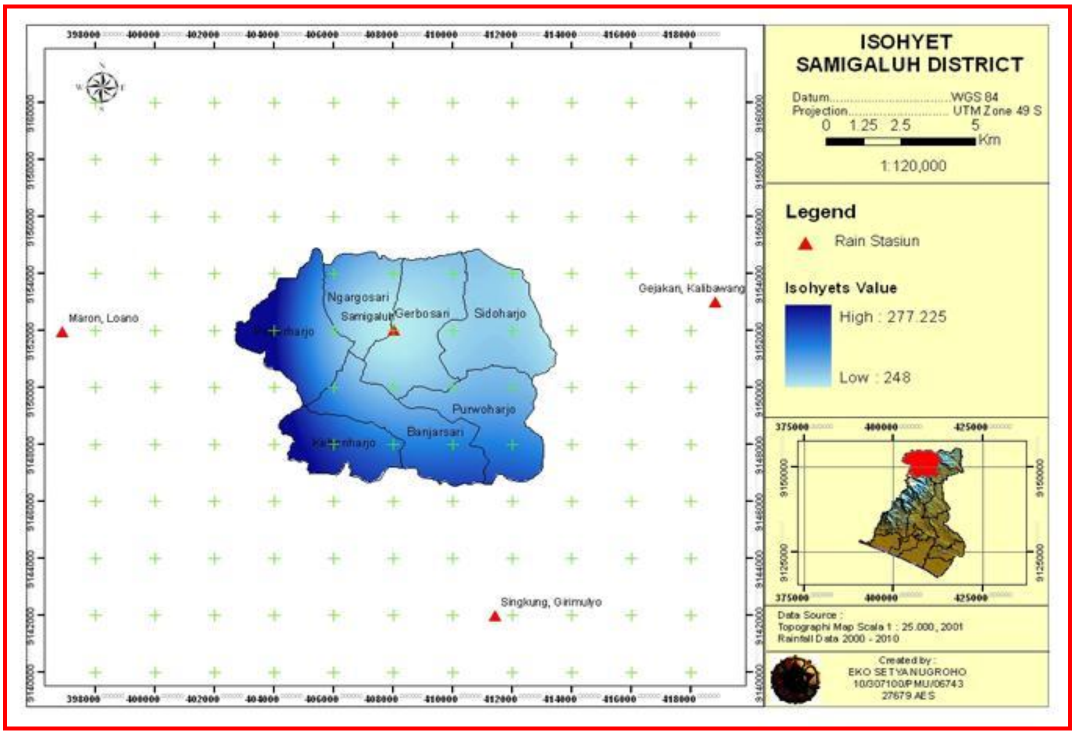


Figure 3.5: Isohyets Samigaluh District map

Based on the classification above, Samigaluh District has rainfall value ranging between 248 mm - 277 mm which can be categorized as almost high class (Figure 3.6).

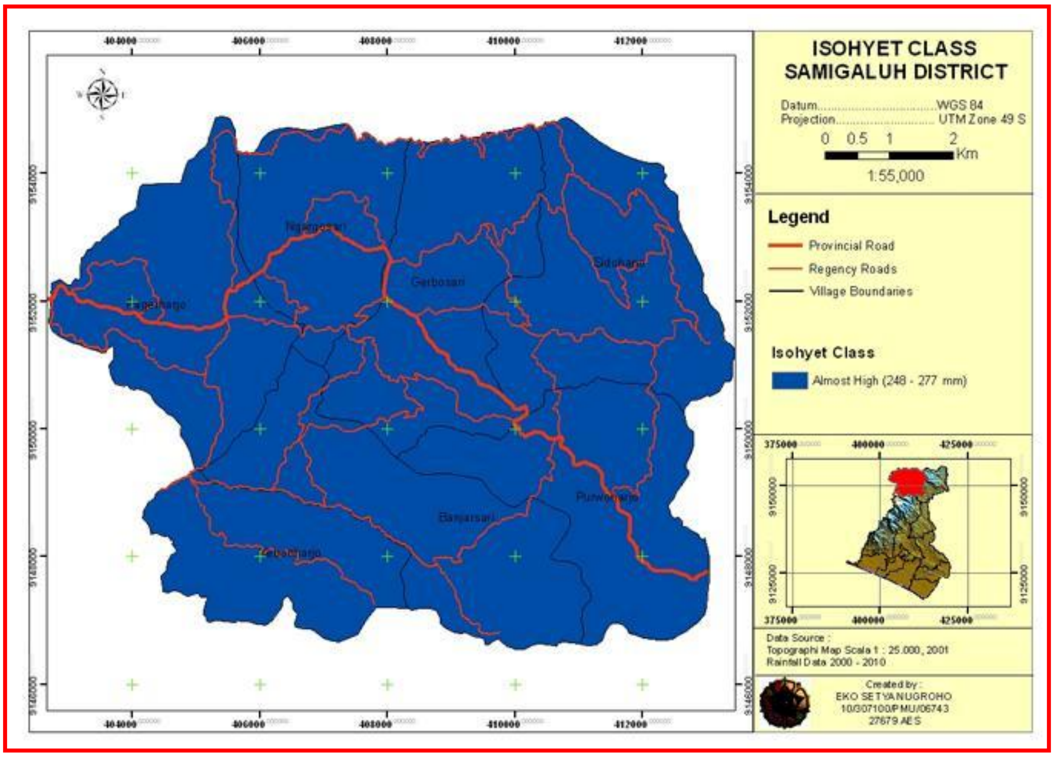


Figure 3.6: Isohyets class Samigaluh District map

3.5. Lithology

Samigaluh District is composed of igneous rock (e.g. andesite) and sedimentary rocks (breccias, limestone, sandstone, alluvium deposits). Percentage of each type of rock can be shown in (Table 3.4). (Figure 3.7) depicts spatially lithology distribution in the study area.

Table 3.4: Lithology composition in Samigaluh District

No	Class	Area (Ha)	%
1	**2**	**3**	**4**
1	Andecite	1,326.78	19.69
2	Non Clastic Limestone	954.37	14.17
3	Breccia	3,748.14	55.64
4	Clastic Limestone	320.79	4.76
5	Alluvium	5.80	0.09
6	Sandstone	380.90	5.65
Total		**6,736.78**	**100**

Source: Data Analysis

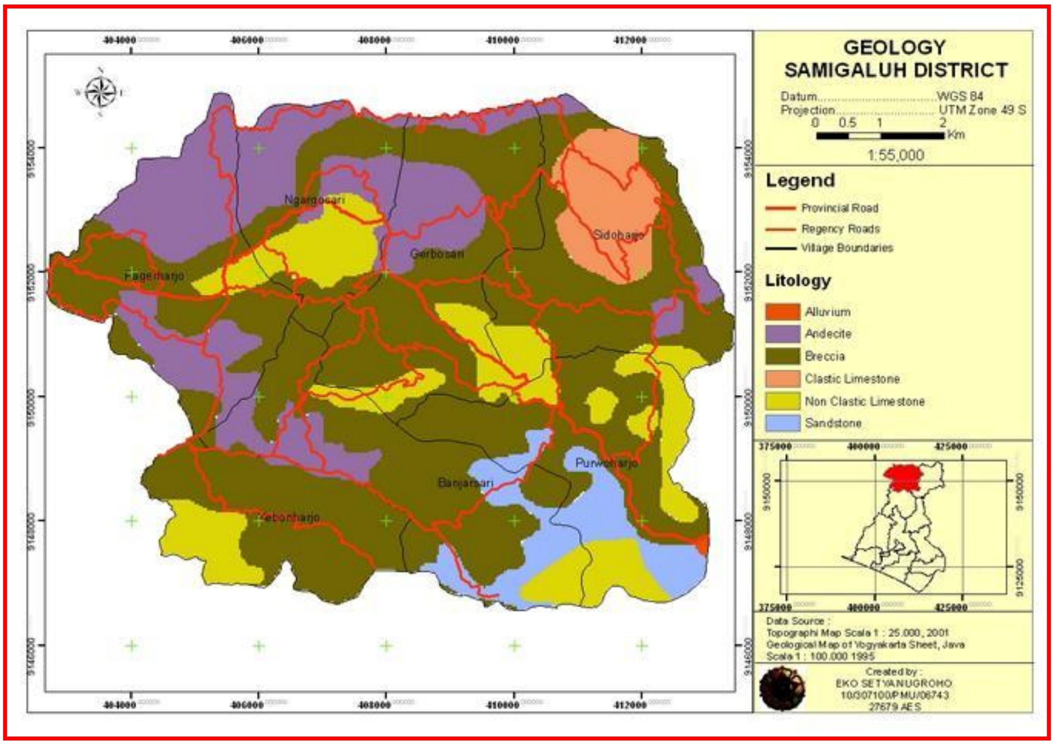


Figure 3.7: Lithology distribution Samigaluh District (Source: Geological Research and Development Centre).

3.5.1. Breccia

Breccia rocks are coarse-grained clastic rocks which are formed from angular gravel and boulder-sized clasts cemented together in a matrix (Thompson et al, 1997). In Samigaluh District, breccia is the largest percentage covering 55.64 % of the total area of research. Breccia rocks in the study area have a high degree of weathering which can cause a mass movement.

3.5.2. Andesite

Andesite rocks are a volcanic rock intermediate in composition between basalt and granite. Because of volcanic, andesite rocks are typically very fine grained (Thompson et al, 1997). The existence of andesitic rocks is influenced by the presence of inactive volcano which is the Volcano Menoreh. Andesite rocks have a high resistance in which there are many join or small faults in this rock. Generally, weathering, erosion, and mass movement occur in this rock type. Andesitic rocks mostly are located in the northwest area of research, namely in the Ngargosari and Pagerharjo Village. The analysis results of lithological map can be seen that the andesite rocks cover 19.69 % of the research total area.

3.5.3. Clastic and Non-Clastic Limestones

Clastic limestones are formed from rock fragments that have been there before. Sedimentary rocks made up of clasts are called clastic (clastic indicates that particles have been broken and transported). Non-clastic limestones are rocks which formed by chemical or biological process (Thompson et al, 1997). Clastic limestones which cover 4.76 % from total area can be found mostly in Sidoharjo Villages. In Samigaluh District, non-clastic limestone which is formed by the results of animal marine decomposition covers 14.17 % from total area. Mass movements which are often found in these rocks are the type of fall.

3.5.4. Sandstone

According to (Thompson et al, 1997), sandstone consists of lithified sand grains. The most of sandstones consist predominantly of rounded quartz grains. Distribution of sandstone can be found in the Purwoharjo and Banjarsari Village which cover 5.65 % of the total study area. Sandstone has moderate resistance.

3.5.5 Alluviums

Alluvium is sediment that has carried and deposited by running water. It is usually most extensively developed in the lower part of the course of a river, forming floodplains and deltas. These materials spread in Purwoharjo Village 0.09 % which lies on flat relief. That’s way there are rarely landslide occurrences.

3.6. Land Use

In Samigaluh District, there are 8 landuse classes which are shrubs, mixed garden, moor, settlement, grass, paddy fields, rain fed paddy field, and water body. Spatial distribution of each landuse can be seen in (Figure 3.8).

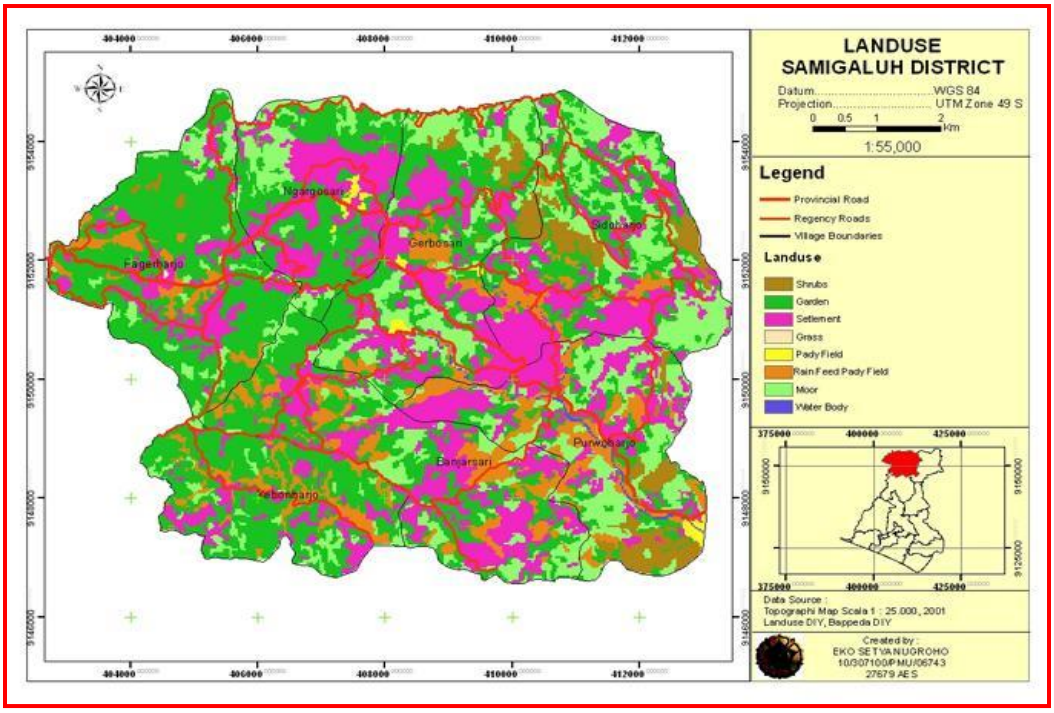


Figure 3.8: Landuse Samigaluh District map (Source : BAPPEDA DIY)

Landuse is dominated by mixed garden which covers 39.54 % from total area. Mixed garden spread all of area, but the most of this class can be found on the west part of Samigaluh District. Mixed garden is composed by fruits and trees (such as *Tectona Grandis, Swietenia Mahagoni, Albizzia, Dalbergia Latifolia, Coconut* and *Bamboo*). Moor which is composed by coconut trees, cassava, and banana can be easily found around human settlements. Paddy field which covers 0.53 % from total area can be found on the south east part of Samigaluh District (around Tinalah River). Rain fed paddy fields is located on the hillside terraces using conservation techniques. Water body consists of Tinalah River, irrigation canals, or ponds created by the community. The composition of each landuse can be seen in (Table 3.5).

Table 3.5: Landuse composition in Samigaluh District

No	Landuse	Area (Ha)	Percentage (%)
1	**2**	**3**	**4**
1	Shrubs	253.24	3.76
2	Mixed Garden	2,663.81	39.54
3	Settlement	1,822.32	27.05

Table 3.5: Continue

1	2	3	4
4	Grass	0.70	0.01
5	Paddy Field	35.45	0.53
6	Rain Fed Paddy Field	634.98	9.43
7	Moor	1,303.97	19.36
8	Water Body	22.31	0.32
Total		**6,736.78**	**100.00**

Source: Data Analysis

Landuse is the human aspect which affects the degree of landslides susceptibility in some places. This is due to human activities conducted in steep areas which can reduce the stability of slopes. Many studies have been conducted that the landuse such as construction of roads in hilly-mountainous will increase landslides susceptibility. As a result, many landslides have occurred on the road networks, whether they are on the upper or lower road slopes.

IV. RESEARCH METHODOLOGY

4.1. Method

Method is a series of way to achieve the research objectives. The main objective of the research is to estimate the landslide risk impact to road in Samigaluh District. To achieve the research objectives, several methods have been used and are explained as follow:

4.1.1. Landslide Inventory and Landslide Density

In this study, authors collected landslide historical data by using information from people who lived around the incident and key informant. (Wahono, 2010) the local community information can help to determine the landslide location and landslide boundary. The lack of historical data (especially historical data of landslide hit road) in institutional/office is usually caused people didn't report this event to office. They assume that these events (landslide hit road) normally occur every year. Resident will report landslides occurrences to the village office, if the landslides cause damage to their house, their property or causing the death of their family. (Budeta, 2002) stated landslide events which didn't cause life threatening and heavy damage were usually not reported. On the other hand, village office will collect data related with big landslides hitting road or causing heavy damage only. That's why historical data of landslide hit road is difficult to obtain in the village office. Although people didn't record landslide events, they still remember those events, especially people who lived in the surrounding events.

(Voskuil, 2008) stated there are several indicators to recognize landslide both by using remote sensing (RS) or field work as follow:

- Semi-circular back scars and cracks
- Irregular ground beneath the scars (local)
- Irregular slope
- Pounding of water in slide material, anomalies in drainage.

- Vegetation anomalies
- Presence of man-made structure

In this study, landslide density was considered in term of the landslide area and the number of landslide events. Landslide area density can be calculated by dividing the landslide area of each segment by the road segment area. Otherwise, landslide number density can be determined from the number of landslide divided by the road segment area. Landslide density is used to determine which of road segment having highest susceptibility. The impact of landslide both of direct and indirect impact will be analyzed in this road segment.

4.1.2. Mapping Unit

Mapping unit can be derived by using several methods which are grid cells, terrain units, unique-condition units, slope units, and topographic units (Nayak, 2010). Mapping unit can be determined by combining various thematic layers in GIS which include several factors, such as: lithology, landuse, geomorphology, soil, slope, landcover (Van Westen et al, 1997). According to (Chakraboethy, 2008) the determination of mapping unit used depend on the objective of study, type and size of landslide and the capability of data handling tools.

In this study, author used several factors to create mapping unit, namely; slope, and landuse in which those factors will influence landslide event. Rainfall and lithology factors were not considered because these factors have 1 class only (homogeneous). It means that spatially, these factors aren’t significant on segment 174. Mapping unit was created by considering road buffer 30 m right and left along roads. This value (30 m) was used because the furthest of landslide boundary is 30 m from road. Mapping unit as the unit of analysis was focused on a road segment which has the highest landslide density, in this case is a road segment of 174. There are several factor to create mapping unit, as follows:

4.1.2.1. Slope

In this research, it was used detail slope which was measured by using suunto. It is called micro slope. Segment 174 which has 4.85 km was taken 62 slope measurement points. Slope were classified into 6 classes which are (0-10)°, (10-20)°, (20-30)°, (30-40)°, (40-50)°, and (50-60)° (Figure 4.1). This classification was used by (Yalcin et al, 2007) and (Akgun et al, 2010) to classify slope in Turkey. By using this classification will depict more detail slope classes.

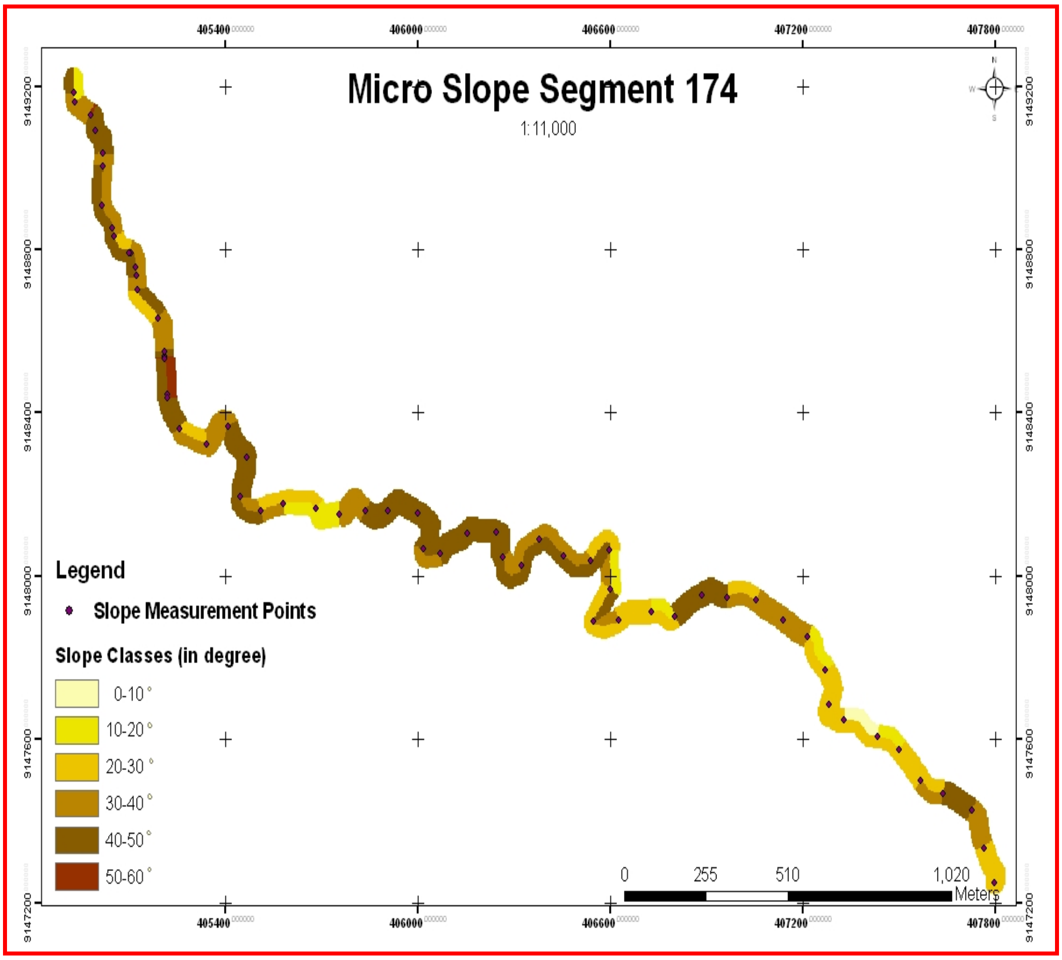


Figure 4.1: Slope segment 174

4.1.2.2. Landuse

In Segment 174, it can be found 4 kind of landuse which are mixed garden, settlement, moor and rain feed paddy field. These landuse types can be depicted in (Figure 4.2).

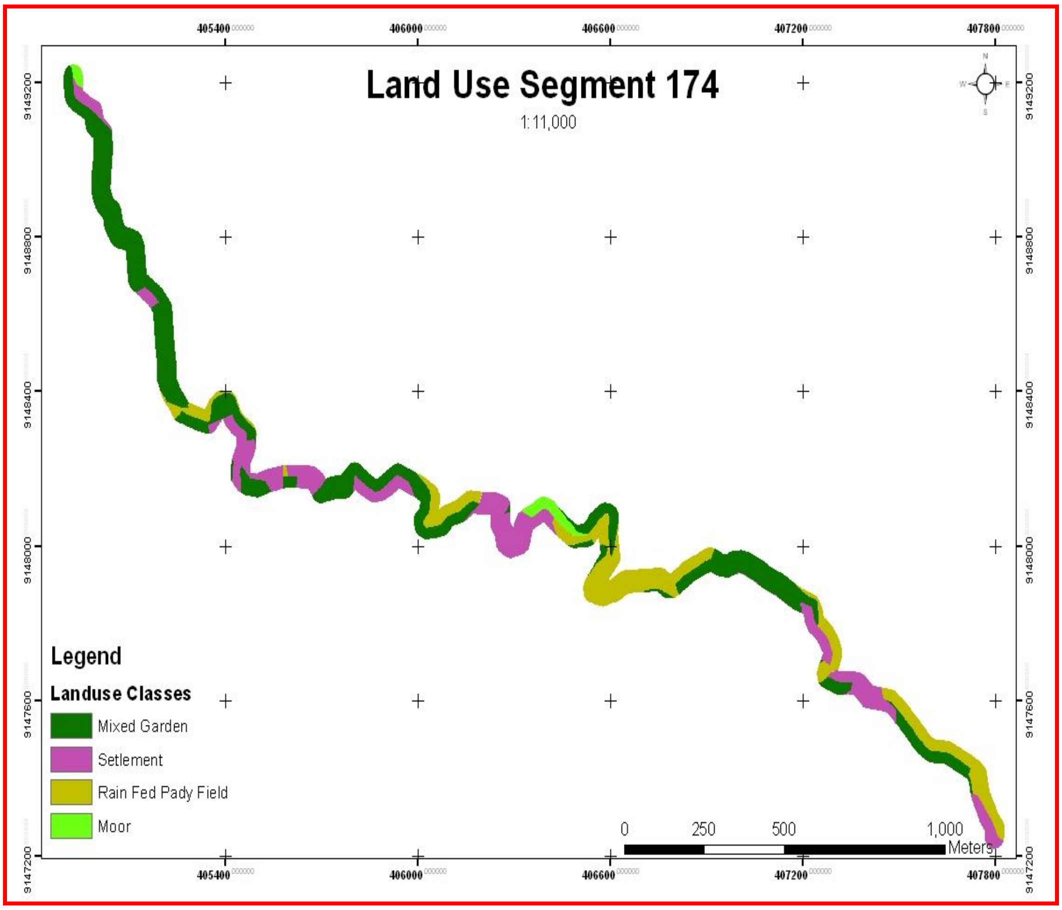


Figure 4.2: Landuse segment 174

After overlying 2 factors above, it can be obtained mapping unit of road segment 174 which contains 77 mapping units (Figure 4.3).

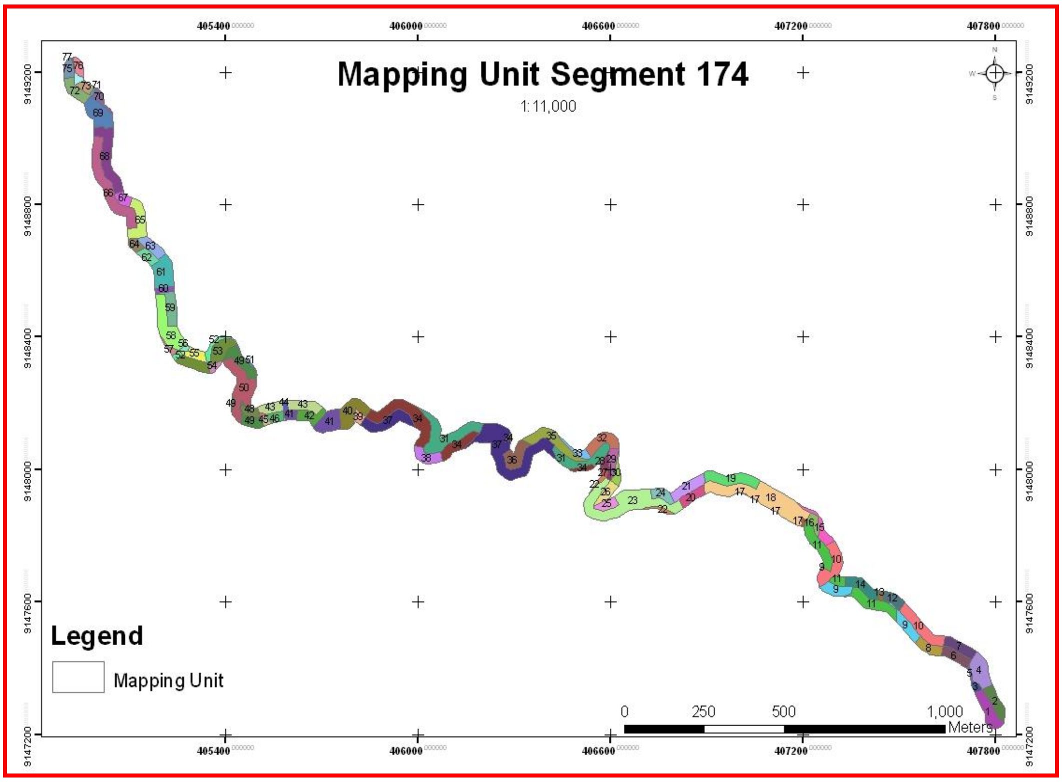


Figure 4.3: Mapping unit segment 174

4.1.3. Hazard Zone

Landslide occurrence, in space or time, can be obtained from heuristic investigations, computed through the analysis of environmental information as a result of combination of physical factors. Five parameter maps were used in order to build landslide hazard maps, namely landform map, slope map, geological map, soil map and landuse map (Hadmoko et al, 2010). Normally, a landslide hazard zonation consists of two major aspects e.g. spatial probability of landslide occurrence which can be conducted by zoning different hazardous areas and temporal probability which is related to the magnitude return period of the triggering event and the occurrence of landslides (Varnes, 1984). To determine hazard, it was used the equation below (Nayak, 2010):

$$\mathbf{H = P(s) \times T(p) \times M} \quad \text{............} \quad (4.1)$$

P (s) = spatial probability

T (p) = temporal probability

M = magnitude

4.1.3.1. Spatial Probability

Spatial probability was built by combining landslide historical event and mapping unit. Mapping unit can be created by using several parameter maps. In this case, author used 2 parameter maps to build landslide hazard maps, namely slope map, and landuse map. Spatial probability was obtained from the possibility of landslides that occurred in each mapping unit. It was approached by determining the density of landslides per unit of mapping, which shows the spatial probability. Spatial probability can be determined by using the following equation (Nayak, 2010).

P(s) = AL / AM ………………………………………………..………… (4.2)

P(s) = spatial probability of landslide in a mapping unit

AL = area of particular landslide type and particular magnitude in a mapping unit

AM = area of that particular mapping unit

4.1.3.2. Temporal Probability

Temporal probability can be approximated by using poisson model. Poisson model is a continuous time model consisting of random point event that occur independently in ordinary time, which considered naturally continuous.(Nayak, 2010). This method was used by (Nayak, 2010) and (Chakraborty, 2008) to determine the temporal probability of landslide in road corridor, in India. The assumptions of the poisson model are as follows:

- The numbers of events (landslide) which occur in disjoint time intervals are independent.
- The probability of an event occurring in a very short time interval is proportional to the length of time interval. The probability of more than one event in such a short time interval is negligible.

The probability distribution of number of events remains the same for all time intervals of a fixed length. The probability of occurring n number of slides in a time t is given by equation below (Nayak, 2010):

P [N(t)] = 1 – [exp(-λt)]……………………………………………..…...(4.3)

N = total number of landslide occurred a time t

λ = average rate landslides occurrence

Here time t is specified, whereas rate λ is estimated

4.1.3.3. Magnitude

Magnitude is related to the amount of energy released during the hazardous event, or refers to the size of the hazard. Magnitude is indicated by using a scale, consisting of classes, related to a (logarithmic) increase of energy (Van Westen et al, 2009). In this research, author used the magnitude classification based on standard created by Jaiswal to determine magnitude level for different type of landslide (Table 4.1). This method was used by (Nayak, 2010) to determine landslide magnitude of road corridor.

Table 4.1: The magnitude separation of different type of landslide on the basis of field investigation and damaging potential

Magnitude Scale	Landslide Type	Criteria used to define magnitude	
		Characteristic Feature	**Damage and Human Perception**
1	**2**	**3**	**4**
I	Rock Slide	Area < 1000 m^2;shallow translational; occurrence on moderate slope; shallow slide; run out distance depend on the slope; initiated from joins and fractures; occurrence probability is high; rapid downhill movement; multiple occurrence; fragmented material	Minor damage to the road, vehicle, and infrastructure, can be escaped, and controlled by cutting of hanging walls.
II	Rock Slide	Area 1000-10000 m^2; deep translational; occurrence on steeper slopes, run out distance depend on the slope; initiated from highly fractured zone; occurrence probability is more; accumulated on flat land; single occurrence; material size 2-3 m	Mayor damage to the road, vehicle, and infrastructure, can't be escaped, controlled using improved stabilization method.

Table 4.1: Continue

1	2	3	4
III	Rock Slide	Area > 10000 m^2; deep translational; occurrence on very high steeper slopes, run; initiated due to high infiltration of water into bedding or joint planes (weak zone); occurrence probability is less; single occurrence; material size ± 8 m	Full damage to the road, vehicle, and infrastructure, difficult to escape, sure death, can't be controlled.
I	Debris Slide	Area < 1000 m^2; occurred in low weathered zones; run out distance ± 20 m; shallow translational slides; occurrence probability is high.	Only blockage of road, minor damage to vehicle, infrastructure, easy to escape, and controlled by making retaining walls.
II	Debris Slide	Area 1000-10000 m^2; occurred in low vegetation; shallow translational slides; run out distance ± 220 m; occurrence probability is moderate.	Partial damage to road, vehicle, infrastructure, not so easy to escape, and controlled by retaining walls.
III	Debris Slide	Area > 10000 m^2; occurred in high water content and high weathered zones; deep translational slides; run out distance ± 320 m; occurrence probability is less.	Full damage to the road, vehicle, and infrastructure, sure death, can't be escaped, controlled by spreading wire sheets.

Source: Landslide magnitude classification based on standard created by Jaiswal

4.1.4. Vulnerability of road network

Road vulnerability considered the degree of loss of road network which was shown in the degree of road damage. To calculate vulnerability of road network was used the following formula:

V = AD / TA…………………………………………..……………..… (4.4)

V = vulnerability of road

AD = road damaged area and or landslide mass covering road area in the road segment

TA = total area of road segment

It was assumed that between road damaged due to landslide and landslide mass covering road have the same influence of traffic interruption.

4.1.5. Estimation of the landslide risk direct impact (Direct Impact Assessment).

The impact of landslide directly on the exposed element like road can be estimated by using direct risk assessment. In this study, direct risk assessment was developed for various scenarios on the basis of hazard (e.g. magnitude class, landslide type, and return period), vulnerability and estimating cost of road damage in term of road construction cost and removing debris cost. This equation was used by (Nayak 2010) to calculate landslide direct impact to road in India.

Sp(e) = H [(s x t x m)] x V(d) x A……………………………………… (4.5)

Sp(e) = specific risk for different kind of element at risk

H [(s x t x m)] = spatio - temporal occurrence of particular slide and particular magnitude in road section

V(d) = vulnerability of different type of element at risk to specific landslide

A = amount in term of monetary value of particular element at risk

In this study, vehicles and commuters were not included in the calculation of the direct impact because there has been no incidence of landslides that hit the object. So it was difficult to determine vulnerability of vehicle and commuters because of the absence of historical record. Based on local community information, landslide events usually occurred in the situation (heavy rainfall or night time) in which people lived in their home.

4.1.6. Estimation of the landslide risk indirect impact (Indirect Impact Assessment).

Indirect risk assessment was derived from traffic interruption. Because of road blockage, driver or commuter will find alternative road which has longer distance. It means this will result in increased costs of fuel purchases. It was used network analysis and community perception to determine the optimal road which was chosen by commuter. Community perception was used to know the real desire of commuter related with the optimal road used. Indirect impact due to landslide events on the road network can be calculated by using this equation:

IDL = R(d) x N(v) x L(r) x F(c) x F(s) ……………………………...…… (4.6)

IDL = indirect loss

R(d) = road blockage days

N(v) = number of vehicle of a particular type

L(r) = extend distance by using road alternative

F(c) = fuel consumption per km long road

F(s) = fuel standard cost per km long road

4.1.7. Data Classification

Classification is needed to classify hazard, vulnerability and direct impact level. In this research, author used Equal Intervals method. This method sets the value ranges in each category equal in size. This method is the most easily computed and adequate to display data that varies linearly. The entire range of data values (max - min) was divided equally into many classes have been chosen. In order to get detail classes, it was used 5 class criteria which are very low, low, moderate, high, and very high. Hazard, vulnerability, and direct impact were classified by using this method. In order to get the same reference, the class interval used for making hazard and direct impact classification is the class interval for return period 1 yr. Interval class can be calculated by using this equation:

Interval class = (max value – min value) / 5………………..……….……….. (4.7)

4.2. Theoretical Framework

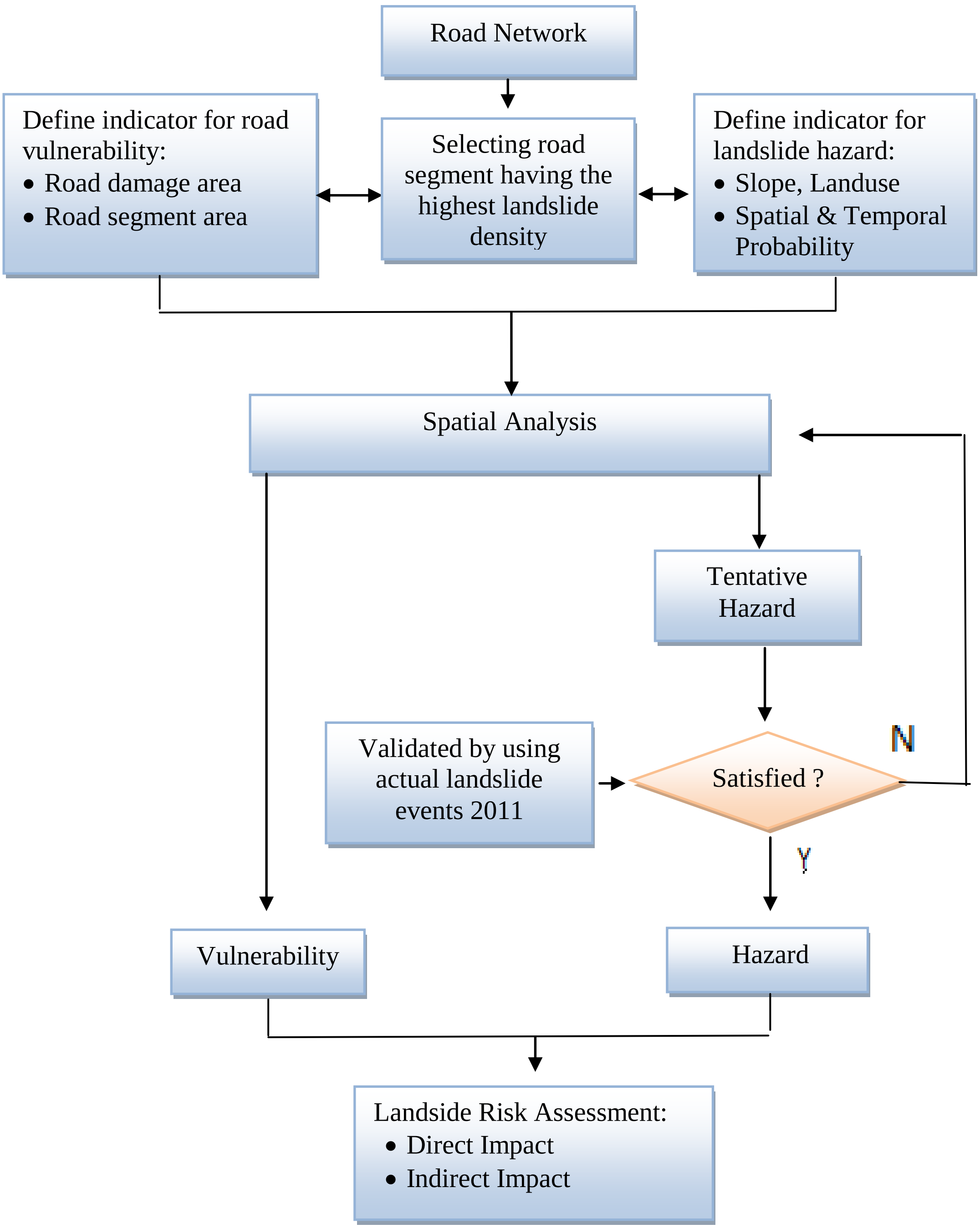


Figure 4.4: Theoretical frame work

4.3. Research Framework

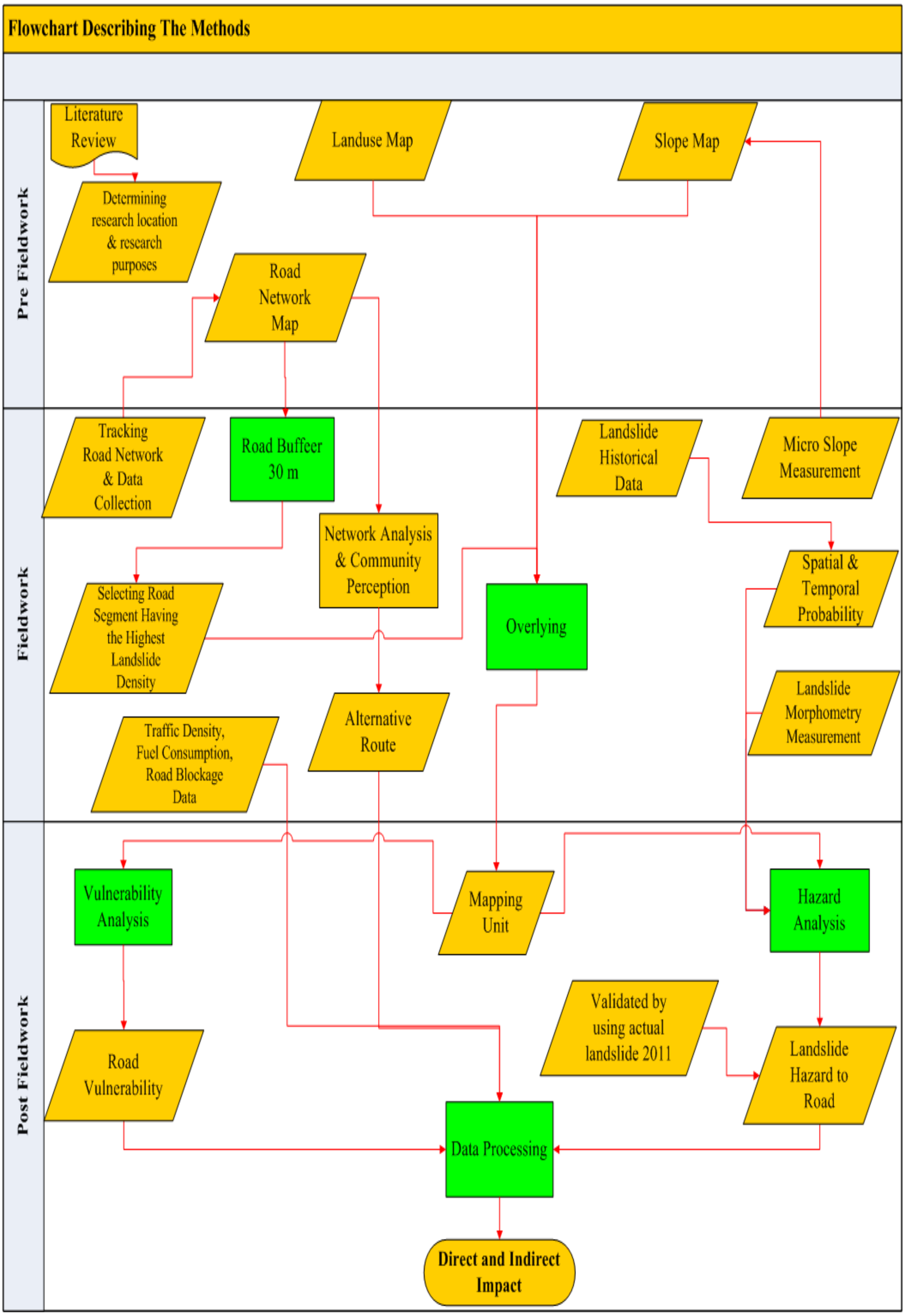


Figure 4.5: Research frame work

4.3.1. Pre Field Work

Preparation/pre field work deals with the collecting of literature reviews including journals, reports, books, and the result of previous research related to the data needed and the analysis methods information. In this phase, data which related with research have been collected. For example: demographic data, rainfall data (isohyets), slope map, geology map, topographic map, DEM map, road network map and landuse map.

4.3.2. Field Work

In this phase, There are two main activities ; colecting the secondary data and primary data.

a. Secondary Data

   Secondary data consists of landslides occurrence data, road network classification data, standard cost deal with road (repairs, construction and maintenance), road blockage day data, debris slide volume and so on.

b. Primary Data

   Primary data collection was conducted by interviewing and observasing landslide occurrence to road. In order to obtain landslide historical events, author has to observe landslide and discuss with local community deal with past landslide events. Data was also collected from discussion with community leaders and key informants. Landslide observation include identify type of landslide and measure landslide morphometry (length, width, run out and soon) by using lacer ace. In order to ensure and measure the actual road network in the field, author has to do road tracking. Slope data in term of upper and lower road which was used to create micro slope can be measured by using suunto. In this stage, primary data deal with number of vehicle of a particular type was used to calculate indirect impact to road. The primary data of community perception related with the route alternative and fuel consumption can be obtained by using quisionere.

4.3.3. Post Field Work

For the finalization of the fieldwork result, data was analyzed according to the objective of the research such as ; constructing roads hazard zone, constructing roads vulnerability level, estimating direct risk and indirect risk impact .

4.4. Data Needed

In this research, data needed consist of primary data and secondary data. Primary data were collected directly during fieldwork, while secondary data were obtained from the institution related to this research (Table 4.2).

Table 4.2: Data needed and data source

No	Data Needed	Data Source
1	**2**	**3**
1	Isohyets Map	Generation from rainfall data
2	Slope Map	Generation from DEM (macro slope), Fieldwork using Suunto (micro slope)
3	Lithology Map	Geological Research and Development Centre
4	Landuse Map	BAPPEDA DIY
5	Topography Map	BAKOSURTANAL
6	Samigaluh District Map	BAKOSURTANAL
7	Digital Elevation Model (DEM)	www.gdem.aster.ersdac.or.jp
8	Road Classification Data	Public Works Office Kulon Progo Pegency
9	Rainfall Data	Agriculture and Forestry Office Kulon Progo, Public Works Office Kulon Progo Pegency, Irrigation Office Purworejo Regency.
10	Cost Standard of Road Construction	Public Works Office Kulon Progo Pegency
11	Cost Standard of Removing Debris	Public Works Office Kulon Progo Pegency

Table 4.2: Continue

1	2	3
12	Volume Debris	Secondary Data from Kebonharjo Village Office and local community discussion
13	Road Blockage Days	Secondary Data from Kebonharjo Village Office and local community discussion
14	Traffic Density	Field work
15	Landslide Morphometry	Field work
16	Road damaged area and landslide mass covering roads boundary	Fieldwork and local community discussion
17	Landslide Historical Data	Kesbang Linmas Office Kulon Progo Regency, Kebonharjo Village Office and local community discussion
18	Alternative Roads based on Community Perception, fuel consumption	Field work (interview)

4.5. Instruments and Software

In this research, we will use instrument and software such as:

a. GPS Garmin Oregon 450 to determine landslide position on fieldwork.
b. Program of Arc GIS 9.3 to analyze spatial data.
c. MS Word and Excel to analyze and display research data
d. Camera for documentation.
e. Laser Ace to determine landslide morphometry
f. Suunto to measure the slope angle
g. Compass to measure the azimuth
h. Counter to count traffic density

4.6. Timetable

This research will start from June 2011 to March 2012. The time table of the research is shown in (Table. 4.3).

Table 4.3: Time table

No	Activity	Jun	Jul	Ags	Sept	Oct	Nop	Dec	Jan	Feb	Mar
I.	**Pre Fieldwork**										
a.	Proposal										
b.	Establishing Contact										
c.	Preliminary Fieldwork										
e.	Consultation										
II.	**Fieldwork**										
a.	Secondary Data Collection										
b.	Fieldwork										
c.	Consultation										
III.	**Post Fieldwork**										
a.	Analysis Data										
b.	Consultation										
c.	Thesis Writing										
d.	Thesis Submitting										
e.	Final Exam										

V. RESULT AND DISCUSSION

5.1. Landslide Analysis

5.1.1. Landslide Density Analysis

In this research, we focused on landslides occurring surrounding the road, that are distributed on 21 main road segments in Samigaluh District. During the period of 2001-2010 are 270 damaging landslides that devastate the road that covered and destroyed roads. We measured landslide dimensions (width, length etc) through lacer ace device in order to determine landslide magnitude, spatial probability and landslide density (Figure 5.1). In this study, landslide density was considered in term of the landslide area and the number of landslide events. Landslide density was used to determine which of road segment having highest susceptibility. The impact of landslide both of direct and indirect impact will be analyzed in this road segment.

Figure 5.1: Field work activity to measure landslide morphometry. A) Rock fall type, B) Debris slide type (Source: Eko Setya N, 2011)

Area density of landslide was calculated by dividing the landslide area of each segment by the road segment area (Table 5.1 and Figure 5.2). In addition, number density of landslide was calculated from number of landslide divided by the road segment area (Table 5.1 and Figure 5.3).

Table 5.1 : Landslide density Samigaluh roads segment in term of the landslide area and in term of the landslide events

No	Segment	Roads				Landslide		Landslide Density	
		Length		Width	Area	Area	Events	In term of area	In term of events
		Km	m	m	Ha	m^2	No	(m^2/Ha)	(No/Ha)
1	2	3	4	5	6	7	8	9	10
1	5	6.73	6,728.90	60	40.37	427.80	7	10.60	0.17
2	4	3.11	3,107.91	60	18.65	165.65	4	8.88	0.21
3	164	6.63	6,632.75	60	39.80	823.50	19	20.69	0.48
4	152	3.79	3,790.30	60	22.74	390.32	7	17.16	0.31
5	169	3.98	3,976.60	60	23.86	127.64	5	5.35	0.21
6	3	6.01	6,011.66	60	36.07	501.61	13	13.91	0.36
7	94	2.06	2,064.63	60	12.39	620.95	10	50.13	0.81
8	170	2.69	2,687.39	60	16.12	461.11	11	28.60	0.68
9	91	5.57	5,567.50	60	33.41	439.26	13	13.15	0.39
10	168	2.85	2,851.87	60	17.11	487.03	7	28.46	0.41
11	28	0.44	439.20	60	2.64	0	0	0.00	0.00
12	148	11.36	11,359.84	60	68.16	1,245.71	29	18.28	0.43
13	82	5.96	5,961.70	60	35.77	850.29	19	23.77	0.53
14	171	1.73	1,731.46	60	10.39	42.56	2	4.10	0.19
15	157	4.62	4,616.76	60	27.70	438.45	9	15.83	0.32
16	172	4.89	4,886.77	60	29.32	1,396.35	25	47.62	0.85
17	**174**	**4.85**	**4,854.90**	**60**	29.13	**2,073.26**	**38**	**71.17**	**1.30**
18	175	2.25	2,248.72	60	13.49	363.82	9	26.97	0.67
19	81	4.12	4,120.68	60	24.72	540.67	13	21.87	0.53
20	167	3.38	3,379.15	60	20.27	325.93	7	16.08	0.35
21	Prov	15.89	15,889.96	60	95.34	1,766.14	23	18.52	0.24

Source: Data Analysis

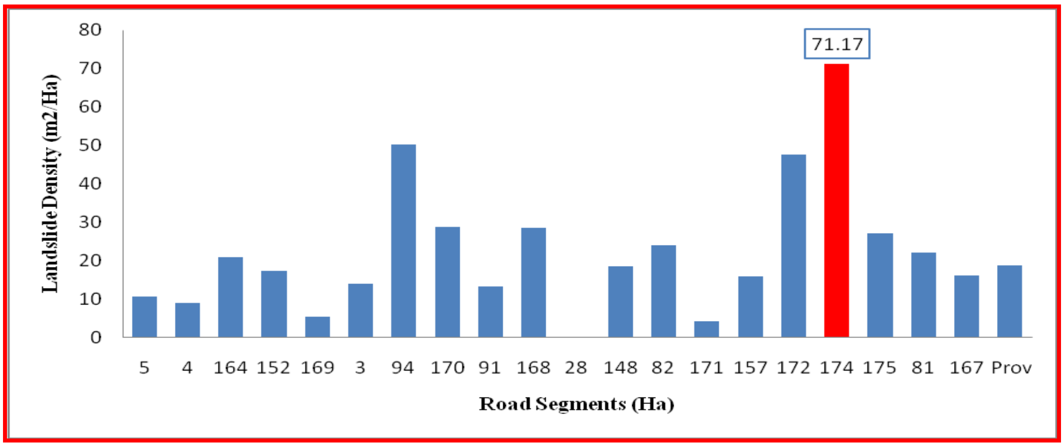


Figure 5.2 : Landslide density Samigaluh road segment in term of the landslide area

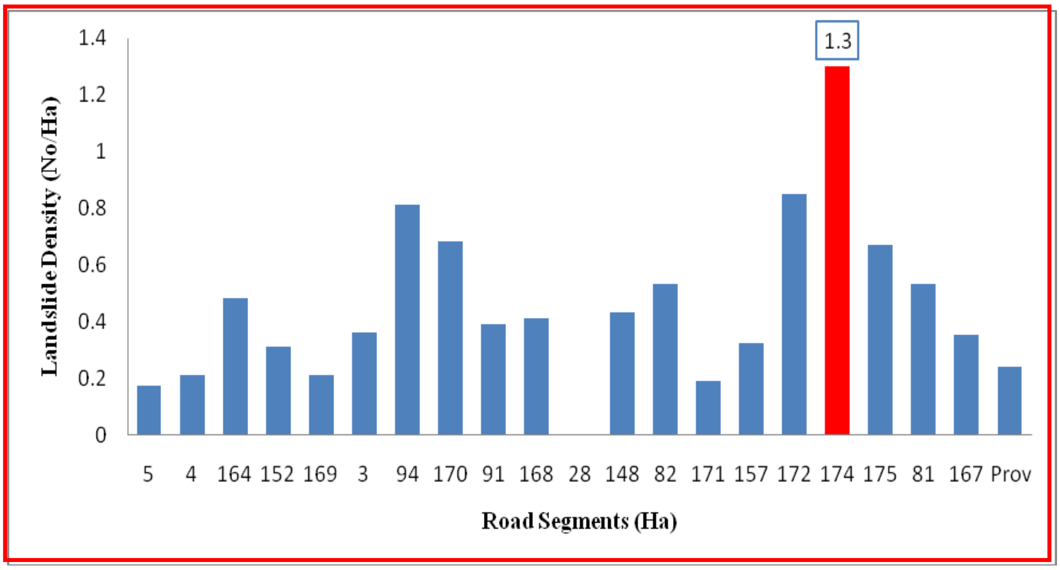


Figure 5.3 : Landslide density Samigaluh road segment in term of the landslide events

Based on (Table 5.1, Figure 5.2 and Figure 5.3), segment 174 is a segment which has the highest in both value area and number density with the values are 71.17 m^2/Ha and 1.30 event/ Ha respectively. It means that road segment 174 experienced the highest landslide events both in magnitude and frequency. The frequency and magnitude of landslide in segment 174 is highly correspondent with the presence of steep slope, high rainfall intensity and fully weathered volcanic breccias rocks. Thereby, this area was classified as landslide susceptible area.

Road segment 28 which is located in gentle slope has the smallest in both value area and number density. There is no landslide incident occurred on segment 28. (Figure 5.4) shows the entire road segments of the study area, the red color represent the road segment no 174 having the highest density of landslide and used in the analysis. Landslide estimation which includes direct and indirect impacts will be conducted on a segment having the highest landslide density (segment 174).

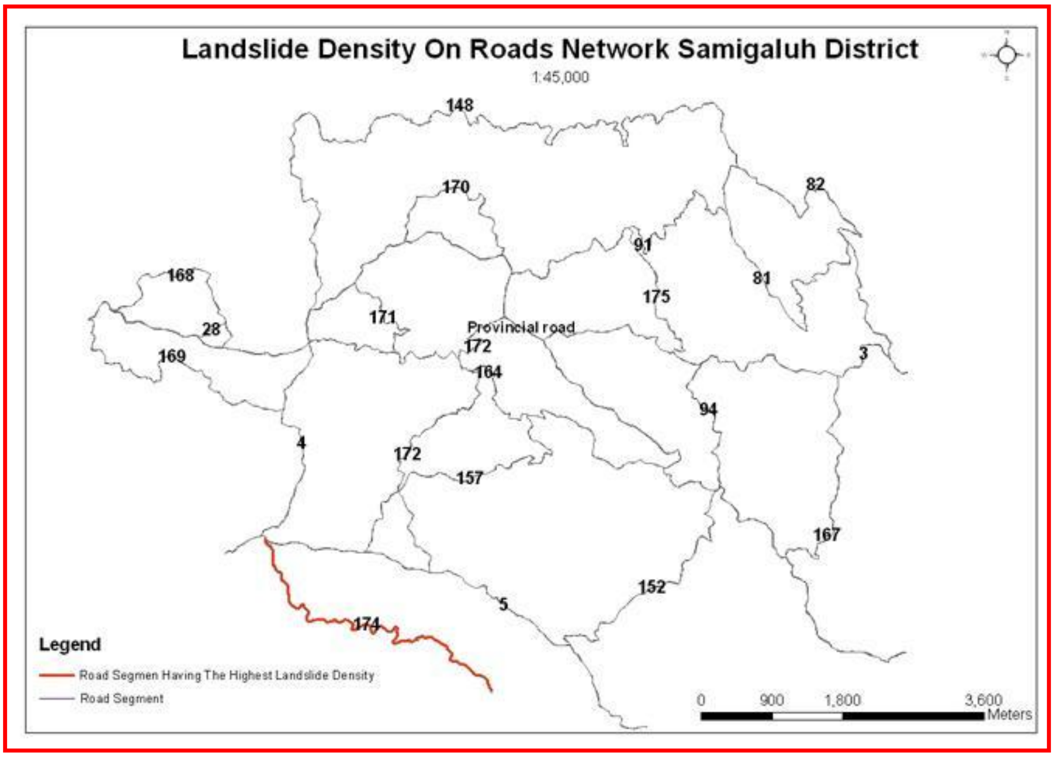


Figure 5.4 : Landslide density on Samigaluh road segment

5.1.2. Spatio – Temporal Characteristic of Landslides

Only two types of landslides occurred in segment 174 that are dominated by debris slides (94.74 %) and 5.26 % of rock falls were mapped in this segment (Figure 5.5).

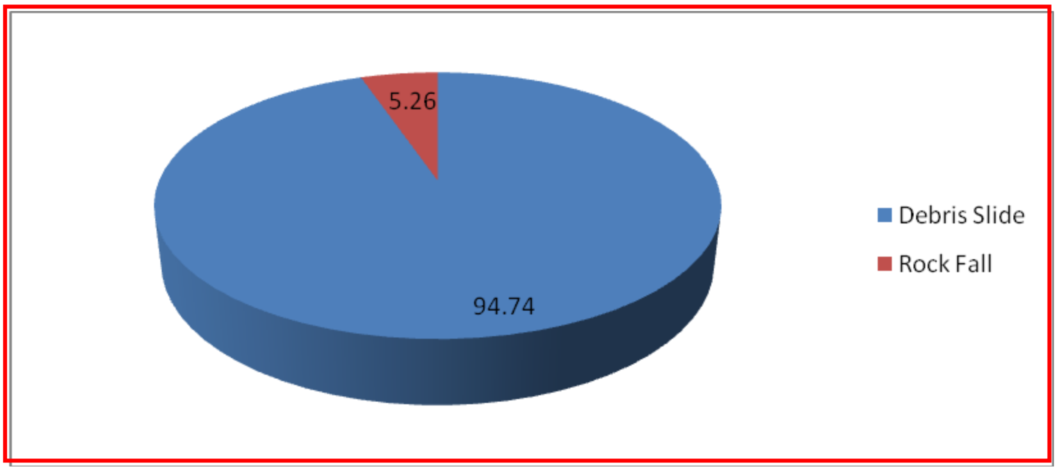


Figure 5.5 : The percentage of landslide type on segment 174

Our morphometrict measurement through lacer ace device that the landslide areas ranging from 5.66 m^2 to 494.11 m^2 with the average is 54.56 m^2. The average area of landslide in segment 174 reached the value of < 1000 m^2. It means that based on Jaiswal's magnitude classification, the magnitude of landslide in road segment 174 is I.

Our intra annual landlside data base showed that landslide occurences of the years are distributed on the November, December, January, February, and March (Figure 5.6). These data bases have been crossed with our rainfall data in order to determine the landslide pattern versus the monthly rainfall. Our data indicated that more than 80% of landslide evens have been mostly concentrated on November, December, January, February, and March due to the maximum precipitation down pours during these periods. It means that temporal lanslide distributions for 10 years (2001-2010) are distributed on November, December, January, February and March.

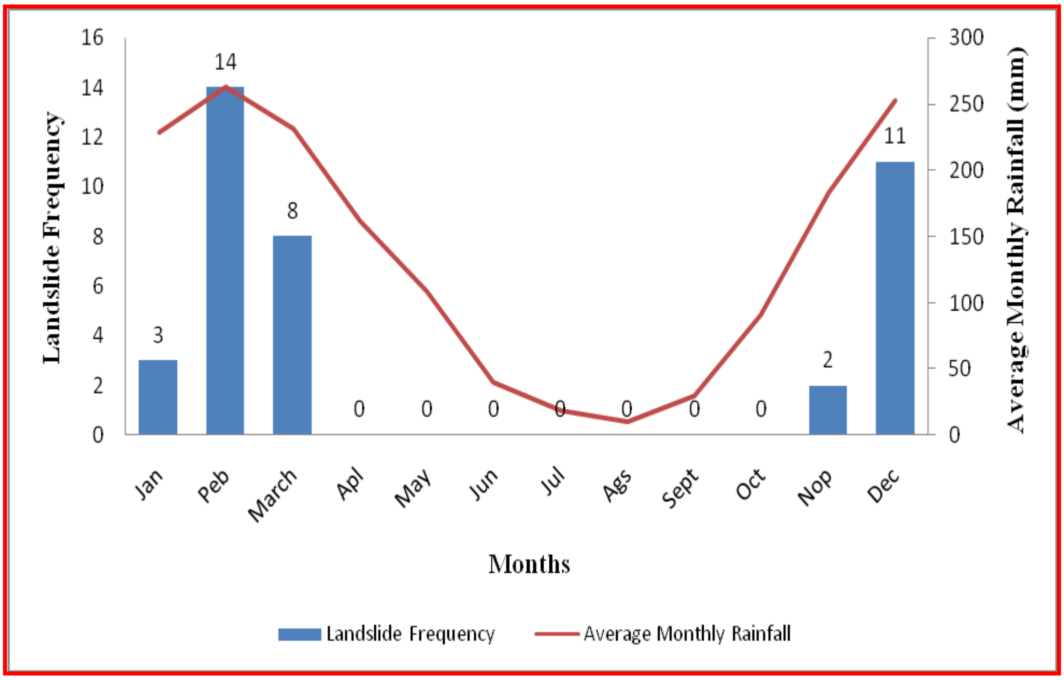


Figure 5.6 : Temporal landslide distributions on Segment 174

Spatially, landslide events which have 38 occurances for 10 years are distributed in road segment 174 (Figure 5.7). Actually road segment 174 contains 77 mapping units, but only 20 mapping units can be found landslide events.

The most of landslide events can be found in the 31[st], 37[th], 49[th], 50[th], 58[th], 69[th] mapping units in which are located in steep slope (40°-50°).

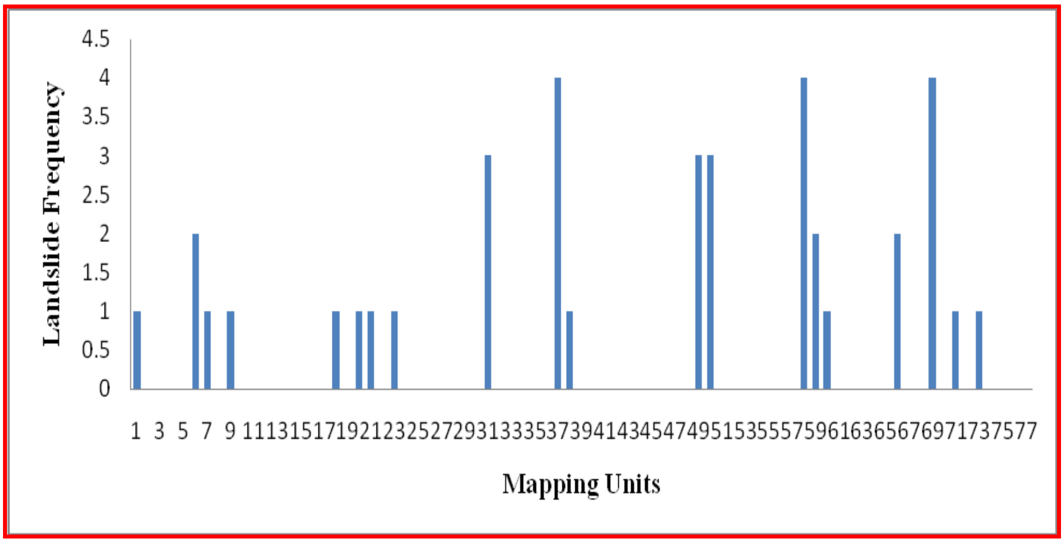


Figure 5.7 : Spatial landslide distributions on Segment 174

5.1.3. Slope Failure Causing Factors

Landslide occurrences can be caused several factors which give slope failure contribution. Several factors which were determined as slope failure causing factor are slope, rainfall, lithology and landuse.

5.1.3.1 Slope

Slope plays an important role as the main causative feature of landslide. We built two kinds of slope maps i.e. macro slope and micro slope. Macro slope was built from Digital Elevation Model (DEM), while the micro slope was obtained from direct measurement in the field. The later was also used to build our mapping unit.

We measured 62 segments a lay the road of 174 in order to build the micro slope. We applied slope classification from (Yalcin et al, 2007) and (Akgun et al, 2010) who classified the slope steepness into 6 classes e.g. 0°-10°, 10°-20°, 20°-30°, 30°-40°, 40°-50°, and 50°-60°. Besides that, this classification will depict more detail slope classes. (Figure 5.8) shows micro slope classification and its visualization on segment 174 based on slope measurement.

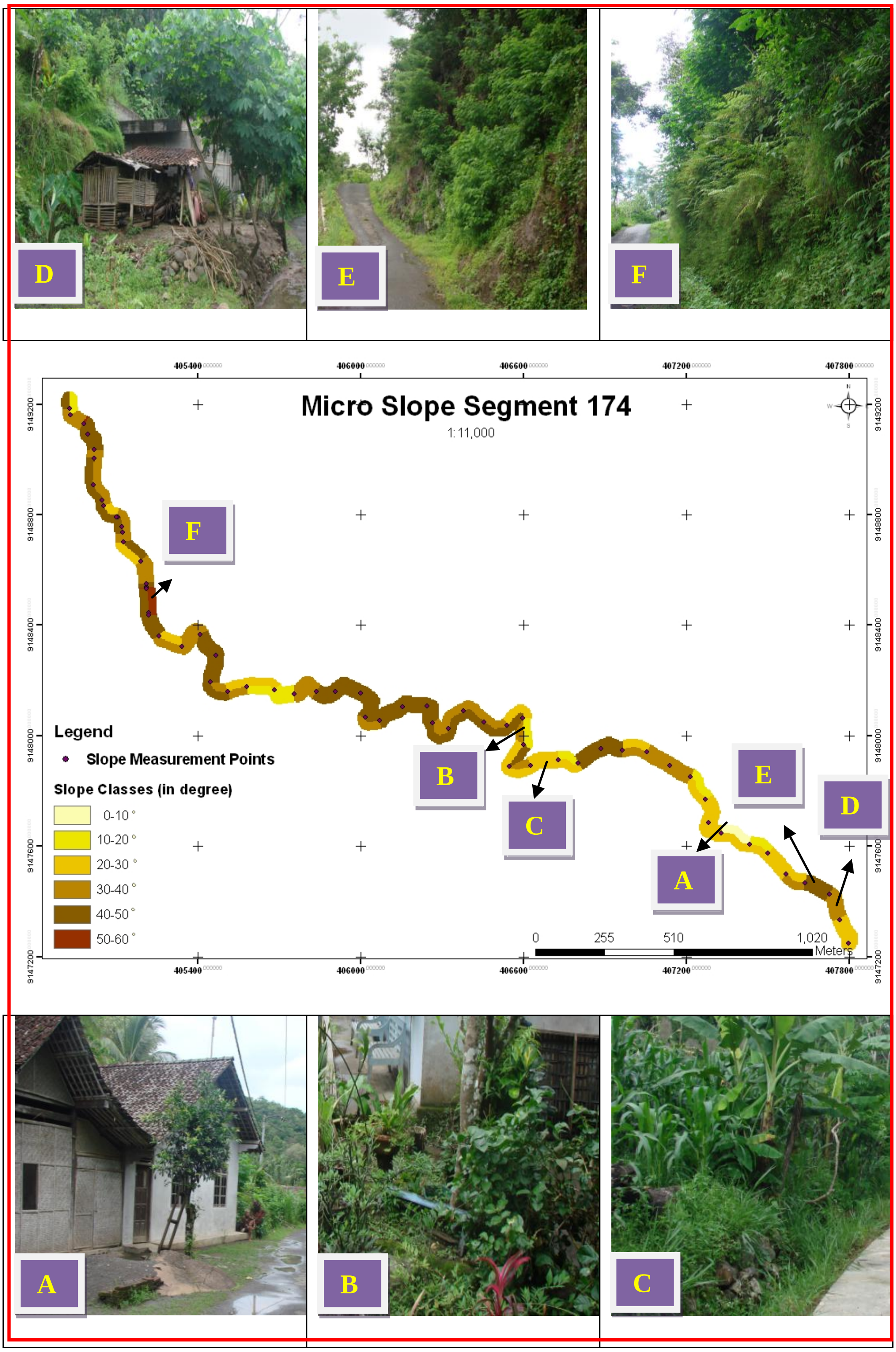


Figure 5.8 : Micro slope segment 174 and its visualization; A) Slope class of (0-10)°, B) Slope class of (10-20)°, C) Slope class of (20-30)°, D) Slope class of (30-40)°, E) Slope class of (40-50)° and F) Slope class of (50-60)°. (Source: Eko Setya N, 2011).

In this segment, slope classes area are dominated by 30°-50° and followed by slope class of 20°-30°, < 20° and > 50° which have 66.19 %, 24.02 %, 8.58% and 1.20 % of total area (Table 5.2). It means that the study area was dominated as steep slope.

Based on micro slope classification, landslides are distributed mostly on steep slopes 30°-50°. It shows that 86.88 % landslide areas are located on steep slopes. Landslides do not occur on gentle slope < 20° (Table 5.2). About 2.27 % of landslides lie on slope class > 50°. The slope class > 50° is relatively stable due to the presence of bed rock. Human interaction on this slope class is very limited due to the high degree of difficulty to access.

Table 5.2: Landslide distribution based on micro slope on segment 174

No	Slope Classes	Slope Classes Area (m^2)	%	Landslide Area (m^2)	%
1	2	3	4	5	6
1	0°- 10°	3,566.23	1.23	0	0
2	10°- 20°	21,310.37	7.35	0	0
3	20°- 30°	69,642.87	24.02	224.77	10.85
4	30°- 40°	79,471.74	27.41	98.58	4.75
5	40°- 50°	112,437.58	38.78	1,702.79	82.13
6	> 50°	3,479.24	1.20	47.12	2.27
	Total	**289,908.03**	**100**	**2,073.26**	**100**

Source: Data Analysis

A 30 x 30 m of DEM has been used to build the macro slope map through 3D analyses in Arc Gis 9.3 (Figure 5.9 and Table 5.3). Slope distribution of the study area indicates that the study area is dominated by the slope steepess of < 20° (71.64 %) and followed by 20°- 30° (18.14 %), 30°- 50° (10.22%) and > 50° (0 %). The study area was dominated as gentle slope.

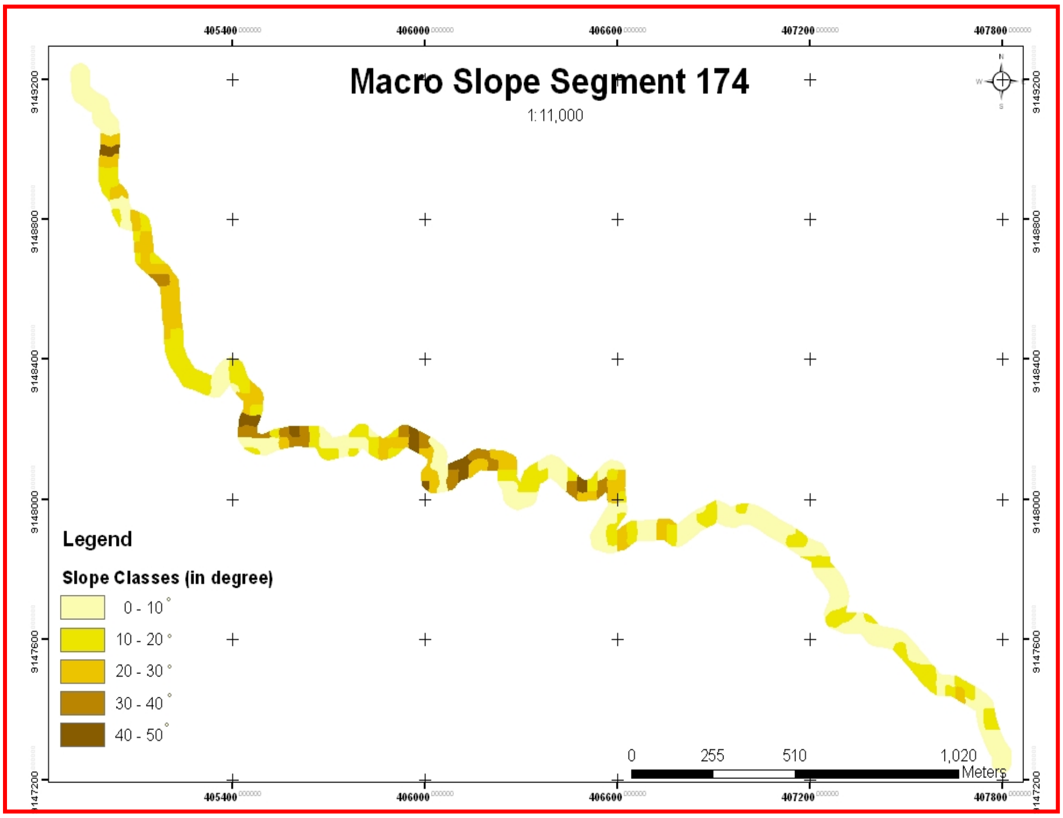


Figure 5.9 : Macro slope classes distribution on segment 174

Table 5.3: Macro slope classis area on segment 174 derived from DEM

No	Slope classes	Slope Classes Area (m^2)	%
1	**2**	**3**	**4**
1	0° - 10°	126,631.83	43.68
2	10° - 20°	81,058.29	27.96
3	20° - 30°	52,589.32	18.14
4	30° - 40°	18,119.25	6.25
5	40° - 50°	11,509.35	3.97
6	> 50°	0	0
	Total	**289,908.03**	**100.00**

Source: Data Analysis

From (Table 5.2 and Table 5.3), we can see that the slope classes between micro slope and macro slope are very different. Micro slope is dominated by slope class of 30°-50° which has 66.19% from all of classes, while the macro slopes is dominated by a class of < 20° which has 71.64 %. This data indicates that the macro slope resulted from DEM (size pixel 30 x 30 m) has less detail than the micro slope result obtained from slope measurement. Actually, macro slope cannot be used to analyze the terracing system in the study area. The gentle slopes which are reflected in macro slope can be steep terrace in real condition. In other hand, micro slope can depict the real slope condition in the road segment 174.

5.1.3.2. Rainfall

Isohyets (rainfall) in the road segment 174 have a small range of values which has the minimum value 257.39 mm and maximum value 261.53 mm. That’s why isohyets class was classified in one of isohyets classes. Based on Standard Operational Procedure (SOP) from Serayu Opak Progo Watershed Bureau, these isohyets value can be categorized as “Almost High Classes”. It can be seen in (Table 3.3). Because of homogeneous of rainfall value in road segment 174, spatially, rainfall factor is less significant than the other factors. However, temporarily, rainfall factor will influence landslide events (Figure 5.6).

5.1.3.3. Lithology

Breccia rocks are coarse-grained clastic rocks which are formed from angular gravel and boulder-sized clasts cemented together in a matrix (Thompson et al, 1997) (Figure 5.10). Actually, breccia rock types which have high degree of decomposition can be a potential factor of landslide. In the rainy season, water will penetrate until impermeable layer which has role as slip surface. It will be worst, if clay layer lies between breccias bed rock and the upper layer. The existence of clay layer will be able to be lubricant, so the upper soil will move as landslide (Figure 5.10.B). However, road segment 174 has one classes of lithology which is Breccia only. Because of the homogenous of lithology class, spatially, lithology is less significant in road segment 174.

Figure 5.10 : Breccia rock type located on Segment 174; A) Breccia rock composed of angular gravel, B) Breccia rock outcrops (Source : Eko Setya N, 2011)

5.1.3.4. Landuse

Landslides in the road segment 174 are widely distributed on mixed garden 49.12%, and respectively followed by rain feed paddy field 38.35%, settlements 12.53% and moor 0% (Table 5.4). Usually, landslides occurred in mixed garden which has low vegetation density and shallow-fiber root vegetation type (such as: bamboo, coconut trees, and banana trees). Fiber root vegetation type also can be found in rain feed paddy field. Thus these roots have a low ability to withstand landslides. As additional information, local community said the landslides hit the road usually were occurred on the dominance of bamboo trees. (Figure 5.11) shows landuse type in which the most of landslide events occurs.

Table 5.4: Landslide distribution based on landuse classes on segment 174

No	**Landuse Classes**	**Landslide Area (m^2)**	**%**
1	2	3	4
1	Rain Feed Paddy Field	795.07	38.35
2	Mixed Garden	1,018.45	49.12
3	Moor	0.00	0.00
4	Settlement	259.74	12.53
	Total	**2,073.26**	**100.00**

Source: Data Analysis

Figure 5.11 : Landuse type in which the most of landslide events occurs
A) Bamboo, B) Low vegetation density, C) Coconut trees D) Rain fed paddy field. (Source: Eko Setya N, 2011)

5.2. Hazard

According to (Varnes, 1984) landslide hazard consists of two major elements, namely landslide spatial probability and landslide temporal probability which is related to the magnitude, return period and the occurrence of landslides.

5.2.1. Spatial Probability

Spatial probability was built by combining landslide historical event and mapping unit. Mapping unit can be created by using several parameter maps which are slope map, and landuse map. Mapping unit can be used as basis to build landslide hazard maps. Spatial probability was obtained from the possibility of landslides that occurred in each mapping unit.

Segment 174 which has 77 mapping units has total area 289,908.03 m^2. But they are 20 mapping units only which contain landslide events. There are 38 landslide events and total landslides areas 2,073.26 m^2 or 0.72% of total area of mapping units. They contain 2 types of landslides which are debris slide type and rock fall type. Debris slides dominate segment 174 while rock falls lie on the 6^{th} mapping unit only. All of landslide types which have landslide area < 1000 m^2 were categorized as magnitude I (based on Jaiswal Classification). Spatial probability was determined on the basis of landslide area of different landslide type and magnitude by dividing the mapping unit area (equation 4.2). Spatial probability segment 174 and its calculation can be depicted in (Table 5.5 and Figure 5.12).

Table 5.5: Spatial probability calculation on segment 174

MU	**MU Area (m^2)**	**Landslide Area (m^2)**	**Spatial Probability** (3 : 2)	**Landslide Type**	**Magnitude**
1	2	3	4	5	6
1	4,217.37	54.04	0.0128	Debris Slide	I
6	2,831.61	136.74	0.0483	Rock fall	I
7	3,108.84	96.54	0.0311	Debris Slide	I
9	5,853.38	35.35	0.0060	Debris Slide	I
18	15,302.49	10.97	0.0007	Debris Slide	I
20	2,500.44	494.11	0.1976	Debris Slide	I
21	3,594.60	169.22	0.0471	Debris Slide	I
23	15,011.50	135.38	0.0090	Debris Slide	I
31	13,960.32	266.46	0.0191	Debris Slide	I
37	20,941.13	75.62	0.0036	Debris Slide	I
38	2,856.22	65.37	0.0229	Debris Slide	I
49	6,034.60	70.88	0.0117	Debris Slide	I
50	8,334.88	138.46	0.0166	Debris Slide	I
58	7,081.77	67.11	0.0095	Debris Slide	I
59	3,206.62	23.70	0.0074	Debris Slide	I
60	940.07	18.39	0.0196	Debris Slide	I
66	9,771.59	94.78	0.0097	Debris Slide	I
69	5,221.01	74.47	0.0143	Debris Slide	I
71	234.00	23.41	0.1001	Debris Slide	I
73	1,319.41	22.24	0.0169	Debris Slide	I

Source: Data Analysis

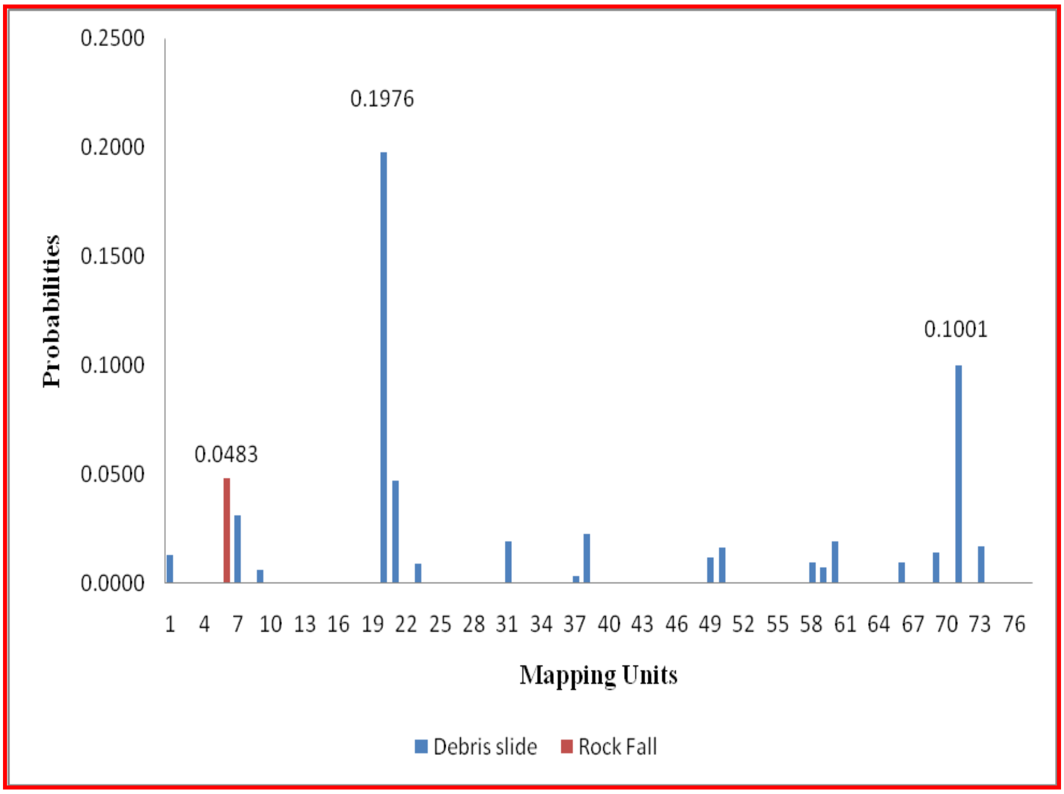


Figure 5.12: Spatial probability for magnitude I for rock fall and debris slide on segment 174

Based on (Table 5.5 and Figure 5.12), it can be known that the highest spatial probability of debris slide of magnitude I having probability 0.1976 located in the 20th mapping unit. The highest probability due to the small of mapping unit area (2,500.44 m^2) , while landslide area is the biggest (494.11 m^2) for 10 years on segment 174. The biggest landslide is located in 20th mapping unit, because this mapping unit lies on the bad irrigation system (situational condition in 2009), the steep slope 40°- 50°, and the medium vegetation density. It was worst by the presence of a road which is situated above this location, so the vibration which is generated by vehicles can trigger landslide event. The second highest spatial probability located in the 71th mapping unit which has 0.1001 probabilities. The lowest of spatial probability lies in the 18th mapping unit which has 0.0007 probabilities. The lowest of spatial probability due to the 18th mapping unit is located on moderate slope 30°- 40° and high vegetation density. Meanwhile rock fall type of magnitude I located on the 6th mapping unit only which has 0.0483 spatial probabilities.

5.2.2. Temporal probability

Temporal probability was calculated by using the poisson equation (equation 4.3) considering the number of landslide in different landslide type and magnitude in every particular mapping unit. In this study area, the author used return period 1 yr, 3 yr and 5 yr. It was used small return period (1 yr, 3 yr and 5 yr) because by using the big return period (10 yr) the temporal probability will be 1 for maximum landslide which give fault result (Nayak, 2010). Temporal probability of debris slides of magnitude I by using return period 1 yr, 3 yr and 5 yr can be seen in (Figure 5.13), while temporal probability of rock falls of magnitude I by using return period 1 yr, 3 yr and 5 yr can be seen in (Figure 5.14).

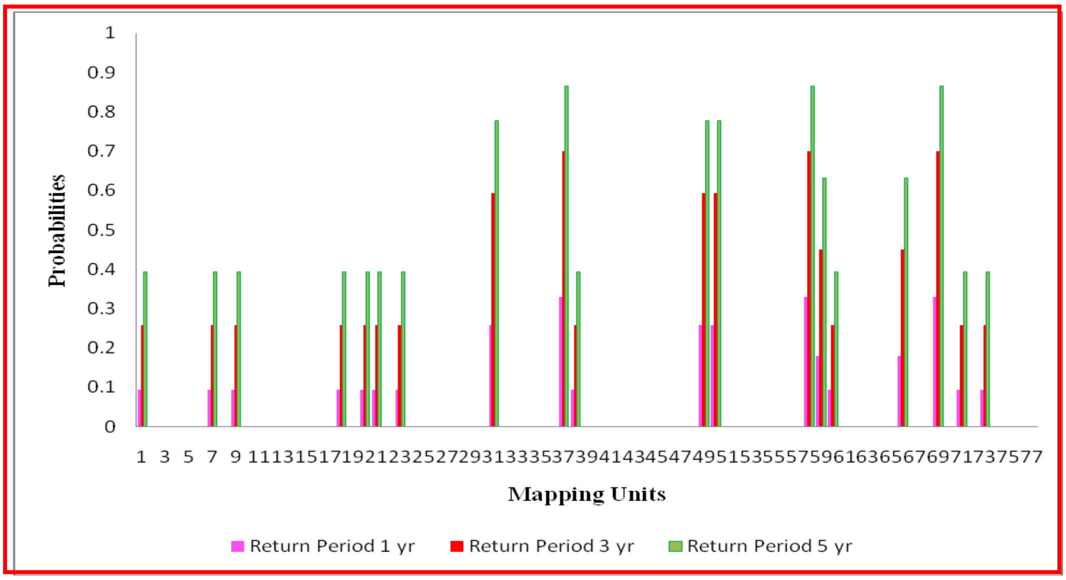


Figure 5.13: Temporal probability for debris slide, magnitude I, return period 1 yr, 3 yr and 5 yr on Segment 174

As shown in (Figure 5.13), the highest temporal probability of debris slide of magnitude I can be found in 3 mapping units (i.e. 37th, 58th and 69th) which have 0.3297, 0.6988, and 0.8647 probabilities for return period 1 yr, 3 yr, and 5 yr respectively. These mapping units have 4 times of debris slide occurrences during 10 years from 2001 to 2010. The highest temporal probability of debris slide of magnitude I in the 37th, 58th and 69th mapping units due to the high of slope failure causing factors which have steep slope 40^o-50^o, mixed garden (bamboo species dominated type and low vegetation density type) and settlements. These conditions give the high contribution of slope failure. The lowest temporal probability of debris slide of magnitude I can be found in 11 mapping units (e.g. 1st, 7th, 9th, 18th, 20th, 21st, 23th, 38th, 60th, 71st, and 73th) which have 0.0952, 0.2592, and 0.3935 probabilities for return period 1 yr, 3 yr, and 5 yr respectively. These mapping units have 1 times of debris slide occurrence during 10 years from 2001 to 2010. Although some of these mapping units are located on moderate and steep slope, but the most of these mapping units have moderate - high vegetation density and deep roots system (i.e. *Tectona Grandis*, *Sweitenia Mahagoni*, and *Dalbergia Latifolia*) which tend to withstand landslides. That's why; these mapping units are more stable to landslide.

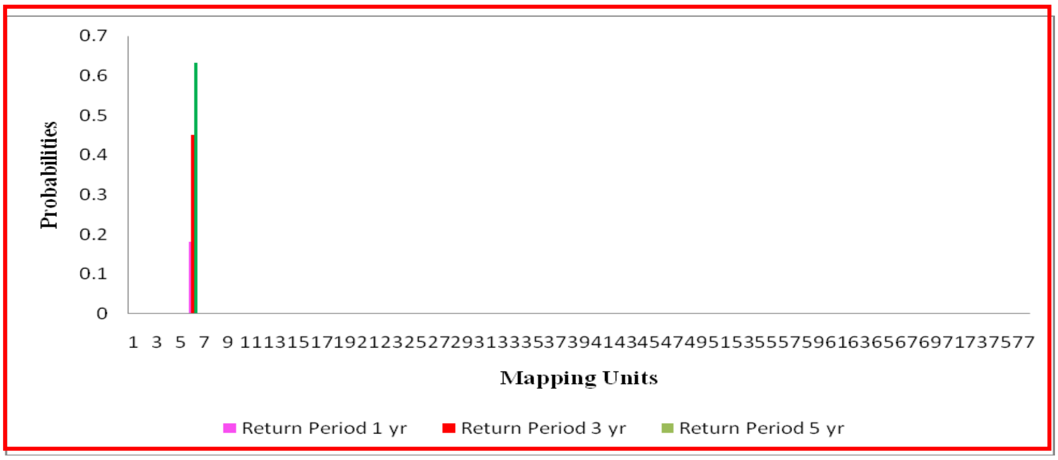


Figure 5.14: Temporal probability for rock fall, magnitude I, return period 1 yr, 3 yr and 5 yr on segment 174

While, the rock fall type of magnitude I can be found in 6th mapping unit only which has 0.1813, 0.4512 and 0.6321 for return period 1 yr, 3 yr and 5 yr respectively (Figure 5.14). The 6th mapping unit has 2 times of rock fall events during 10 years from 2001 to 2010. The 6th mapping unit located in steep slope 40^o-50^o, mixed garden type. Based on (Figure 5.13 and Figure 5.14), in the same mapping unit and particular landslide type, we can know that the higher return period the higher temporal probability. For example, the temporal probability of return period 5 yr will be higher than the temporal probability of return period 1 yr or 3 yr.

5.2.3. Landslide Hazard

Landslide hazard can be calculated by multiplying between landslide spatial probability (section 5.2.2) and landslide temporal probability (section 5.2.3) by using equation 4.1. In this study, landslide hazard was determined by considering 2 types of landslide, 1 type of magnitude and 3 scenarios return period. The hazard calculation can be shown in (Table 5.6).

Table 5.6: Landslide hazard calculation on segment 174

MU	**Spatial Probability**	**Temporal Probability**			**Hazard**			**Landslide Type**	**M**
		1 yr	**3 yr**	**5 yr**	**1 yr** (2x3)	**3 yr** (2x4)	**5 yr** (2x5)		
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0.0128	0.0952	0.2592	0.3935	0.0012	0.0033	0.0050	Debris Slide	I
6	0.0483	0.1813	0.4512	0.6321	0.0088	0.0218	0.0305	Rock Fall	I
7	0.0311	0.0952	0.2592	0.3935	0.0030	0.0080	0.0122	Debris Slide	I
9	0.0060	0.0952	0.2592	0.3935	0.0006	0.0016	0.0024	Debris Slide	I
18	0.0007	0.0952	0.2592	0.3935	0.0001	0.0002	0.0003	Debris Slide	I
20	0.1976	0.0952	0.2592	0.3935	0.0188	0.0512	0.0778	Debris Slide	I
21	0.0471	0.0952	0.2592	0.3935	0.0045	0.0122	0.0185	Debris Slide	I
23	0.0090	0.0952	0.2592	0.3935	0.0009	0.0023	0.0035	Debris Slide	I
31	0.0191	0.2592	0.5934	0.7769	0.0049	0.0113	0.0148	Debris Slide	I
37	0.0036	0.3297	0.6988	0.8647	0.0012	0.0025	0.0031	Debris Slide	I
38	0.0229	0.0952	0.2592	0.3935	0.0022	0.0059	0.0090	Debris Slide	I
49	0.0117	0.2592	0.5934	0.7769	0.0030	0.0070	0.0091	Debris Slide	I
50	0.0166	0.2592	0.5934	0.7769	0.0043	0.0099	0.0129	Debris Slide	I
58	0.0095	0.3297	0.6988	0.8647	0.0031	0.0066	0.0082	Debris Slide	I
59	0.0074	0.1813	0.4512	0.6321	0.0013	0.0033	0.0047	Debris Slide	I
60	0.0196	0.0952	0.2592	0.3935	0.0019	0.0051	0.0077	Debris Slide	I
66	0.0097	0.1813	0.4512	0.6321	0.0018	0.0044	0.0061	Debris Slide	I
69	0.0143	0.3297	0.6988	0.8647	0.0047	0.0100	0.0123	Debris Slide	I
71	0.1001	0.0952	0.2592	0.3935	0.0095	0.0259	0.0394	Debris Slide	I
73	0.0169	0.0952	0.2592	0.3935	0.0016	0.0044	0.0066	Debris Slide	I

Source: Data Analysis

Based on (Table 5.6), the highest hazard probability of debris slide of magnitude I is located in the 20th mapping unit which has 0.0188, 0.0512 and 0.0778 hazard probabilities for return period 1 yr, 3 yr and 5 yr respectively. Although the 20th mapping unit has the low of temporal probability which has 1 event during 10 years, but the spatial probability is quite big which has 0.1976 probabilities. This segment experienced the biggest landslide which is 494.11 m^2 areas. Based on the information from local community, the biggest landslide lies on the bad irrigation system (situational condition in 2009), the medium vegetation density, and the steep slope 40°-50°. Because of steep slope and bad irrigation system on upper location, water flows down to the location and trigger big landslide in rainy season. It was worst by the presence of a road which is situated above the 20th mapping unit, so the vibration which is generated by vehicles can trigger landslide event. The lowest hazard probability of debris slide of magnitude I can be found in the 18th mapping unit which has 0.0001, 0.0002, and 0.0003 hazard probabilities respectively. The lowest hazard probability is caused by the low probability in term of spatial and temporal in this mapping unit. The 18th mapping unit tends to more stable to landslide, because it is located on moderate slope 30°–40°, high vegetation density and having deep roots system. While, rock fall type of magnitude I which can be found in the 6th mapping unit for return period 1 yr, 3 yr and 5 yr has 0.0088, 0.0218 and 0.0305 hazard probability respectively.

After calculating landslide hazard, the next step is the hazard classification which was classified by using equation 4.7 in (section 4.1.7). (Figure 5.15, Figure 5.16, Figure 5.19, Figure 5.20, Figure 5.23, and Figure 5.24) show landslide hazard map and their histogram before classification. We can see that landslide probability distributions are dominated by the low probability values (yellow color). The maximum and minimum value of return period 1 yr was considered to calculate the hazard class interval. There are 5 interval of classes which are very low (< 0.00376), low (0.00376 - 0.00752), moderate (0.00752 - 0.01128), high (0.01128 - 0.01504), and very high (> 0.01504). Return period 1 yr, 3 yr and 5 yr were classified based on these criteria. Spatially, the distribution of hazard classes and their histogram for return period 1 yr, 3 yr and 5 yr after classification can be seen in (Figure 5.17, Figure 5.18, Figure 5.21, Figure 5.22, Figure 5.25, and Figure 5.26). The most class for hazard return period 1 yr, 3 yr and 5 yr is the very low class. Landslides hazard return period 1 yr was distributed on the very low class 87.35 %, the low class 10.73 %, the moderate class 1.06% and the very high class 0.86% respectively followed by the high class 0% (Table 5.7).

Table 5.7: Percentage of landslide hazard class for return period 1 yr

No	Hazard Classes	Class Area (m^2)	%
1	2	3	4
1	Very Low	253,231.16	87.35
2	Low	31,110.80	10.73
3	Moderate	3,065.61	1.06
4	High	0.00	0.00
5	Very High	2,500.44	0.86
	Total	**289,908.03**	**100**

Source: Data Analysis

(Table 5.8) shows that landslide hazard class for return period 3 yr are still dominated very low class and followed by low class, high class, moderate class, and very high class which has percentage of 76.62%, 9.66%, 6.06%, 5.75%, and 1.92% respectively. In the hazard return period 3 yr, the percentage of very low and low class decrease compare with the hazard return period 1 yr. Otherwise, the increasing of moderate class, high class and very high class occurred in the hazard period 3 yr.

Table 5.8: Percentage of landslide hazard class for return period 3 yr

No	Hazard Classes	Class Area (m^2)	%
1	2	3	4
1	Very Low	222,118.67	76.62
2	Low	28,003.65	9.66
3	Moderate	16,664.73	5.75
4	High	17,554.91	6.06
5	Very High	5,566.06	1.92
	Total	**289,908.03**	**100**

Source: Data Analysis

The same trends still occurs in hazard return period 5 yr in which the percentage of moderate, high and very high class increase and followed by the decreasing of percentage of very low and low class compare with the hazard return period 1 yr and 3 yr. (Table 5.9) shows that the study area are still dominated by very low class and followed by high class, low class, moderate class, and very high class which have 74.06%, 10.56% , 6.39%, 5.83%, and 3.16% of total area respectively for the hazard return period 5 yr.

Table 5.9: Percentage of landslide hazard class for return period 5 yr

No	Hazard Classes	Class Area (m^2)	%
1	2	3	4
1	Very Low	214,694.68	74.06
2	Low	18,514.99	6.39
3	Moderate	16,912.66	5.83
4	High	30,625.05	10.56
5	Very High	9,160.65	3.16
	Total	**289,908.03**	**100**

Source: Data Analysis

Based on these tables, although the higher return period will result the higher hazard classes but the most of hazard class for return period 1 yr, 3 yr and 5 yr is still dominated by the very low class. This condition compatible with The Jaiswal's Landslide Magnitude Classification that magnitude I have little landslide area or less spatial probability occurrence. As explained before, segment 174 has landslide magnitude which was categorized magnitude I. That's why, segment 174 has the dominance of very low hazard class.

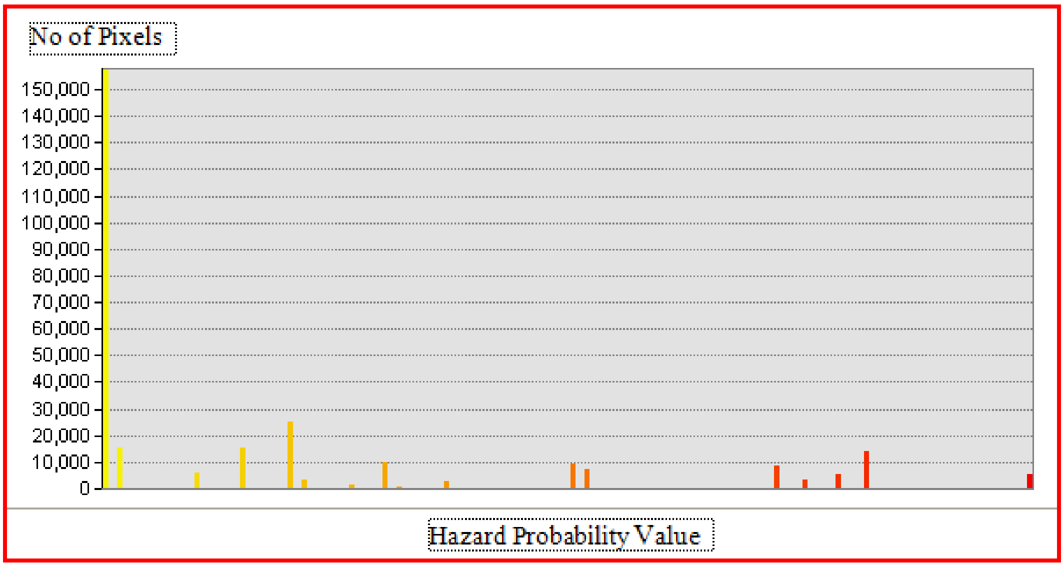


Figure 5.15: Histogram of hazard return period 1 year before classification

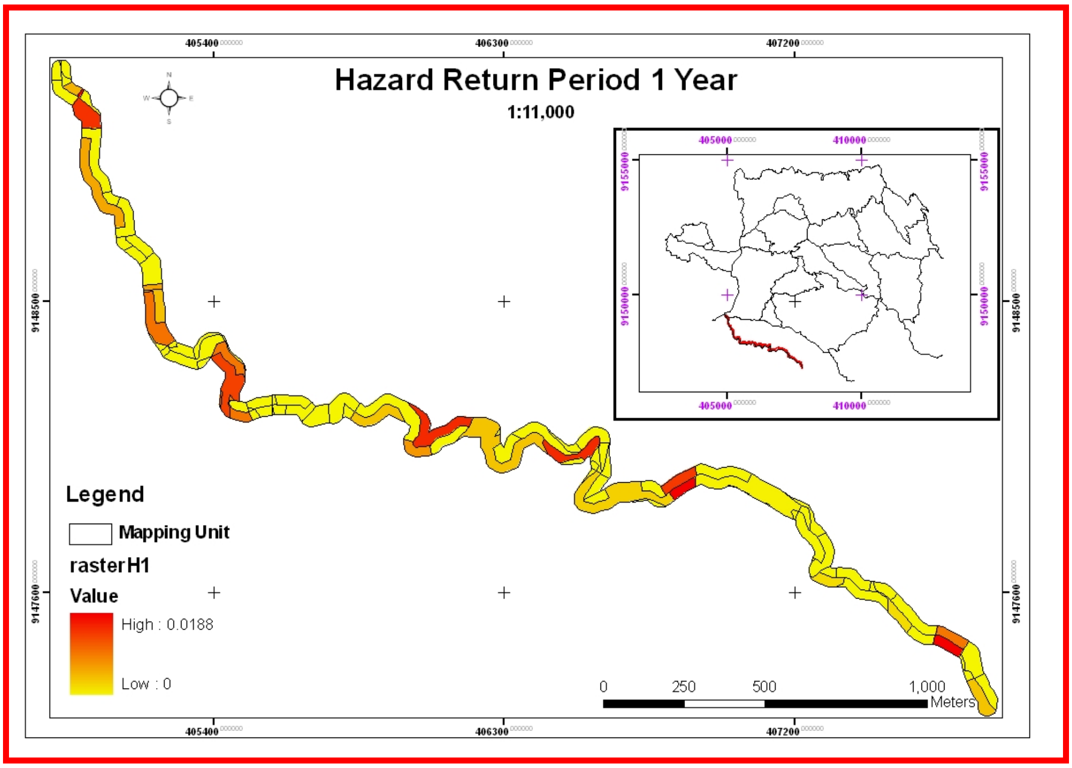


Figure 5.16: Hazard return period 1 year before classification

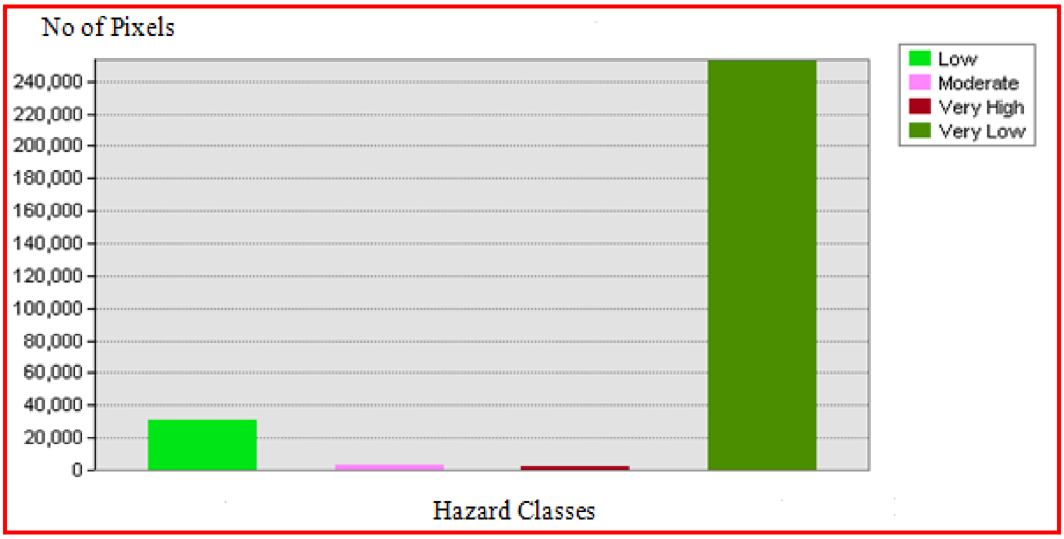


Figure 5.17: Histogram of hazard return period 1 year after classification

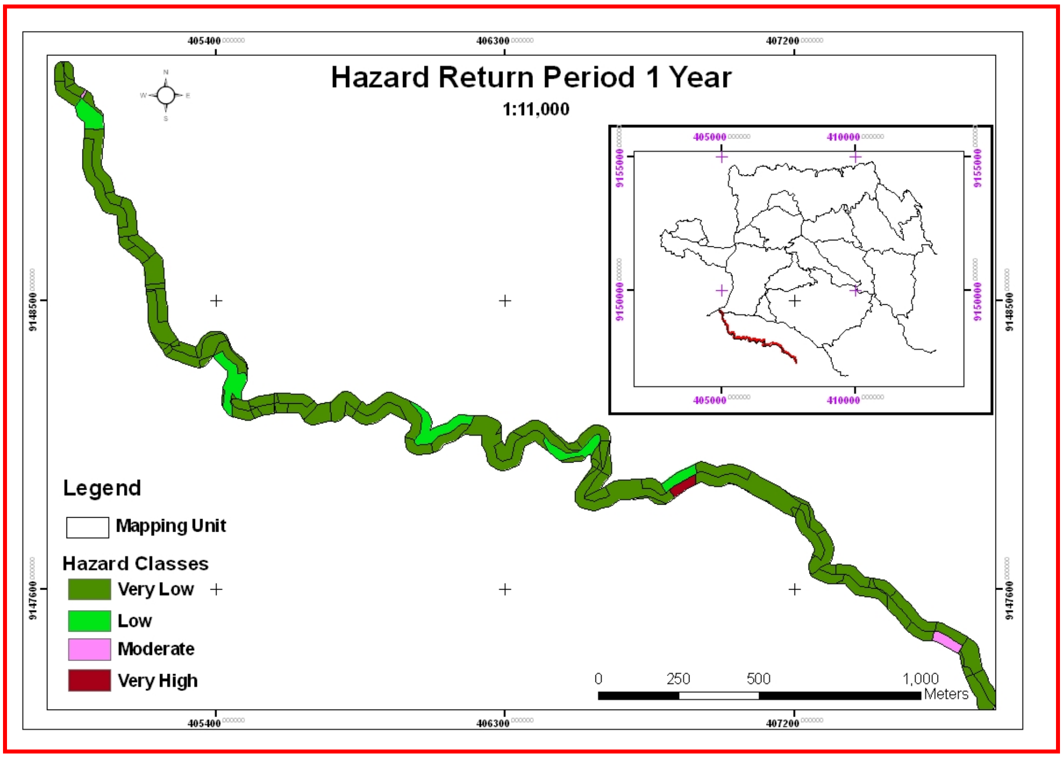


Figure 5.18: Hazard return period 1 year after classification

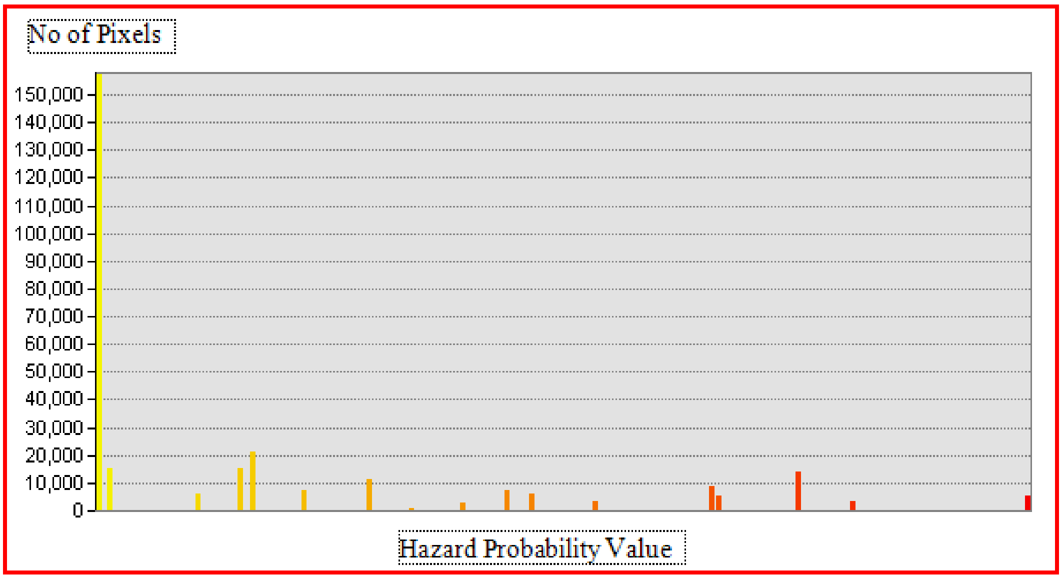


Figure 5.19: Histogram of hazard return period 3 year before classification

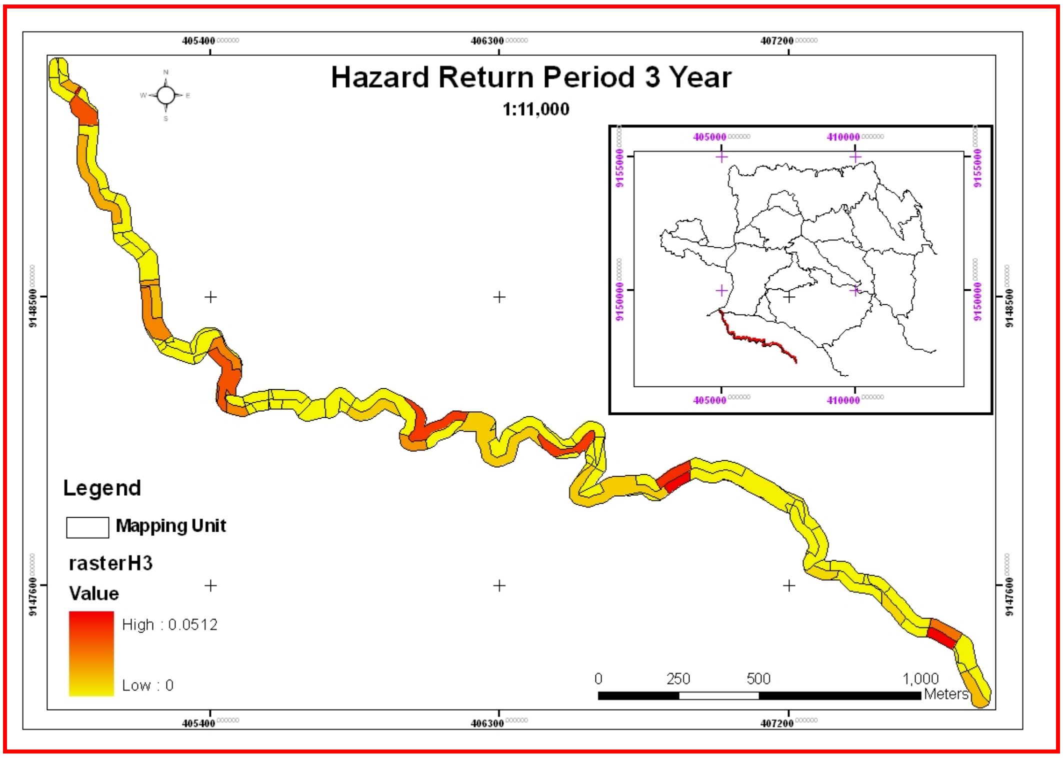


Figure 5.20: Hazard return period 3 year before classification

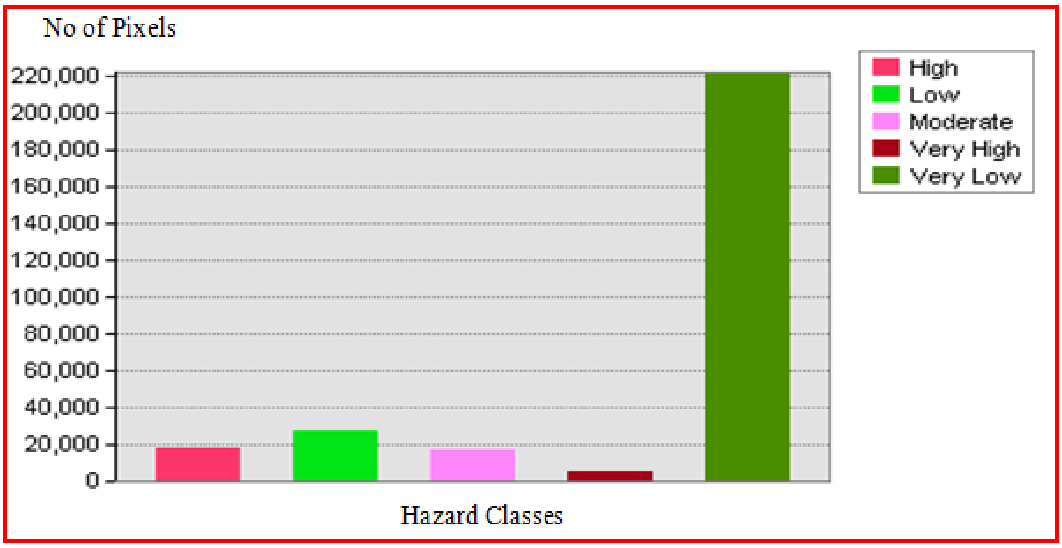


Figure 5.21: Histogram of hazard return period 3 year after classification

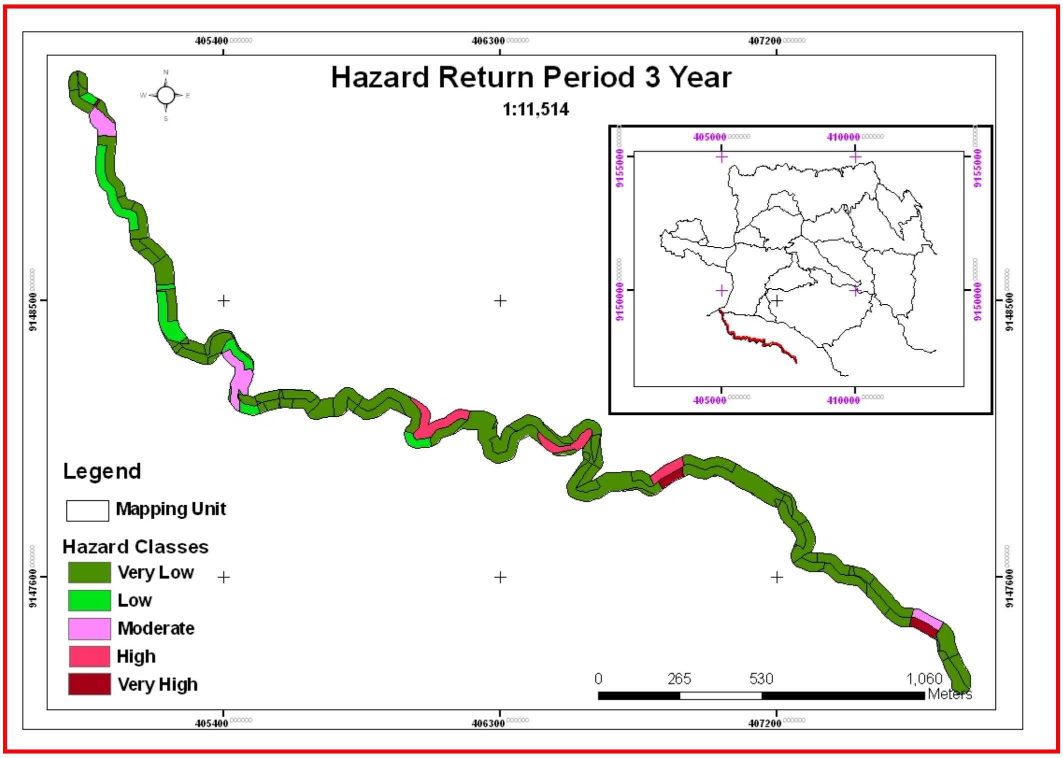


Figure 5.22: Hazard return period 3 year after classification

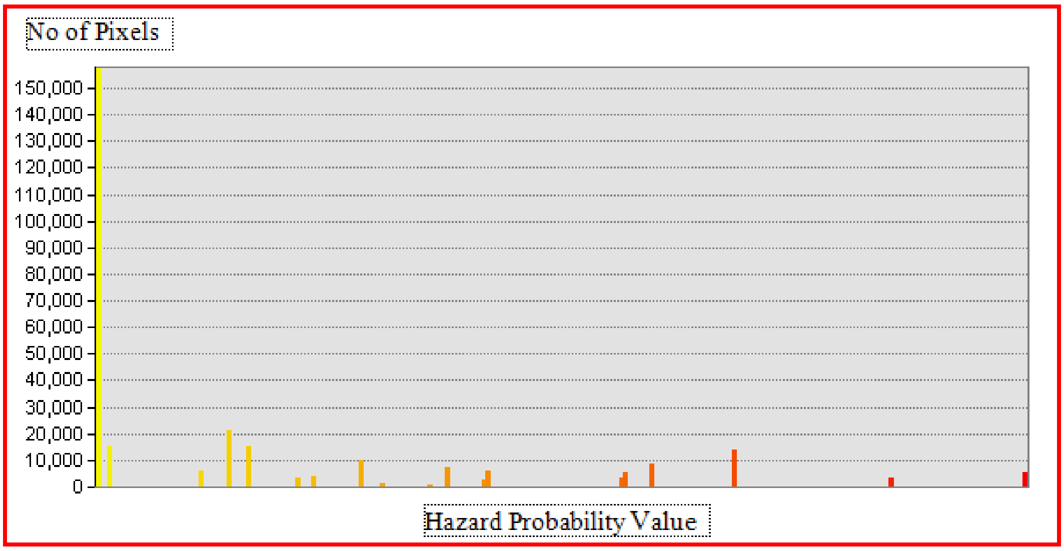


Figure 5.23: Histogram of hazard return period 5 year before classification

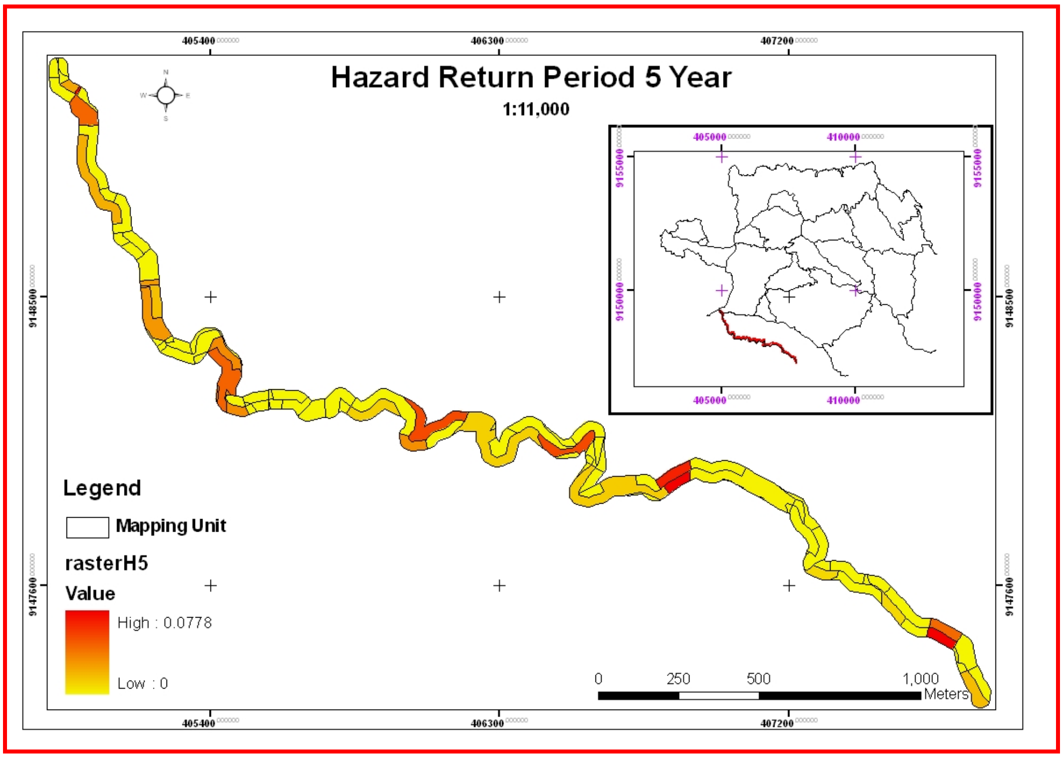


Figure 5.24: Hazard return period 5 year before classification

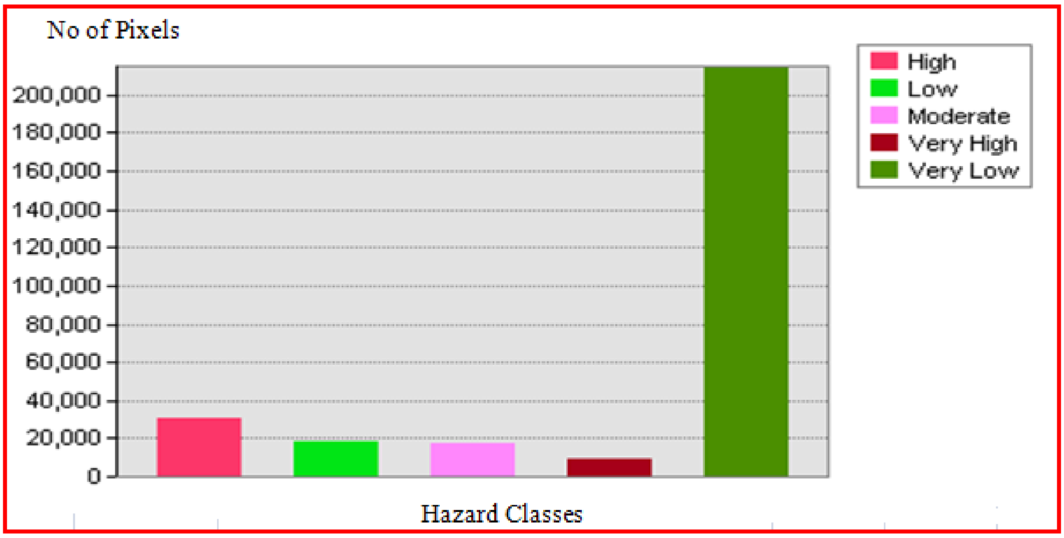


Figure 5.25: Histogram of hazard return period 5 year after classification

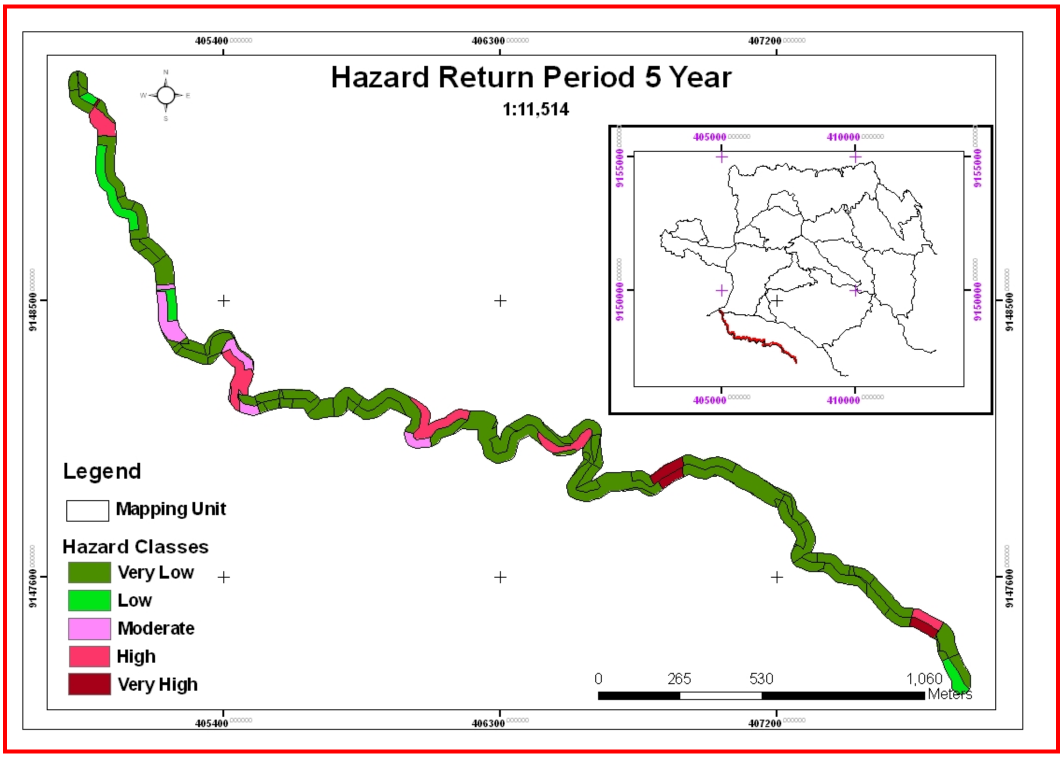


Figure 5.26: Hazard return period 5 year and its histogram after classification

5.2.4. Hazard Validation

Before calculating the risk impact, hazard must be validated by using the actual data of landslide occurrences in 2011 which have 20 landslide events. Hazard validation was done to know whether the hazard model used accordance with the real condition. In this research, author uses 3 scenarios of hazard validation which was the hazard validation to validate hazard return period 1 yr, 3 yr, and 5 yr.

Table 5.10: Hazard return period 1 year validation

No	Classes	Landslide Area (m^2)	%
1	2	3	4
1	Very Low	90.44	19.40
2	Low	135.94	29.16
3	Moderate	133.23	28.58
4	High	0.00	0.00
5	Very High	106.57	22.86
	Total	**466.18**	**100.00**

Source: Data Analysis

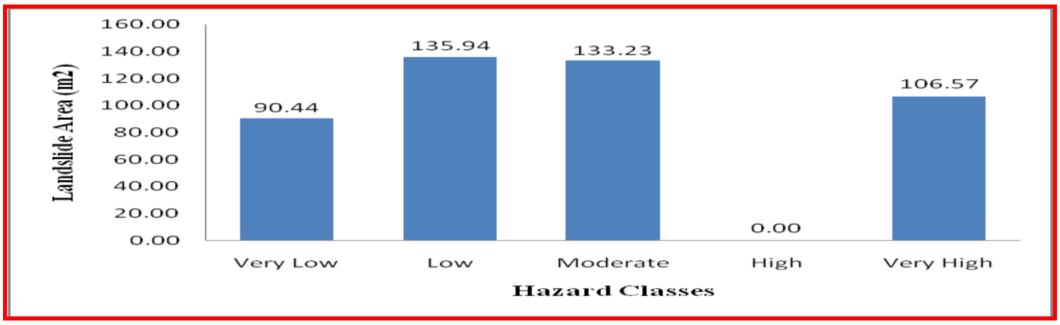


Figure 5.27: Hazard return period 1 year validation

As shown in (Table 5.10 and Figure 5.27), the distribution of landslides in term of very low, low, moderate and very high class are almost equal which are more less 20% for the validation of the hazard return period 1 yr. It due to the most of hazard class for return period 1 yr which were categorized as the very low and the low classes are 98.08% (Table 5.7)

Table 5.11: Hazard return period 3 year validation

No	Classes	Landslide Area (m^2)	%
1	2	3	4
1	Very Low	9.15	1.96
2	Low	81.29	17.44
3	Moderate	62.17	13.34
4	High	73.77	15.82
5	Very High	239.80	51.44
	Total	**466.18**	**100.00**

Source: Data Analysis

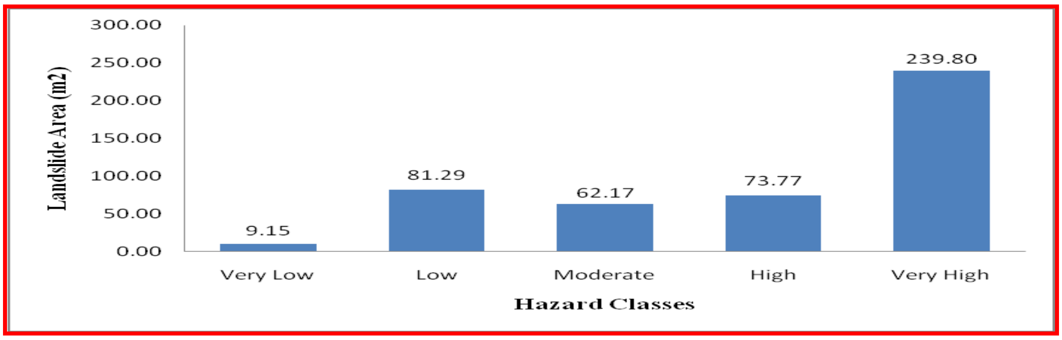


Figure 5.28: Hazard return period 3 year validation

For hazard return period 3 yr validation, the most of landslide events in 2011 are located in the high and very high classes which have percentage of 15.82% and 51.44% respectively (Table 5.11 and Figure 5.28).

Table 5.12: Hazard return period 5 year validation

No	Classes	Landslide Area (m^2)	%
1	2	3	4
1	Very Low	5.94	1.27
2	Low	15.74	3.38
3	Moderate	68.75	14.75
4	High	135.94	29.16
5	Very High	239.80	51.44
	Total	**466.18**	**100.00**

Source: Data Analysis

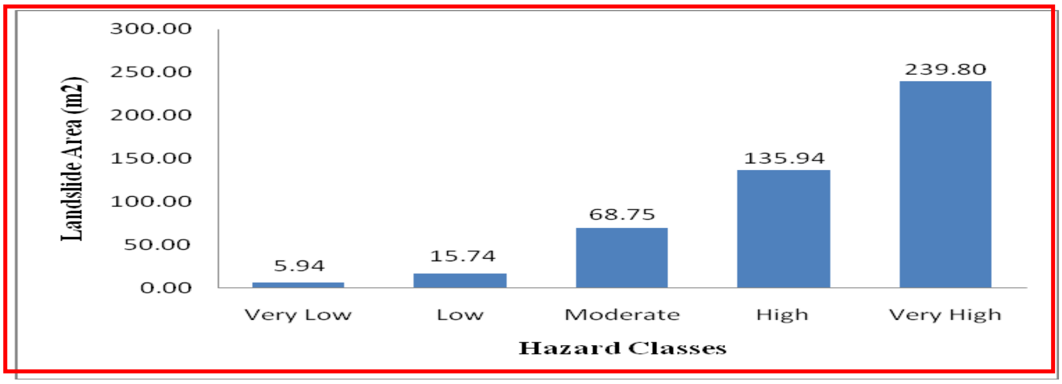


Figure 5.29: Hazard return period 5 year validation

According to (Table 5.12 and Figure 5.29), the same trend still occurred in hazard return period 5 yr validation in which the most of landslide occurrences can be found in the high (29.16%) and very high class (51.44%).

Based on (Table 5.10, 5.11, 5.12 and Figure 5.27, 5.28, 5.29), the most of landslide events in 2011 are distributed in the high class and the very high class. It means that the hazard model can be used.

5.3. Road Vulnerability

In this study, author focused only on road network as element at risk. Author didn't consider vehicle and commuters vulnerability, because there has been no incidence of landslides that hit the object. So it was difficult to determine vulnerability of vehicle and commuters because of the absence of historical record. Based on local community information, landslide events usually occurred during heavy rainfall and or night time in which the most people lived in their home.

Road vulnerability was calculated by dividing road damage area with road area in particular of mapping unit (equation 4.4). It can be shown in (section 4.1.4). In this case, road damage was caused by the landslide destroying roads and the landslide mass covering roads. It was assumed that between road damage due to the landslide destroying road and the landslide mass covering road have the same influence of traffic interruption. Road damage area was obtained from field work and local community discussion. Fortunately, local community still remembers the boundary of road damage, so it can be determined road damage area. Road vulnerability segment 174 can be shown in (Table 5.13 and Figure 5.30).

Table 5.13: Road vulnerability on segment 174

MU	**Road Area (m^2)**	**Road Damage Area (m^2)**	**Road Vulnerability** (2 : 3)
1	2	3	4
1	187.84	10.58	0.0563
6	310.21	76.23	0.2458
7	318.53	25.26	0.0793
9	658.37	10.82	0.0164
18	1,143.65	2.03	0.0018
20	111.49	79.52	0.7133
21	235.52	14.47	0.0614
23	1,236.48	12.75	0.0103
31	448.51	128.10	0.2856
37	1,284.77	45.50	0.0354
38	211.71	28.38	0.1341
49	566.78	23.68	0.0418
50	352.64	84.72	0.2402
58	568.32	42.65	0.0750
59	225.50	14.42	0.0639
60	49.98	8.16	0.1633
66	1,031.78	39.24	0.0380
69	360.64	48.18	0.1336
71	29.57	5.67	0.1918
73	173.15	11.17	0.0645

Source: Data Analysis.

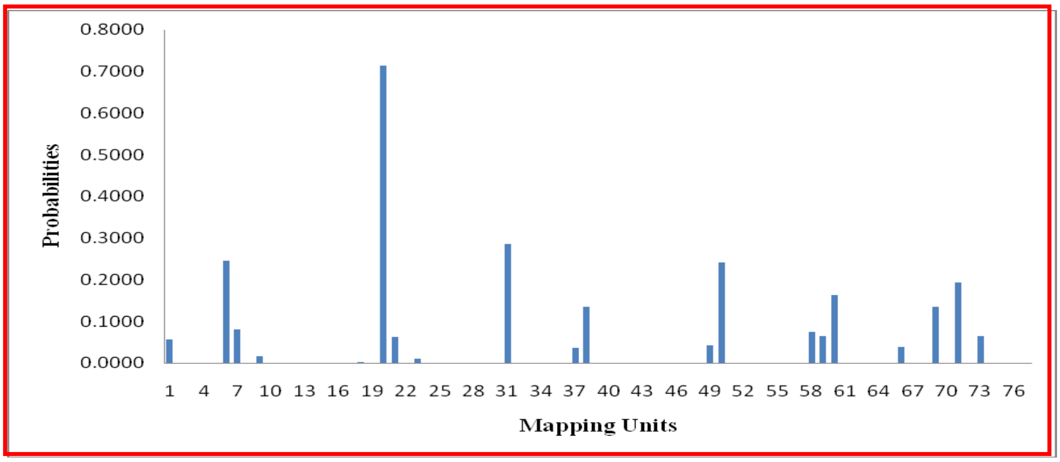


Figure 5.30: Road vulnerability distribution on segment 174

In roads segment 174, the most of road damage was caused by the landslide covering road which is 86.84% of all of landslide events. 13.15% of landslide events were categorized as the landslide destroying road. Based on (Table 5.13 and Figure 5.30), the highest road vulnerability lies on the 20th mapping unit which is 0.7133 road vulnerability. The biggest landslide with the volume of 280 m^3 was occupied in this mapping unit. This landslide was categorized as the landslide covering road which will cause asphalt covered (79.52 m^2). In the 20th mapping unit, the road area (asphalt) is 111.49 m^2. It means the percentage of road damaged is the biggest of all of mapping units. That's why, the 20th mapping unit has the highest road vulnerability. The lowest road vulnerability located in the 18th mapping unit which has 0.0018 road vulnerability. This landslide was categorized as the landslide destroying road which caused asphalt destroyed (2.03 m^2) only. The road area (asphalt) of the 18th mapping unit is 1143.65 m^2 which is larger than the road area of the 20th mapping unit. In other hands, the percentage of road damaged in the 18th mapping unit is the lowest among all of mapping units.

By using equation 4.7 in (section 4.1.7.), road vulnerability data were classified. (Figure 5.31, Figure 5.32) shows road vulnerability map and their histogram before classification. We can see that road vulnerability probability distributions are still dominated by the low probability values (yellow color).

Road vulnerability classification considers 5 interval of classes which are very low (0 - 0.14266), low (0.14266 - 0.28532), moderate (0.028532 - 0.42798), high (0.42798 - 0.57064), and very high (0.57064 - 0.7133). After classifying, road vulnerability segment 174 has 4 vulnerability classes only which are very low, low, moderate, and very high class and followed by the absence of high class. Spatially, after classifying, road vulnerability and its histogram can be depicted in (Figure 5.33, Figure 5.34) and the percentage of road vulnerability classes can be seen in (Table 5.14).

The very low class dominates road vulnerability class on segment 174 which can be found in almost of mapping unit or 90.07% of total area. The very high class located in the 20th mapping unit which has the highest of road vulnerability. The moderate class located in the 31st mapping unit only. The low class can be found 4 times on segment 174 which are the 6th, 50th, 60th and 71th mapping units. This condition compatible with the Jaiswal's Landslide Magnitude Classification that landslide magnitude I caused minor damage only. That's why, the vulnerability class is still dominated by very/low class.

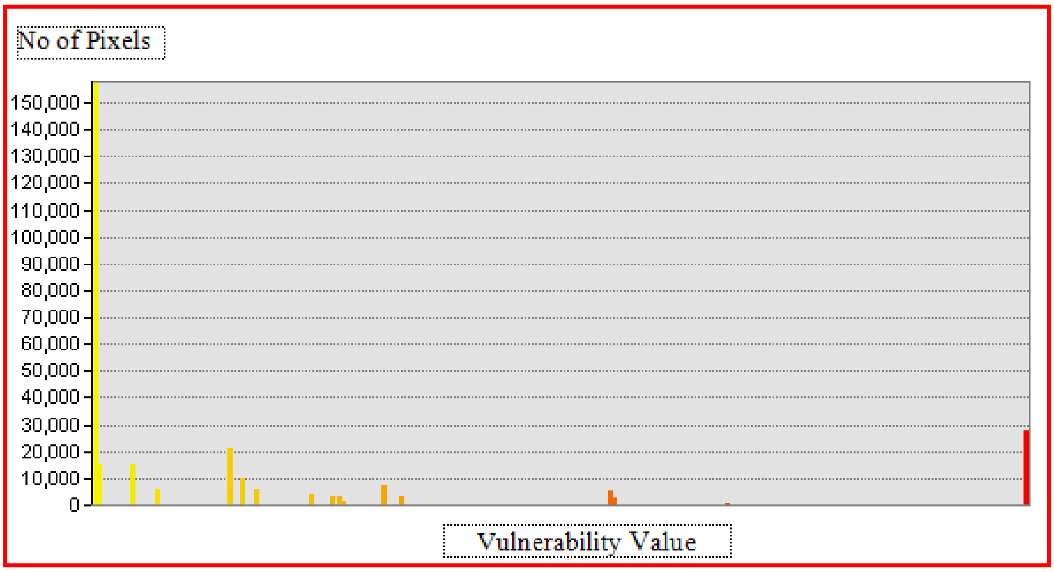


Figure 5.31: Histogram of road vulnerability before classification

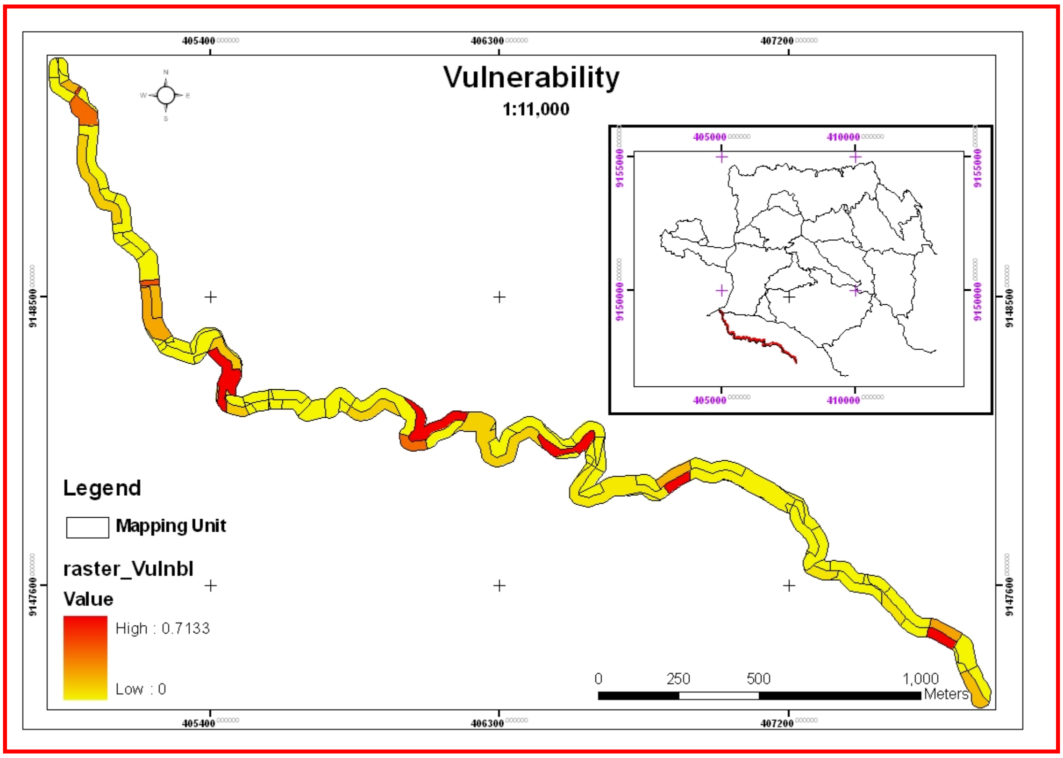


Figure 5.32: Road vulnerability before classification

Figure 5.33 : Histogram of road vulnerability after classification

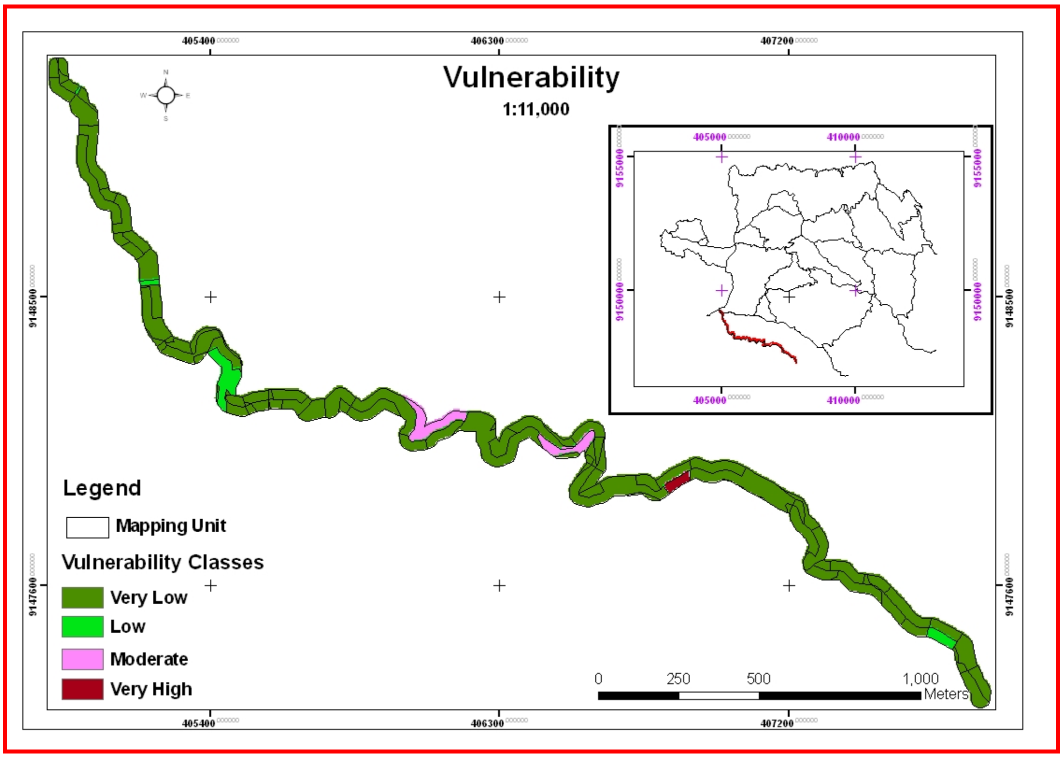


Figure 5.34 : Road vulnerability after classification

Table 5.14: Percentage of road vulnerability classes on segment 174

No	Vulnerability Classes	Class Area (m^2)	%
1	**2**	**3**	**4**
1	Very Low	261,106.71	90.07
2	Low	12,340.56	4.26
3	Moderate	13,960.32	4.82
4	High	0.00	0.00
5	Very High	2,500.44	0.86
	Total	**289,908.03**	**100.00**

Source: Data Analysis.

5.4. Direct Impact

Direct risk assessment in this study was developed for various scenarios on the basis of magnitude class, landslide type, return period, and estimating cost of road damage. In this study, all of landslides which have 2 types of landslides (i.e. rock fall and debris slide) were categorized as magnitude I. Return period used 3 types of return period scenarios which were 1 yr, 3 yr and 5 yr. Cost of road damage was calculated in term of road construction cost and removing debris cost. Cost standard of road construction and removing debris can be obtained from Public Works Office Kulon Progo Regency (Table 5.15). In this case, removing debris was done manually by local people. Debris volume for each landslide can be obtained from Kebon Harjo Village Office estimation. Road construction will be done on road destroyed landslide which is located in 5 of mapping units (i.e. 1^{st}, 7^{th}, 18^{th}, 21^{st} and 49^{th}). The most of road damage cost was caused by removing landslide debris which was occurred in 15 of mapping units. Actually, road damage cost during 10 years is Rp. 32,334,444.29. Actual road damage cost is not equal with direct impact, because it hasn't considered vulnerability and hazard probability.

Table 5.15: Cost Standard of Removing Debris and Road Construction

No	**Detail Cost**	**Unit**	**Cost Standard (Rp)**
1	2	3	4
1.	Removing Debris	m^3	23,854
2.	Road Construction, consist of :		
a.	Upper Foundation Layer (0.1 m of thickness)	m^3	288,593
b.	Lower Foundation Layer (0.2 m of thickness)	m^3	240,284
c.	Asphalt (0.05 m of thickness)	m^3	1,739,951

Source: Public Works Office Kulon Progo Regency

By using formula 4.5 in (section 4.1.5), it can be determined landslide direct impact which can be shown in (Table 5.16). The distribution of direct impact on segment 174 is depicted in (Figure 5.35).

Table 5.16: Direct impact calculation on segment 174

MU	Hazard Return Period 1 yr	Hazard Return Period 3 yr	Hazard Return Period 5 yr	Vulnerability	Road Damage Cost (Rp)	Direct Impact (Rp) Return Period 1 yr (2x5x6)	Direct Impact (Rp) Return Period 3 yr (3x5x6)	Direct Impact (Rp) Return Period 5 yr (4x5x6)	Landslide Type
1	2	3	4	5	6	7	8	9	10
1	0.0012	0.0033	0.0050	0.0563	1,733,550.76	119.01	324.14	492.08	Debris Slide
6	0.0088	0.0218	0.0305	0.2458	1,848,396.68	3,976.34	9,897.32	13,866.27	Rock Fall
7	0.0030	0.0080	0.0122	0.0793	4,140,458.80	970.32	2,642.73	4,011.98	Debris Slide
9	0.0006	0.0016	0.0024	0.0164	477,882.45	4.52	12.30	18.67	Debris Slide
18	0.0001	0.0002	0.0003	0.0018	332,334.93	0.04	0.11	0.17	Debris Slide
20	0.0188	0.0512	0.0778	0.7133	6,679,120.00	89,586.69	243,995.46	370,414.67	Debris Slide
21	0.0045	0.0122	0.0185	0.0614	2,371,830.52	652.83	1,778.02	2,699.26	Debris Slide
23	0.0009	0.0023	0.0035	0.0103	1,829,991.51	16.19	44.10	66.95	Debris Slide
31	0.0049	0.0113	0.0148	0.2856	3,602,407.21	5,089.75	11,653.64	15,255.98	Debris Slide
37	0.0012	0.0025	0.0031	0.0354	1,022,244.86	43.10	91.35	113.03	Debris Slide
38	0.0022	0.0059	0.0090	0.1341	883,586.98	257.99	702.66	1,066.73	Debris Slide
49	0.0030	0.0070	0.0091	0.0418	1,159,104.81	147.43	337.55	441.89	Debris Slide
50	0.0043	0.0099	0.0129	0.2402	1,871,624.91	1,936.00	4,432.72	5,802.95	Debris Slide
58	0.0031	0.0066	0.0082	0.075	907,091.26	212.67	450.79	557.78	Debris Slide
59	0.0013	0.0033	0.0047	0.0639	320,422.95	27.45	68.32	95.72	Debris Slide
60	0.0019	0.0051	0.0077	0.1633	248,543.67	75.52	205.69	312.27	Debris Slide
66	0.0018	0.0044	0.0061	0.038	1,282,121.49	85.74	213.40	298.98	Debris Slide
69	0.0047	0.01	0.0123	0.1336	1,006,593.70	632.39	1,340.44	1,658.59	Debris Slide
71	0.0095	0.0259	0.0394	0.1918	316,501.43	578.13	1,574.58	2,390.40	Debris Slide
73	0.0016	0.0044	0.0066	0.0645	300,635.40	31.10	84.72	128.61	Debris Slide
		Total			**32,334,444.29**	**104,443.21**	**279,850.04**	**419,692.97**	

Source: Data Analysis.

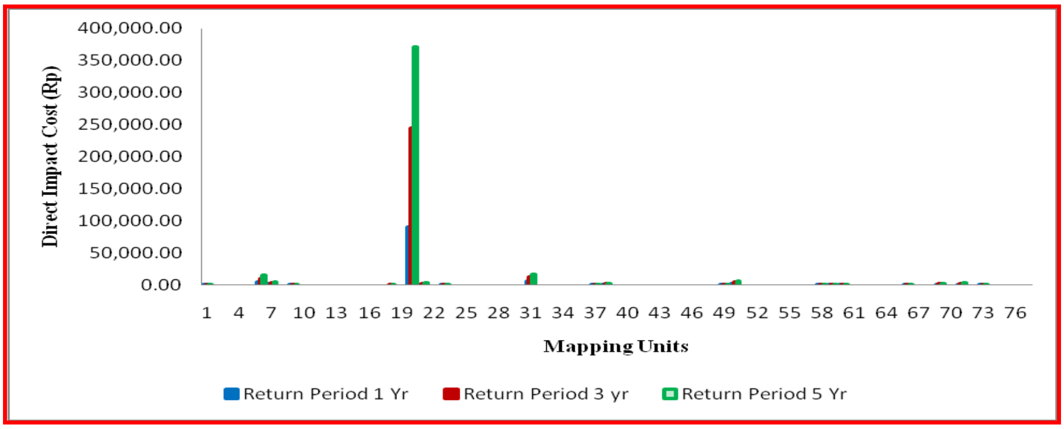


Figure 5.35 : Direct impact distribution on segment 174

As shown in (Table 5.16 and Figure 5.35) above, the highest of direct impact of debris slide of magnitude I located in the 20th mapping unit which is Rp. 89,586.69, Rp. 243,995.46 and Rp. 370,414.67 for return period 1 yr, 3 yr and 5 yr respectively. It is caused the 20th mapping unit has the highest of hazard probability and road vulnerability among the other mapping units. It is needed Rp. 6,679,120 (actual road damage) to remove debris cost which has 280 m^3. This landslide is the biggest landslide during 10 years (2001 to 2010) which caused road blockage for 14 days. The lowest of debris slide direct impact can be founded in the 18th mapping unit which has Rp. 0.04, Rp. 0.11 and Rp. 0.17 for return period 1 yr, 3 yr and 5 yr respectively. As explained before, the 18th mapping unit has the lowest hazard probability and road vulnerability among the others. Direct impact which was caused by rock fall type of magnitude I can be found in the 6th mapping unit only. The value of rock fall direct impact is Rp. 3,976.34, Rp. 9,897.32 and Rp. 13,866.27 for return period 1 yr, 3 yr and 5 yr respectively. Total cost of direct impact during 10 years for return period 1 yr, 3 yr and 5 yr can achieve Rp. 104,443.21, Rp. 279,850.04, and Rp. 419,692.97 respectively. The 20th mapping unit gives the highest direct impact contribution which contributes 85.78%, 87.19% and 88.26% of direct impact total for return period 1 yr, 3 yr and 5 yr respectively.

(Figure 5.36, Figure 5.37, Figure 5.40, Figure 5.41, Figure 5.44, and Figure 5.45) show direct impact and their histogram for return period 1 yr, 3 yr, and 5 yr before classifying. We can see that the value of direct impact distributions are dominated by the low direct impact values (yellow color). The direct impat class interval was calculated by using equation 7 in (section 4.1.7). Based on direct impact return period 1 yr value, there are 5 classes of interval which are very low (< Rp.17.917.34), low (Rp. 17.917.34 – Rp.35.834.68), moderate (Rp 35.834.68 – Rp. 53.752.01), high (Rp. 53.752.01 – Rp. 71.669.35) and very high (> Rp. 71.669.35). After classifying based on class interval above, direct impact has 2 classes only which are very low and very high. Spatialy, after clasification, direct impact class for return period 1 yr, 3 yr and

5 yr and their histogram can be depicted in (Figure 5.38, Figure 5.39, Figure 5.42, Figure 5.43, Figure 5.46, and Figure 5.47).

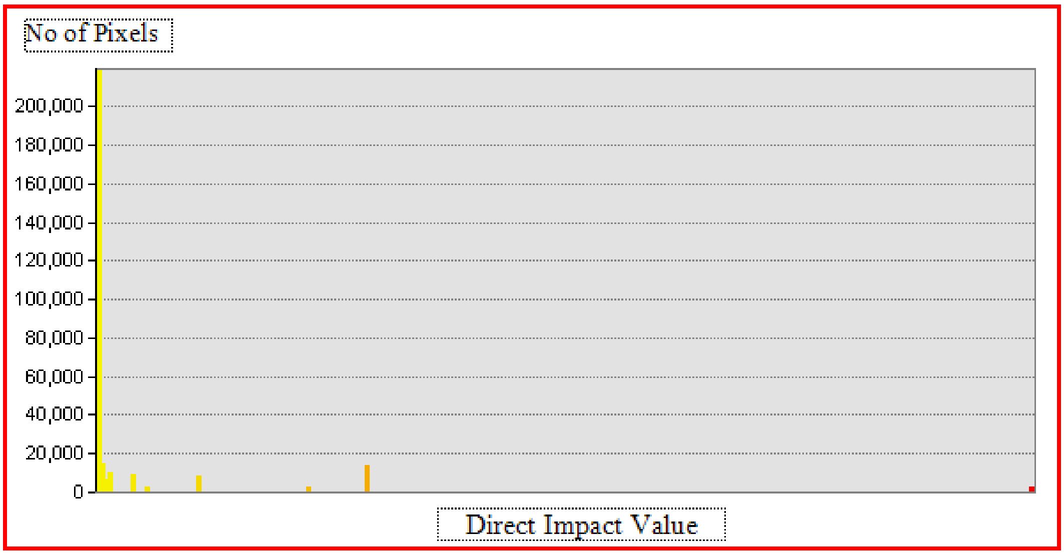


Figure 5.36: Histogram of direct impact return period 1 yr before classification

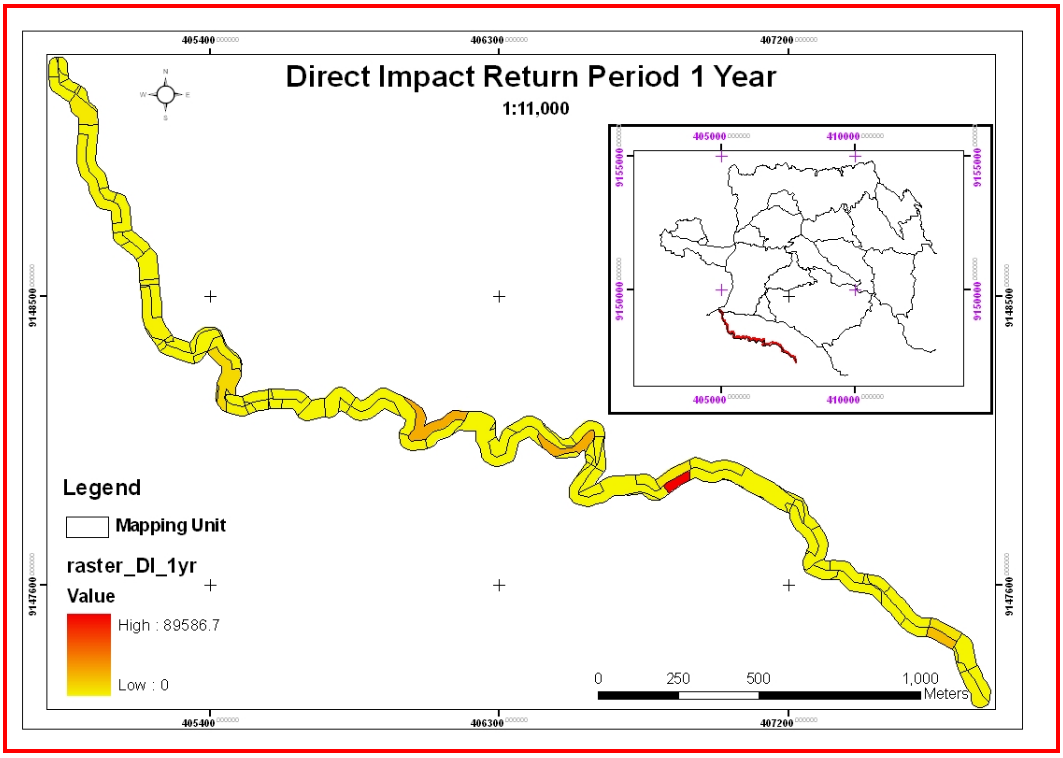


Figure 5.37: Direct impact return period 1 yr before classification

Figure 5.38 : Histogram of direct impact return period 1 yr after classification

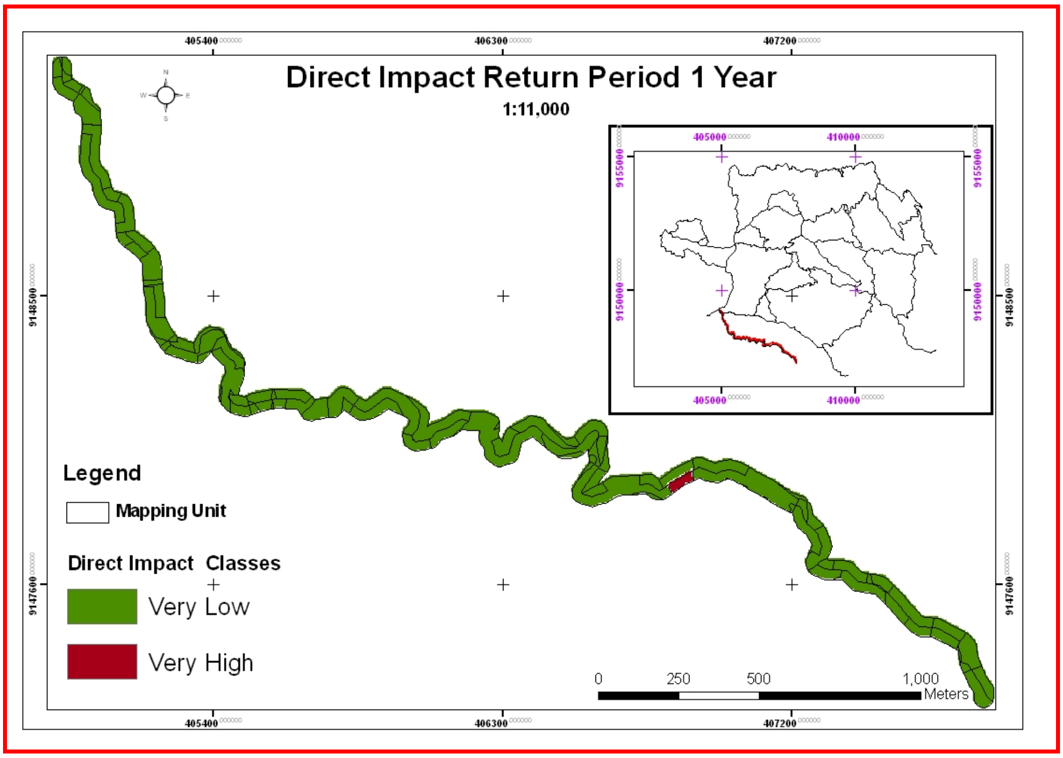


Figure 5.39 : Direct impact return period 1 yr after classification

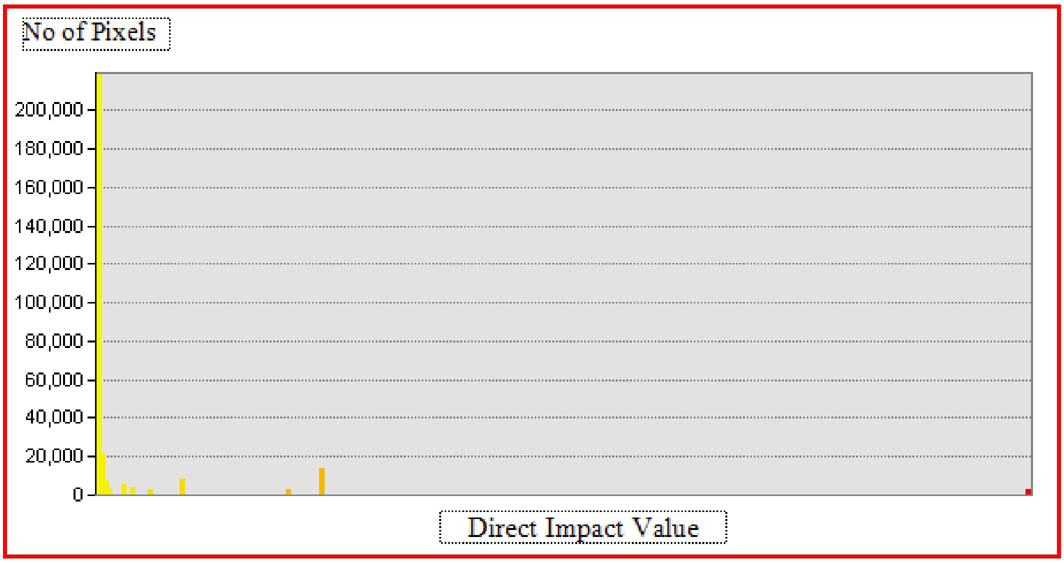


Figure 5.40: Histogram of direct impact return period 3 yr before classification

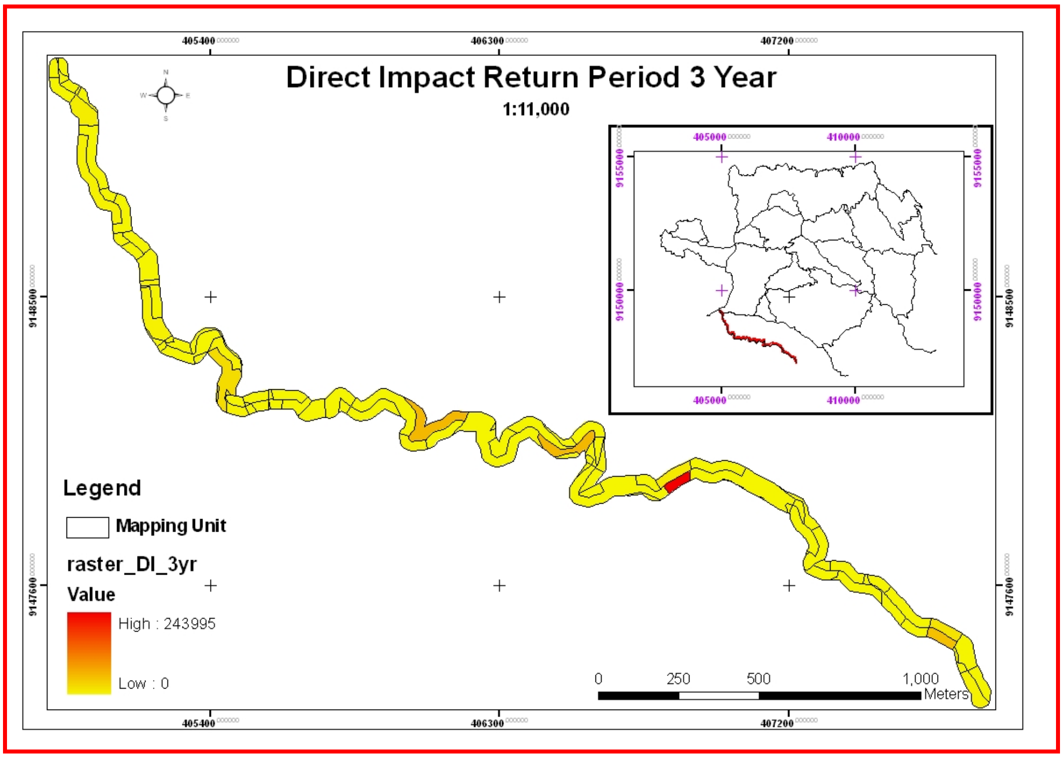


Figure 5.41: Direct impact return period 3 yr before classification

Figure 5.42 : Histogram of direct impact return period 3 yr after classification

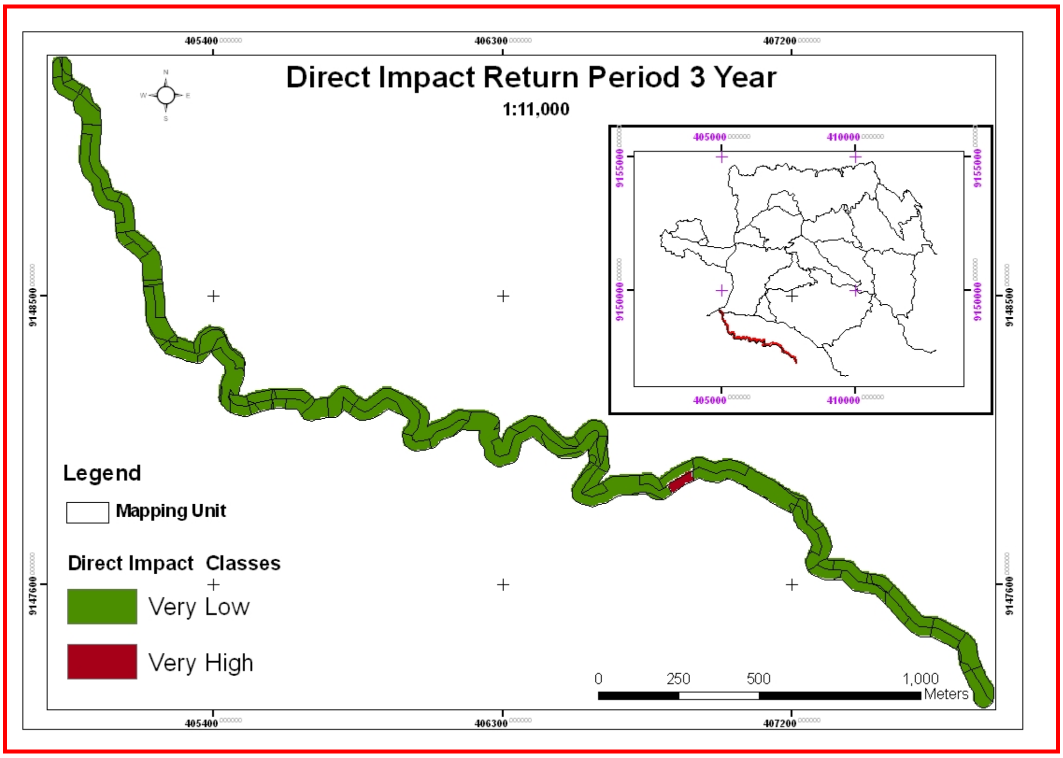


Figure 5.43 : Direct impact return period 3 yr after classification

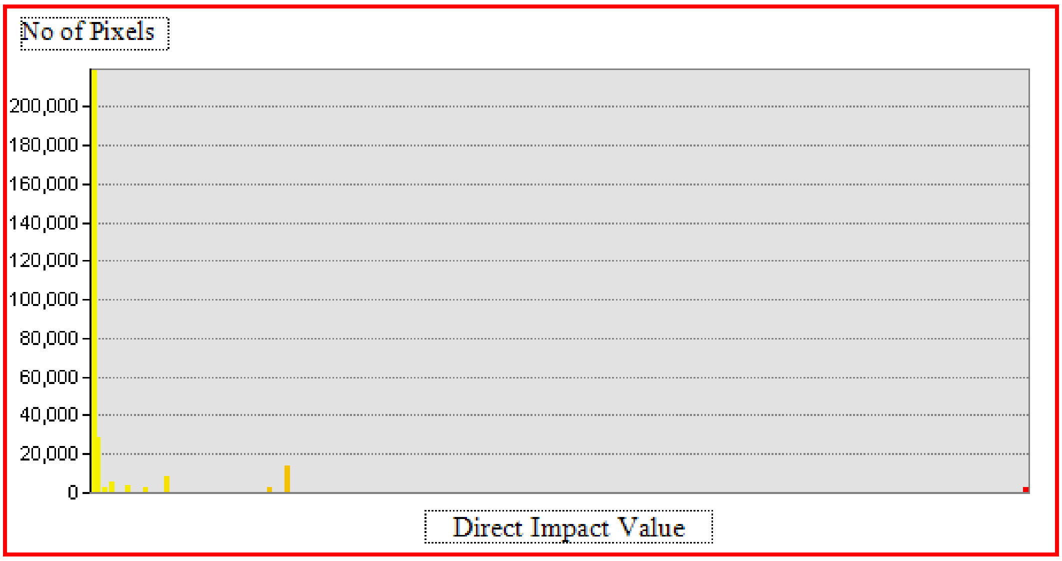


Figure 5.44: Histogram of direct impact return period 5 yr before classification

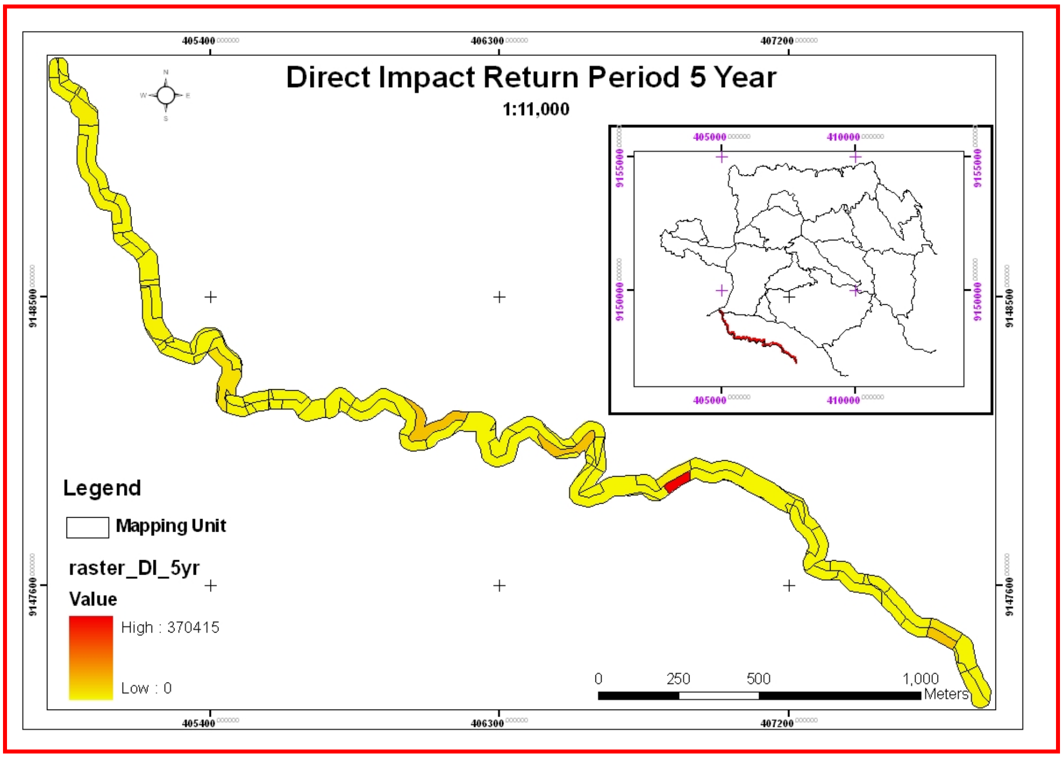


Figure 5.45: Direct impact return period 5 yr before classification

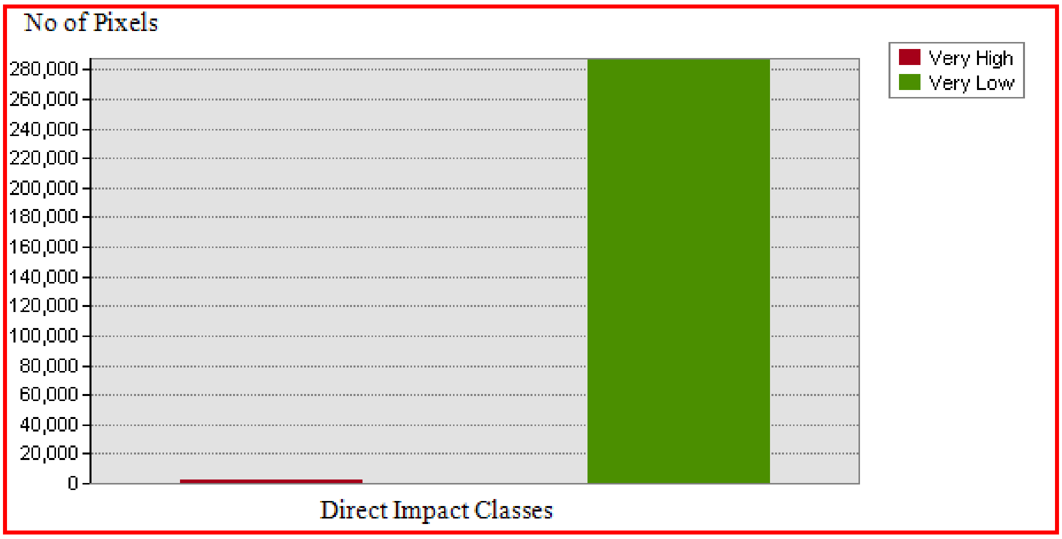


Figure 5.46 : Histogram of direct impact return period 5 yr after classification

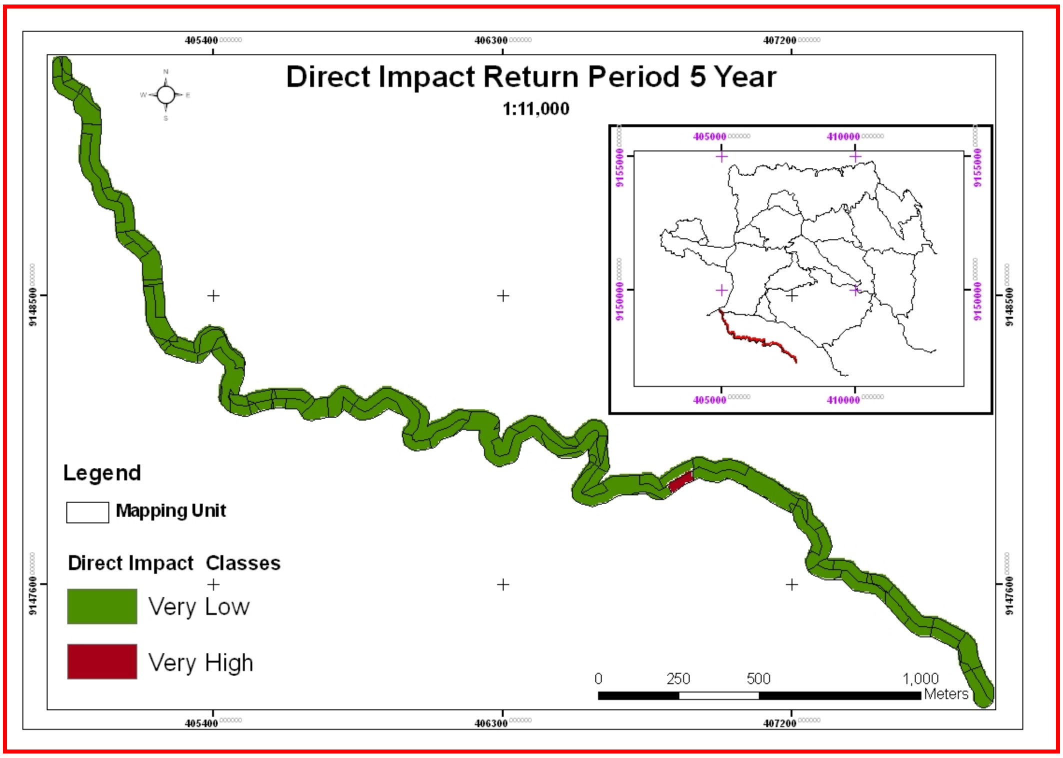


Figure 5.47 : Direct impact return period 5 yr after classification

Based on Figures 5.39, Figure 5.43 and Figure 5.47, segment 174 has 2 classes of direct impact which are the very low and the very high and followed the absence of the low class, the moderate class and the high class. It due to the contrasting of direct impact value between the 20th mapping unit and the others, it can seen in (Figure 5.35). (Figure 5.48) shows the impact of the biggest landslide which lies in the 20th mapping unit can cause road blockage and house damage. The most of mapping unit for return period 1 yr, 3 yr and 5 yr were categorized as the very low direct impact class which is 99.14% of total areas and 0.86% can be categorized as the very high direct impact class. It can be seen in (Table 5.17). The very low of direct impact of segment 174 is caused by the low of road vulnerability and hazard probability for return period 1 yr, 3 yr and 5 yr.

Table 5.17: Percentage of direct impact classes on segment 174

No	Direct Impact Classes	Total Area (m2)	%
1	2	3	4
1	Very Low	287,407.58	99.14
2	Low	0.00	0.00
3	Moderate	0.00	0.00
4	High	0.00	0.00
5	Very High	2,500.44	0.86
	Total	**289,908.03**	**100.00**

Source: Data Analysis

Figure 5.48: Road blockage and house damaged due to the biggest landslide in the 20th mapping unit in 2009. A) House damaged, B) and C) Debris slide was removed by community. (Source: KORAMIL Samigaluh), D) Recent condition of the biggest landslide (Source: Eko Setya N, 2011)

5.5. Indirect Impact

In this research, indirect impact was determined by road blockage which was caused by landslide. Because of road blockage, driver or commuter will find alternative road which has longer distance to reach public facility. This condition will cause the increasing of fuel purchases cost. Landslide indirect impact will be determined on segment 174 which consider the longest of road blockage time and full road blockage. Because it will give a significant contribution to indirect costs

Actually, Segment 174 has 38 landslide events but the significant of road blockage time occurred in the 20^{th} mapping unit. It was caused by the biggest landslide in 2009 year which caused road blockage for 14 days. Landslide has 280 m^3 debris volumes which were removed manually by local people. As discussed in (section 5.2 and 5.3) before, in this segment, it has the highest of landslide hazard and road vulnerability. Actually, along 4.85 Km of segment 174, there are two public facilities which are Balai Desa Kebonharjo (Kebonharjo Village Office) and SDN Kebonharjo (Kebonharjo State Elementary School) (Figure 5.49). Kebonharjo village has SDN Kebonharjo only in which almost of children will study in this school. Balai Desa Kebonharjo also is needed by the all of Kebonharjo Village communities in getting the services related to their rights and obligations as citizens (e.g. social, land affair, population administration, etc.). Because of road blockage, people who will go to Balai Desa Kebonharjo and SDN Kebonharjo will find the alternative route. This condition will cause the increasing of fuel purchases cost for 14 days.

Figure 5.49: Public facility of Kebonharjo Village; A) SDN Kebonharjo, B) Balai Desa Kebonharjo (Source : Eko Setya N, 2011)

Landslide indirect impact can be calculated by using equation 4.6 in (section 4.1.6.). This formula has several variables which are road blockage days, the number of vehicle of a particular type (traffic density), extend road alternative distance and fuel consumption. Road blockage data can be obtained from local community information. Traffic density data were got by field work measurement on segment 174. Alternative routes can be determined by using network analysis and community perception. Fuel consumption and community perception data can be obtained by local community interviewing (questionnaire).

5.5.1. Traffic Density

In this study, author obtained traffic density data from field work measurement which was done by measuring at 6 measurement points simultaneously for 7 days. (Figure 5.50) depicts the 6 measurement points which are I, II, III, IV, V and VI. II and IV located near public facilities which are Balai Desa Kebonharjo and SDN Kebonharjo. While I and VI can be found in the exit and entrance way of road segment 174.

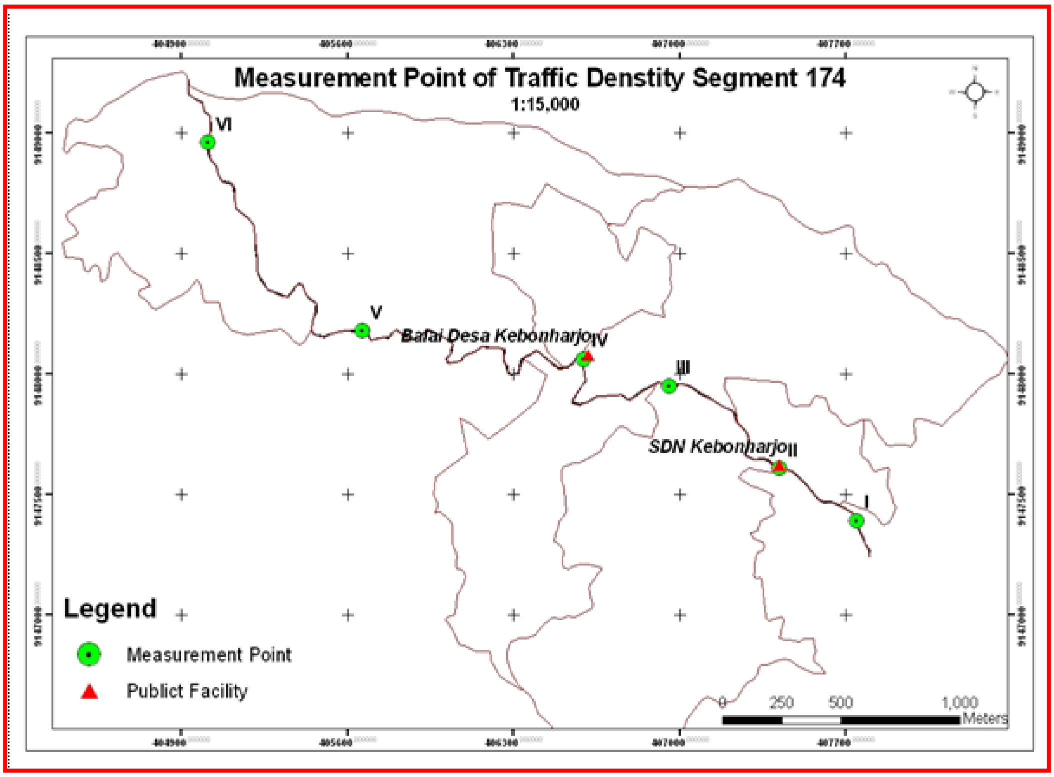


Figure 5.50: Measurement points on segment 174

Traffic density was measured by considering vehicles type (e.g. motor cycle, car and truck) in term of several measurement time scenarios. Measurement time scenarios were divided into 2 categories which are peak time (e.g. 6.30-7.30, 12.30-1.30 and 16.00-17.00) and non peak time (e.g. 9.00-10.00 and 14.00-15.00). Night time wasn't considered in this scenario because there weren't almost nothing commuters passing segment 174. (Table 5.18 and Figure 5.51) show the average of traffic density in term of measurement time. Based on Transportation, Communication and Information Office Kulon Progo Regency, it was used the rounding number to describe traffic density value. Traffic density which has value ≥ 0.5 will be rounded to be 1. Conversely, traffic density has value < 0.5 will be 0.

Table 5.18: The average of traffic density in term of measurement time on segment 174

Measurement	**The Actual Number of Vehicles Type**			**The Rounding Number of Vehicle Type**			**Description**
Time	**Motor Cycle**	**Car**	**Truck**	**Motor Cycle**	**Car**	**Truck**	
1	2	3	4	5	6	7	8
6.30-7.30	12.87	2.08	0.49	13	2	0	Peak time
9.00-10.00	7.94	1.39	0.18	8	1	0	Non Peak Time
12.30-1.30	11.37	2.37	1.04	11	2	1	Peak time
14.00-15.00	8.87	1.52	0.50	9	2	1	Non Peak Time
16.00-17.00	11.64	1.94	0.63	12	2	1	Peak time
Average	**10.54**	**1.86**	**0.57**	**11**	**2**	**1**	

Source: Fieldwork Analyst

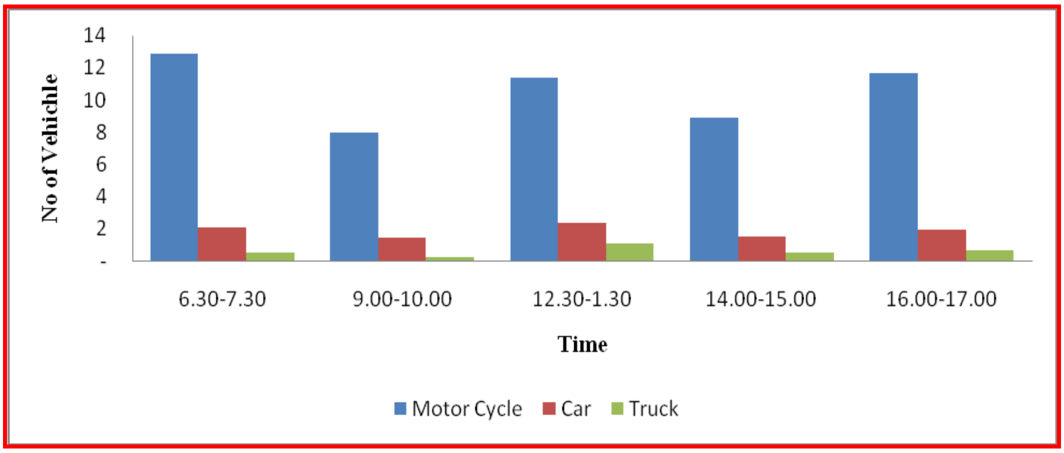


Figure 5.51 :The average of traffict density in term of measurement time on segment 174

As shown in (Tabel 5.18 and Figure 5.51), we can know peak time have higher traffic density than non peak time. It due to several reason which are :

a. The First Peak Time (6.30-7.30)

   In the morning, a lot of commuters who will start their activities pass this segment. They will go to their work place (e.g.office, paddy field, mixed garden etc). Some of them work near Kebonharjo Village. Others work in Yogyakarta or Wates city and come back in the evening. Children accompany with their parents go to school. This condition lead to traffic more dense.

b. The Second Peak Time (12.30-1.30)

   Several people come back from their office, mixed garden, moor and paddy field near their home. Beside that, children have came back from their schools.

c. The Third Peak Time (16.00-17.00)

   Commuter is dominated by people who come back from their working or school in Yogyakarta or Wates City. They work as construction workers, factory workers, office administration, and salesman and so on. While, in the same time, students come back from their campus or school in Yogyakarta city.

Type of vehicles are dominated by motor cycle and followed by car and truck. It shows that the most of Kebonharjo citizens have motor cycle and only few residents have car. This is related with the purchasing power and incomes of Kebonharjo citizen. There are no residents who have trucks. Trucks which are used to transport construction material and log are owned by people outside the village.

As shown in (Figure 5.50), traffic density was measured in 6 locations (measurement points) which are I, II, III, IV, V and V. (Tabel 5.19 and Figure 5.52) show the average of traffic density in term of measurement points in segment 174.

Table 5.19: The average of traffic density in term of measurement points on segment 174

Measurement Points	The Actual Number of Vehicles Type			The Rounding Number of Vehicle Type		
	Motor Cycle	Car	Truck	Motor Cycle	Car	Truck
1	2	3	4	5	6	7
I	11.63	3.13	1.79	12	3	2
II	15.26	2.13	0.47	15	2	0
III	8.49	1.71	0.06	8	2	0
IV	10.56	2.24	0.03	11	2	0
V	8.50	0.76	0.29	9	1	0
VI	8.80	1.20	0.77	9	1	1
Average	**10.54**	**1.86**	**0.57**	**11**	**2**	**1**

Source: Fieldwork Analyst

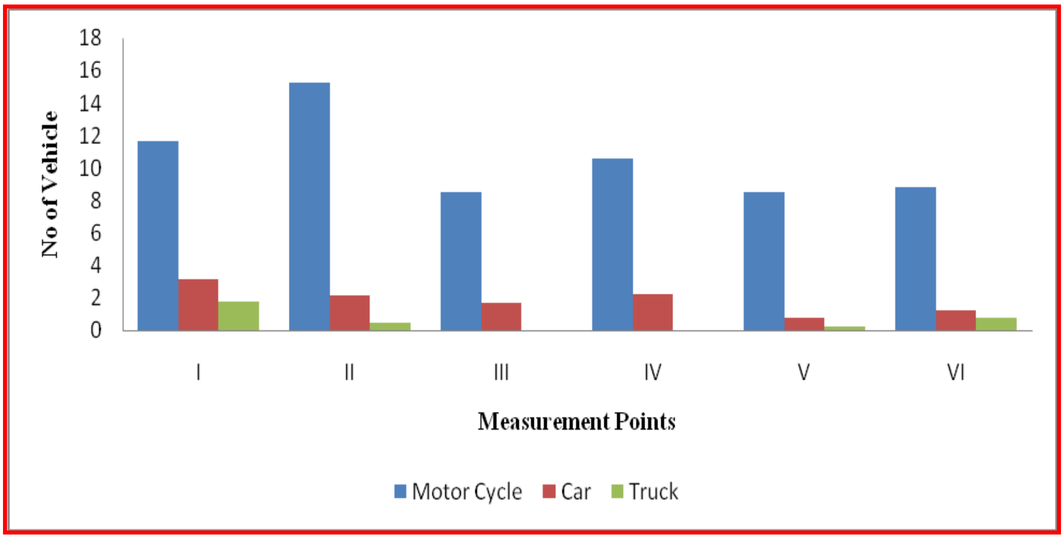


Figure 5.52 : The average of traffict density in term of measurement points on segment 174.

The measurement points of I, II and IV have traffic density higher than others. It due to several reasons which are:

a. The I measurement point

This location has higher traffic density because this location which has gentler slope than slope in the VI measurement point is the entrance and exit paths to and from Kebonharjo Village. This condition causes people who want to get into or out of Kebonharjo Village prefer to choose this location.

b. The II measurement point

   The II measurement point is located near SDN Kebonharjo (public facility) which is as education facility. Many people need this facility, so they will go toward this direction or the opposite direction. That's why the II measurement point has relatively high traffic density.

c. The IV measurement point

   This location lies near Balai Desa Kebonharjo. Balai Desa Kebonharjo is like SDN Kebonharjo as public facility in which many people will come to these locations. It causes this location has a high traffic density.

In this case, motor cycle still dominates all of measurement points and followed by car and truck respectively. Trucks which transport road material are concentrated at the I, II, V and VI measurement points only because there are road reparation activity near these segment. Based on (Table 5.18), it can be determined the average of commuter passing segment 174 per hours which are 11 motor cycles, 2 cars and 1 truck. In other hand, there are 132 motor cycles, 24 cars and 12 trucks in one day (12 hours). In this case, night time scenario wasn't considered in traffic density calculation because almost no commuters pass segment 174 in the night time.

5.5.2. Alternative Route

Debris slide which caused road blockage for 14 days located in the 20th mapping unit. The 20th mapping unit lies between Balai Desa Kebonharjo and SDN Kebonharjo. Thus, it caused commuter will look for alternative route to achieve these public facilities. In this research, author used network analysis and community perception to determine the optimum route as alternative route. Several routes can be considered as the alternative routes to reach Balai Desa Kebonharjo and SDN Kebonharjo. Alternative routes which are the routes connecting between Pringtali to Balai Desa, Pringtali to Kleben, Gebang to Balai Desa and Gebang to Kleben can be used to achieve Balai Desa Kebonharjo. Besides that, to achieve SDN Kebonharjo can be considered several routes as alternative route, such as: the routes connecting between Dangsambuh to Pringtali and Dangsambuh to Gebang. These alternative routes can be seen in (Figure 5.39).

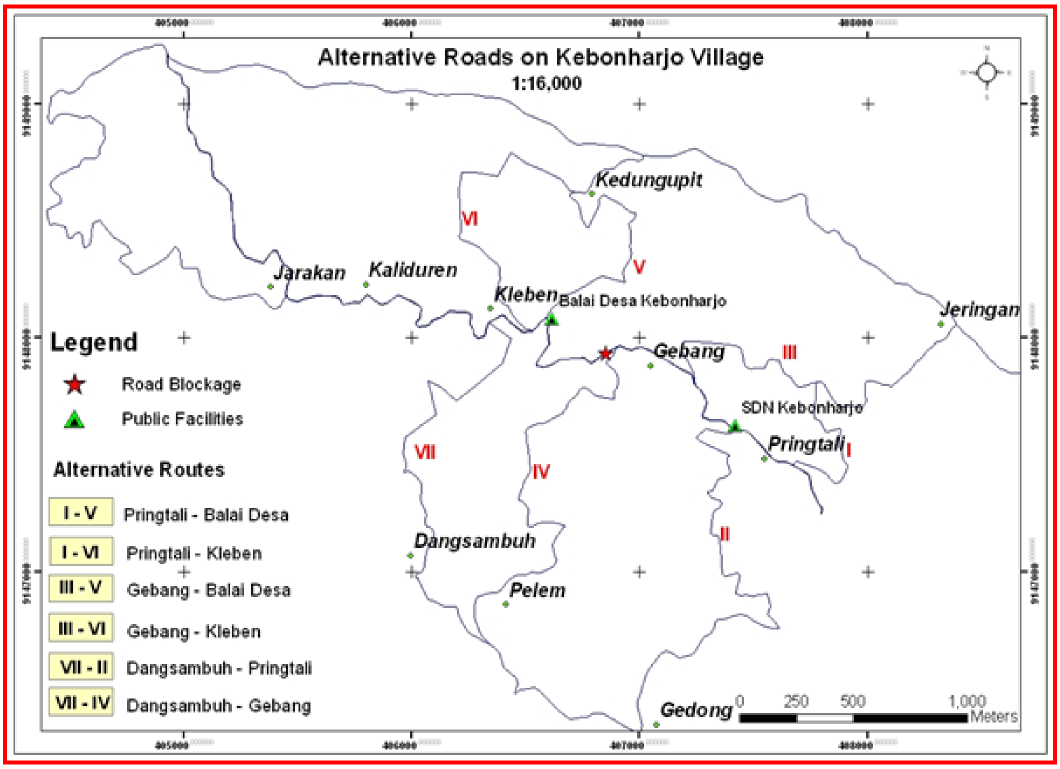


Figure 5.53 :The alternative road on Kebonharjo Village

5.5.2.1. Network Analysis

Network analysis is one of tools operations in GIS which is used to determine optimum route, closest facilities, allocation (service area), location-allocation, urban transportation planning model. (Curtin, 2007) stated that in GIS software, there are four fundamental operations deal with network analysis, such as : finding a route between point locations, determining the service area for a facility, finding the closest facility across the network and creating an origin–destination matrix. In this study, network analysis was used to determine the optimum route which is as alternative route to achieve public facilities (e.g. Balai Desa Kebonharjo and SDN Kebonharjo). In this case, the biggest landslide which was assumed as barrier will close commuters to reach public facilities. The optimum routes which were used as the alternative routes based on network analysis can be depicted in (Figure 5.54). Based on (Figure 5.54), it can be known that the Pringtali to Balai Desa route is optimum route which was chosen as alternative route to achieve Balai Desa Kebonharjo. In other hand, the Dangsambuh to Gebang is the optimum route to achieve SDN Kebonharjo. The origin point which was used network analysis is the highest dense settlement. While, as the final destination point is public facility.

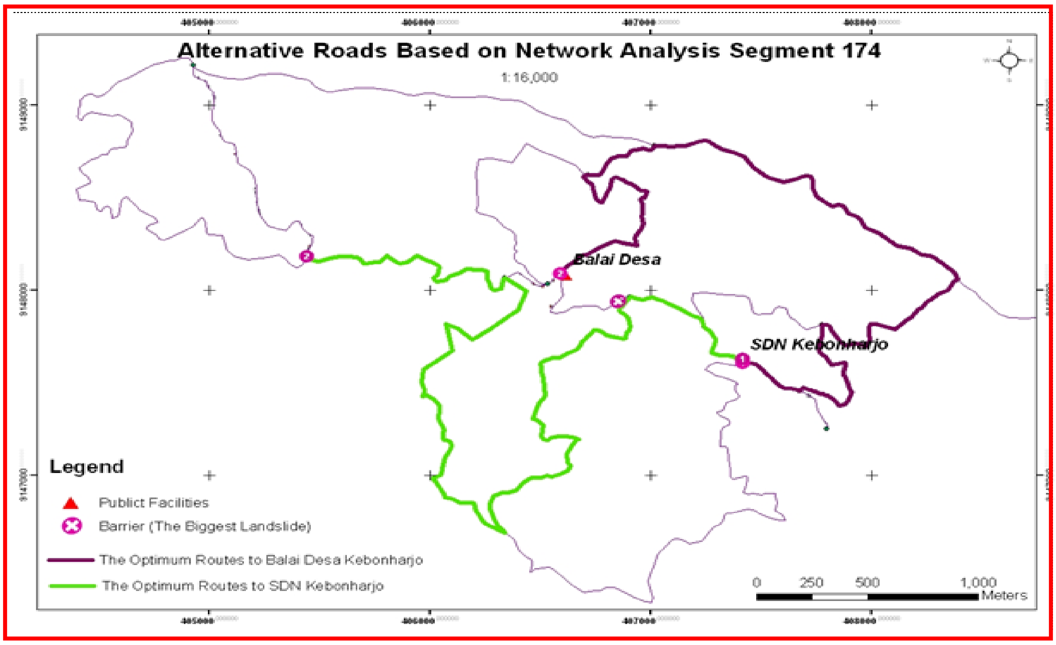


Figure 5.54 :The alternative road on segment 174 based on network analysis

(Figure 5.55) depicts the road condition in the field which can be used as the alternative routes connect to SDN Kebonharjo and Balai Desa Kebonharjo based on network analysis.

Figure 5.55: The alternative road condition based on network analysis; A) The pringtali to balai desa route B) The dangsambuh to gebang route (Source : Eko Setya N, 2011)

The length of optimum route, the road connecting public facilities under normal condition and the increment of route distance can be calculated by using network analysis. The distance result is shown in (Table. 5.20).

Table 5.20: The alternative route, normal route and increment route distance based on network analysis

No	Route Connecting Public Facilities	Alternative Route Distance (Km)	Normal Route Distance (Km)	The Increment of Route Distance (Km)
1	2	3	4	5
1	SDN Kebonharjo	6.26	2.88	3.38
2	Balai Desa Kebonharjo	5.36	1.33	4.03

Source: Data Analysis

Route connecting to SDN Kebonharjo was started from Jarakan Sub Village which has high settlement and ended on SDN Kebonharjo. In normal condition, commuters spend 2.88 Km to achieve SDN Kebonharjo. Meanwhile route connecting to Balai Desa Kebonharjo was started from Pringtali Sub Village which has high settlement and ended on Balai Desa Kebonharjo. Riders spend 1.33 Km only to reach Balai Desa Kebonharjo in normal condition. Because of road blockage, thus commuters will require the addition of the distance 3.38 Km and 4.03 Km to reach SDN Kebonharjo and Balai Desa Kebonhajo respectively (Table 5.20).

5.5.2.2. Community Perception

Community perception is needed to know the real desire of the people to choose alternative route. Community perception was obtained by using samples which were randomly selected. In this case, author used 34 respondents selected which would be interviewed by using questionnaire. Measurement points were located on the street in which the biggest landslide closed commuter to achieve two public facilities. Interview was conducted to commuters who would go to Balai Desa Kebonharjo or SDN Kebonharjo as the final destination. The final result will be obtained by using community perception to determine alternative routes which are the alternative route toward Balai Desa Kebonharjo and toward SDN Kebonharjo. These alternative routes which are based on community perception are presented in (Figure 5.56, 5.57, and Table 5.21, 5.22).

Table 5.21: The alternative route connecting SDN Kebonharjo based on community perception

No	Route	No of Respondents	%
1	2	3	4
1	Dangsambuh-Gebang	16	47.06
2	Balai Desa-Gebang	6	17.65
3	Dangsambuh-Pringtali	11	32.35
4	Kleben-Gebang	1	2.94
	Total	**34**	**100.00**

Source: Data Analysis

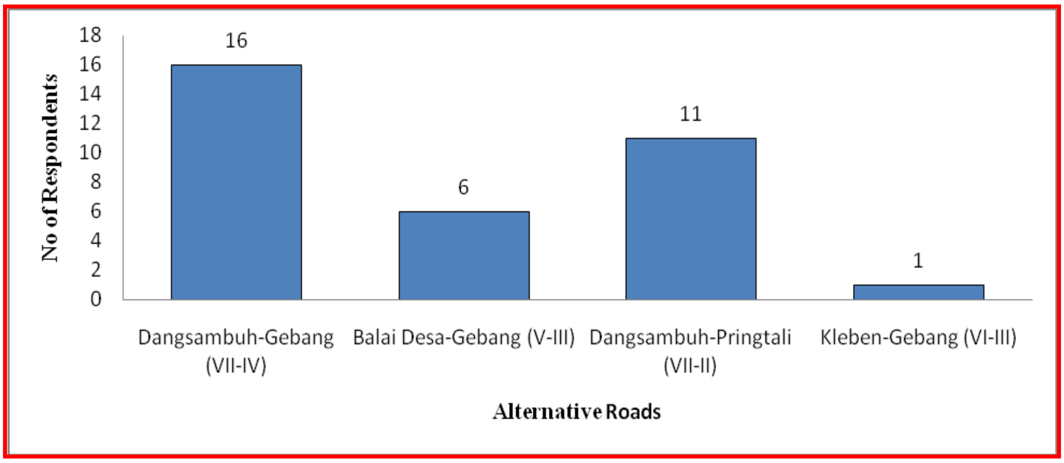


Figure 5.56 :The alternative road connecting SDN Kebonharjo based on community perseption

Table 5.22: The alternative route connecting Balai Desa Kebonharjo based on community perception

No	Route	No of Respondents	%
1	**2**	**3**	**4**
1	Pringtali-Balai Desa	8	23.53
2	Pringtali-Dangsambuh	6	17.65
3	Gebang-Balai Desa	15	44.12
4	Gebang-Dangsambuh	5	14.71
	Total	**34**	**100.00**

Source: Data Analysis

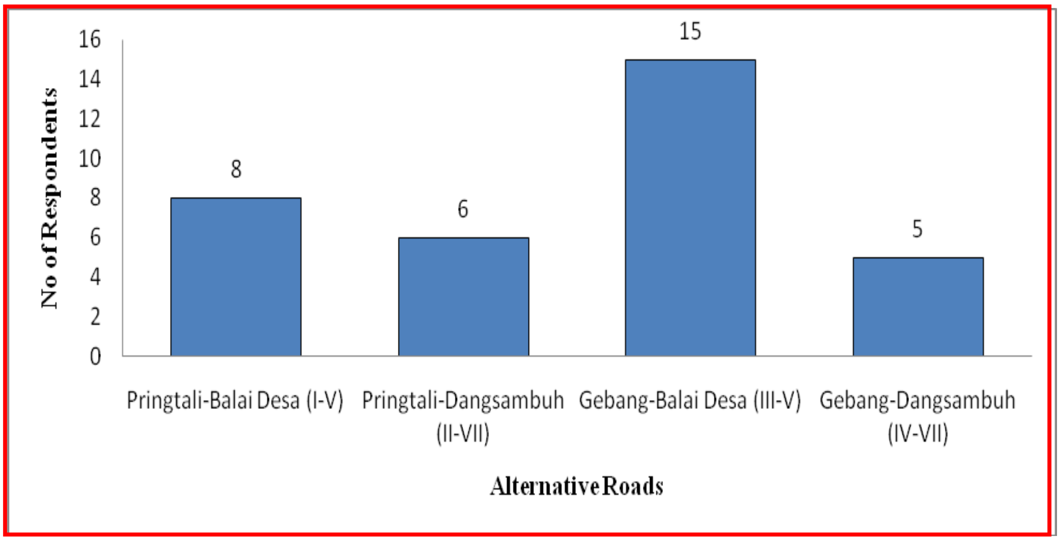


Figure 5.57 :The alternative road connecting Balai Desa Kebonharjo based on community perception

The most community chooses the route connecting Dangsambuh to Gebang which is as the alternative route to reach SDN Kebonharjo. 47.06% of all respondents tend to use the route of Dangsambuh to Gebang as alternative route to reach SDN Kebonharjo and followed by the route of Dangsambuh-Pringtali (32.35%) as the second alternative route (Table 5.21). Based on the community interviewing, local community prefer to choose the route of Dangsambuh to Gebang as the first alternative route because this route has better road condition and shorter road distance to reach SDN Kebonharjo. In other hand, people tend to choose the route of Gebang-Balai Desa as the priority of alternative route to achieve Balai Desa Kebonharjo, it is shown that 44.12 % of total respondents choose this route and followed by 23.53 % respondents use the route of Pringtali-Balai Desa as the second opinion. Although, the Gebang-Balai Desa route distance has longer than the distance of Pringtali-Balai Desa route, community still prefer to use the route of Gebang-Balai Desa. Due to the road condition, communities rarely use the route of Pringtali - Balai Desa which is narrower and bad road condition. The alternative route based on community perception can be depicted in (Figure 5.58). As information addition, (Figure 5.59) shows the road condition in the field which can be used as the alternative route connects to SDN Kebonharjo and Balai Desa Kebonharjo based on community perception.

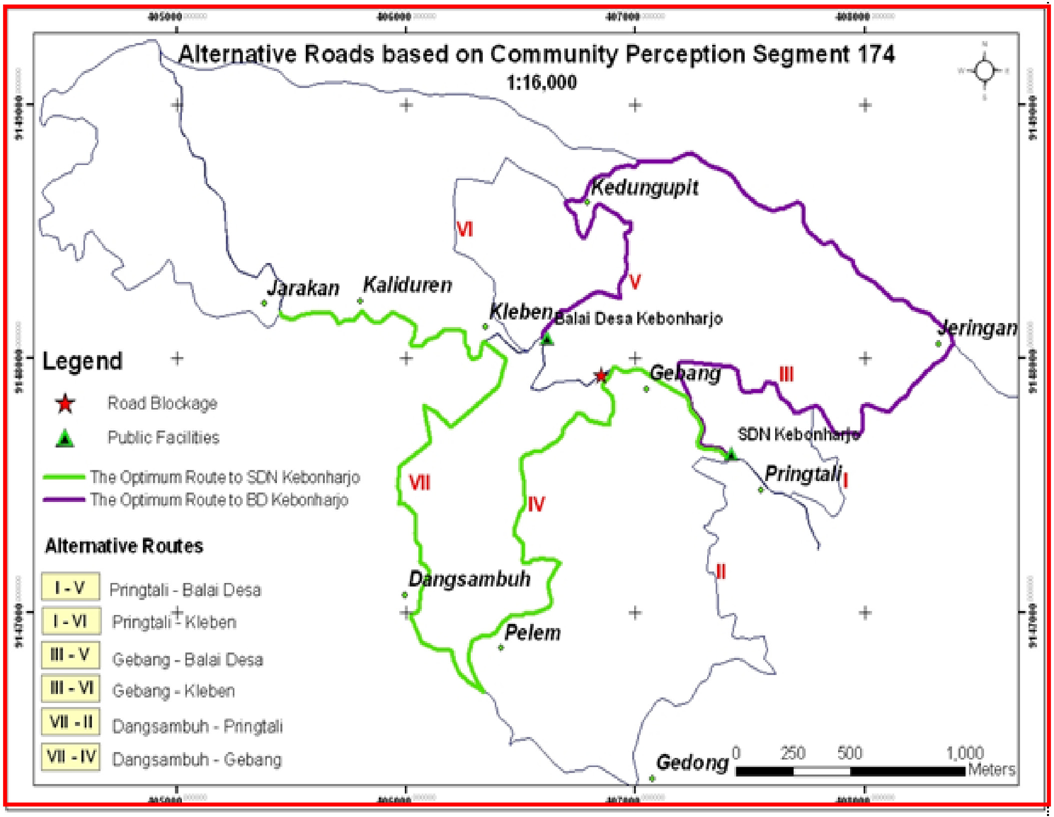


Figure 5.58 :The alternative road on segment 174 based on community perception

Figure 5.59: The alternative road condition based on community perception; A) The gebang to balai desa route B) The dangsambuh to gebang route (Source: Eko Setya N, 2011)

By using Arch GIS 9.3, author can calculate the length of alternative route, the road connecting public facilities under normal condition and the increment of route distance. The road distance result can be seen in (Table. 5.23).

Table 5.23: The alternative route, normal route and increment route distance based on community perception

No	Route Connecting Public Facilities	Alternative Route Distance (Km)	Normal Route Distance (Km)	The Increment of Route Distance (Km)
1	2	3	4	5
1	SDN Kebonharjo	6.26	2.88	3.38
2	Balai Desa Kebonharjo	5.52	1.33	4.19

Source: Data Analysis.

Before road blockage (normal condition), people spent 2.88 Km to achieve SDN Kebonharjo and 1.33 Km only to reach Balai Desa Kebonharjo. Because of road blockage, it is needed the alternative roads which are 6.26 Km and 5.52 Km to reach SDN Kebonharjo and Balai Desa Kebonharjo respectively. Thus commuter will spend the addition of the distance 3.38 Km and 4.19 Km to reach SDN Kebonharjo and Balai Desa Kebonhajo respectively (Table 5.23).

When the alternative route based on network analysis (Table 5.20) and community perceptions (Table 5.23) were compared, we can know that there are some of the differences between 2 methods deal with the determination of alternative route. The comparison between network analysis and community perception methods above can be shown in (Table 5.24).

Table 5.24: The comparison between network analysis and community perception associated with alternative route

No	Route Connecting Public Facilities	Alternative Route Distance		The Differences of Route Distance
		Network Analysis (Km)	Community Perception (Km)	(Km)
1	2	3	4	5
1	SDN Kebonharjo	6.26	6.26	0
2	Balai Desa Kebonharjo	5.36	5.52	0.16

Source: Data Analysis

The alternative route connecting SDN Kebonharjo has the same determination between network analysis and community perception methods. All of methods determine the route of Dangsambuh to Gebang as the alternative route. On the other hand, there are the differences between network analysis and community perception methods in term of the determination of alternative route connecting Balai Desa Kebonharjo. Network analysis method determine the Pringtali to Balai Desa route as the alternative route connecting Balai Desa Kebonharjo, while community perception tend to choose the Gebang-Balai Desa route as the alternative route connecting Balai Desa Kebonharjo. It due to network analysis method considered the shortest of route distance only which was used as variable to determine the alternative route (optimum route). Road condition was not considered as a variable. On community perception method, both of road condition and road distance were considered as variables to determine the alternative route. People prefer to choose route in which has good road condition, although the route chosen has a rather long distance.

5.5.3. Indirect Impact Road Segment 174

By using equation 4.6 (in section 4.1.6), indirect impact on road segment 174 can be calculated. In this study, author used 2 scenarios of indirect impact which are network analysis and community perception methods. The biggest landslide for 10 years (2001-2010) which has the longest blockage day and full road blockage was considered as barrier in the indirect impact calculation. The big landslide which occurred in 2009 has debris slide type and magnitude I. The results of indirect impact calculation regarding 2 methods are presented in (Table 5.25 and Table 5.26).

As shown in (Table 5.25), we can know that indirect impact based on network analysis is Rp. 4,593,607.20. The contribution of indirect impact is dominated by motor cycle and followed by truck and car which has cost contribution of Rp. 2,464,862.40,- (53.66 %), Rp. 1,120,392.00,- (24.39%) and Rp. 1,008,352.80,- (21.95%) respectively. This is caused by the highest traffic density of motorcycle among the other vehicle types. Due to many load, truck spends much fuel consumption than car. That’s why, truck gives higher contribution than car.

Table 5.25: The indirect impact on segment 174 by using network analysis method

No	Vehicle Type	∑Vehicle /day (unit)	Road Blockage (day)	∑Vehicle for Road Blockage (unit)	Fuel consumption per Km (lt)	The extend of road alternative distance (Km)	Fuel Standard Cost (Rp/lt)	Indirect Impact (Rp)
1	2	3	4	5	6	7	8	9
I.	**Indirect Cost to achieve SDN Kebonharjo**							
1	Motor Cycle (Premium)	132	14	1,848	0.04	3.38	4,500	1,124,323.20
2	Car (Premium)	24	14	336	0.09	3.38	4,500	459,950.40
3	Truck (diesel)	12	14	168	0.2	3.38	4,500	511,056.00
	Total I							**2,095,329.60**
II.	**Indirect Cost to achieve Balai Desa Kebonharjo**							
1	Motor Cycle (Premium)	132	14	1,848	0.04	4.03	4,500	1,340,539.20
2	Car (Premium)	24	14	336	0.09	4.03	4,500	548,402.40
3	Truck (diesel)	12	14	168	0.2	4.03	4,500	609,336.00
	Total II							**2,498,277.60**
Grand Total Indirect Impact (I + II)								**4,593,607.20**

Source: Data Analysis

The same trend is still depicted in (Table 5.26), total of indirect impact based on community perception is Rp. 4,692,794.40. The contribution of indirect impact is still dominated by motor cycle and followed by truck and car which has cost contribution of Rp. 2,518,084.80,- (53.66 %), Rp. 1,144,584.00,- (24.39%) and Rp. 1,030,125.60,- (21.95%) respectively.

Table 5.26: The indirect impact on segment 174 by using community perception method

No	Vehicle Type	∑Vehicle /day (unit)	Road Blockage (day)	∑Vehicle for Road Blockage (unit)	Fuel consumption per Km (lt)	The extend of road alternative distance (Km)	Fuel Standard Cost (Rp/lt)	Indirect Impact (Rp)
1	2	3	4	5	6	7	8	9
I.	**Indirect Cost to achieve SDN Kebonharjo**							
1	Motor Cycle (Premium)	132	14	1,848	0.04	3.38	4,500	1,124,323.20
2	Car (Premium)	24	14	336	0.09	3.38	4,500	459,950.40
3	Truck (diesel)	12	14	168	0.2	3.38	4,500	511,056.00
	Total I							**2,095,329.60**
II.	**Indirect Cost to achieve Balai Desa Kebonharjo**							
1	Motor Cycle (Premium)	132	14	1,848	0.04	4.19	4,500	1,393,761.60
2	Car (Premium)	24	14	336	0.09	4.19	4,500	570,175.20
3	Truck (diesel)	12	14	168	0.2	4.19	4,500	633,528.00
	Total II							**2,597,464.80**
Grand Total Indiect Impact (I + II)								**4,692,794.40**

Source: Data Analysis

Based on (Table 5.25 and Table 5.26), the indirect impact on segment 174 can be calculated by using network analysis method and community perception. There are the differences of indirect impact calculation which are Rp. 4,593,607.20 and Rp. 4,692,794.40 by using network analysis and community perception methods respectively. It is caused by the differences of alternative route determination, as explained in (section 5.5.2.) before.

VI.CONCLUSIONS, LIMITATIONS &RECOMMENDATIONS

6.1. Conclusions

In this research, conclusions were made based on the research result and discussion in which the research objectives and research question will be answered. Several conclusions can be presented bellow by following the detail research objectives (in *italic letter*).

1. The first research objective is *to assess level of landslide hazard to road*.

Road segment 174 is a segment which has the highest density of landslides in terms of landslide number and landslide area. This due to several condition such as; steep slopes in which 86.88 % landslide occurred, the dominance of shallow-fiber root vegetation and low vegetation density in mixed garden and rain fed paddy field type. Because of low ability to withstand landslides, 49.12% and 38.35% of landslide occurred in mixed garden and rain feed paddy field type, respectively. Breccia rocks which have high degree of decomposition can be a potential factor of landslide. Besides that, temporarily, rainfall factor will influence landslide events. Actually, debris slide type of magnitude I has the highest spatial probability of 0.1976 located in the 20th mapping unit and the highest temporal probability of 0.3297, 0.6988, and 0.8647 for return period 1 yr, 3 yr and 5 yr respectively situated in 3 mapping unit (i.e. 37th, 58th and 69th). Meanwhile, the rock fall type of magnitude I can be found in 6th mapping unit only which has the spatial probability of 0.0483 and the temporal probability of 0.1813, 0.4512 and 0.6321 for return period 1 yr, 3 yr and 5 yr respectively. The highest hazard probability of debris slide of magnitude I is located in the 20th mapping unit for return period 1 yr, 3 yr and 5 yr which has 0.0188, 0.0512 and 0.0778 probabilities respectively. While rock fall type of magnitude I for return period 1 yr, 3 yr and 5 yr has 0.0088, 0.0218 and 0.0305 probabilities respectively. After the hazard probabilities were classified, the most of hazard class is the very low hazard class. This condition compatible with the Jaiswal's Landslide Magnitude Classification that magnitude I have less spatial probability occurrence.

2. The second research objective is *to assess landslide vulnerability of road.*

Spatially, road vulnerability has 4 classes which are very low, low, moderate very high classes and followed by the absence of high class. The highest road vulnerability lies on the 20th mapping unit which is 0.7133 road vulnerability. The very low class dominates road vulnerability class on segment 174 which can be found in almost of mapping unit. Based on the Jaiswal's Landslide Magnitude Classification that magnitude I caused minor damage only. That's why the vulnerability class is dominated by very/low class.

3. The third research objective is *to estimate landslide direct impact to road*.

The highest of direct impact of debris slide of magnitude I located in the 20th mapping unit which is Rp. 89,586.69, Rp. 243,995.46 and Rp. 370,414.67 for return period 1 yr, 3 yr and 5 yr respectively. Meanwhile direct impact which is caused by rock fall type of magnitude I is Rp. 3,976.34, Rp. 9,897.32 and Rp. 13,866.27 for return period 1 yr, 3 yr and 5 yr respectively. After the direct impact was classified, the most of direct impact class is the very low class. It is caused by the low of road vulnerability and hazard probability for return period 1 yr, 3 yr and 5 yr.

4. The fourth research objective is *to estimate landslide indirect impact to road*

Indirect impact was caused by road blockage in which driver or commuter will find alternative road to reach public facility (Balai Desa Kebonharjo and SDN Kebonharjo). Traffic density was measured by considering vehicles type which were dominated by motor cycle and followed by car and truck. In this research, author used network analysis and community perception to determine route optimum as alternative route. Due to the differences of alternative route determination, there are the differences of indirect impact calculation which are Rp. 4,593,607.20 and Rp. 4,692,794.40 by using network analysis and community perception methods respectively. The contribution of indirect impact cost is still dominated by motor cycle and followed by truck and car which has the contribution percentage of 53.66 %, 24.39% and 21.95% of indirect impact total respectively.

6.2. Limitations

Several limitations can be found in this research. The limitations are as follow:

1. Actually Samigaluh District has 21 main road segments. Because of time limitation, the impacts of landslide both of direct and indirect impact were analyzed on the road segment which has the highest susceptibility (segment 174) only. It will be more detail if the landslide impact will be analyzed on the entire road segment.
2. Due to time limitation, indirect impact used the longest road blockage time (14 days) only to determine alternative routes simulation. Actually, there are several road blockages in segment 174 although road blockage times have a short time period. It will be better if we use several road blockages to determine alternative routes simulation.
3. Traffic density was measured by using measurement time scenarios which are peak time and non peak time. It will be better if the measurement is carried out throughout the day.

6.3. Recommendations

1. Local government must record continuously landslide data related with road damage and traffic density data. Those data can be used to determine the landslide risk zones and calculate the landslide impact to road.
2. For the next research, the indirect impact which relate with the disruption of economic activity, social, educational, delay in travel time can be considered in the indirect impact estimation.
3. In order to reduce landslide susceptibility, authorities have to conduct tree planting with the deep root vegetation. Because the most of landslide events occurred in mixed garden having low vegetation density and shallow-fiber root trees.
4. Local government has to maintain irrigation system which located along road segment. Due to the bad irrigation system, the water will overflow and inundate the road segment, so it will trigger landslide on the road segment, especially in rainy season.

REFERENCES:

Abella, C., (2008). *Multi Scale Landslide Risk Assessment in Cuba*. Disertation, International Institute for Geo information Science and Earth Observation, Enschede, The Netherlands,273.

Anonim, (2004). *Road Laws of Republic of Indonesia No 38 in 2004*. Republic of Indonesia, 43.

Anonim, (2010). *Sistem dan Standart Operasional (SOP) Penanggulangan Banjir dan Tanah Longsor*. Ditjen RLPS, Departemen Kehutanan, Jakarta.

Akgun, A., & Turk, N., (2010). *Landslide susceptibility mapping for Ayvalik (Western Turkey) and its vicinity by multicriteria decision analysis*. Environ Earth Science, 61:595–611.

Arsyad, S., (1989). *Konservasi Tanah dan Air*. Institut Pertanian Bogor Press, Bogor.

Berdica, K., (2002). *An introduction to road vulnerability: what has been done, is done and should be done*. Transport Policy, Vol. 9, Iss. 2, pp. 117-127.

Budeta, P., (2002). *Risk assessment from debris flows in pyroclastic deposits along a motorway, Italy.* Journal Springer, Engineering Geology Env. 61:293–301.

Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasqui, V., & Reichenbach, P., (1991). *GIS Technique and Statistical Model in Evaluating Landslide Hazard*. Earth Surface Processes and Landform Vol. 16 No.5 pp.427-445.

Chakraborty, S., (2008). *Spatio-Temporal Landslide Hazard Analysis Along a Road Corridor Based on Historical Information : Case Study from Uttarakhand India*. Thesis, International Institute for Geo information Science and Earth Observation, Enschede, The Netherlands,72.

Coburn, A.W., Spence, R.J.S., & Parmonis, A., (1994). *Vulnerability and Risk Assessment*. 2^{nd} ed. Disaster Management Training Programme, Cambridge Architectural Reserch Limited, Cambridge, UK, 69.

Coppala, D.P., (2007). *Introduction to International Disaster Management*. Elsevier Inc,539.

Curtin, K. M., (2007). *Network Analysis in Geographic Information Science: Review, Assessment, and Projections.* Cartography and Geographic Information Science, Vol. 34, No. 2, pp. 103-111.

Dai, F.C., Lee, C.F., & Ngai, Y.Y,, (2002). *Landslide risk assessment and management: an overview*. Engineering Geology, 64(1):65-87.

Ebta, A., (2008). *Analisis Risiko dan Mitigasi Bahaya Longsor terhadap Jaringan Jalan di Kecamatan Loano-Purworejo.* Thesis, Pasca Sarjana, Gadjah Mada Universitas, Yogyakarta,118.

Hadmoko, D., Lavigne, F., Sartohadi, J., Hadi, P., & Winaryo, (2010). *Landslide hazard and risk assessment and their application in risk management and landuse planning in eastern flank of Menoreh Mountains, Yogyakarta Province, Indonesia*. Nat Hazards, 54:623–642.

Highland, L.M., & Bobrowsky, P., (2008). *The Landslide handbook – A Guide to Understand Landslide.* US geological Survey Circular 1325, Reston, Virginia, 129p.

Hardiyatmo, H.C., (2006). *Penanganan Tanah Longsor dan Erosi.* Gadjah mada University Press, Yogyakarta,450.

Hardjono, I, (2008). *Pemintakatan Bahaya Longsor Lahan Di Kecamatan Manyaran Kabupaten Wonogiri Propinsi Jawa Tengah.* Forum Geografi vol 22 No 2, Surakarta, 99-201.

Jaiswal, P., & Van Westen, C.J.,(2009). *Estimating Temporal Probability for Landslide Along Transportation Routes Based on Rainfall Threshold.* Journal Elsevier, Geomorphology, 112: 96–105.

Kusky, T., (2008). *Landslide: Mass Wasting Soil, and Mineral hazards*. Fact on File, Inc, New York,145.

Kang, & Chang, T., (2010). *Introduction to Geographic Information System.* 5th ed, McGraw-Hill International Edition,448.

Malamud, B.D., Turcete, D.L., Guzzetti, F., & Reichenbach, P., (2004). *Landslide Inventories and Their Stastitical Properties*. Wiley Inter science, Earth Surface Processes and Landform), 29: 687-711.

Nayak, J., (2010). *Landslide Risk Assessment Along a Major Road Corridor Based on Historical Landslide Inventory and Traffic Analysis*. Thesis, International Institute for Geo information Science and Earth Observation, Enschede, The Netherlands, 91.

Nijagunappa, Shekhar, S., Gurugnanam, Raju & Prabirde, (2007). *Road Network Analysis of Dehradun City Using High Resolution Satellite Data and GIS*. Journal of the Indian Society of Remote Sensing, Vol. 35, No. 3.

Thywissen, K., (2006). *Components of Risk.* SOURCE (Studies of the University: Research, Counsel, Education), Publication Series of UNU Institute for Environment and Human Security (UNU-EHS), Bonn, Germany,52.

Smith, K., (1992). *Environmental Hazards: Assessing and Reducing Disaster*. London: Routlege.

Van westen, C. J., Alkema, D., Rusmini, M., Lubbczynska, M., Kerle, N., Deemen, M., & Woldai, T., (2009). *Multi Hazard Risk Assessment, Guide Book Session 3 Hazard Assessment*. International Institute for Geo information Science and Earth Observation, Enschede, The Netherlands, 3-138.

Van westen, C.J., Van Asch, T.W.J., & Soeters, R., (2006). *Landslide hazard and risk zonation—why is it still so difficult?* Springer Journal Bull Eng Geol Env., 65: 167–184.

Van westen, C.J., Rengers, N., Terlies, M.T.J., & Soeters, R., (1997). *Prediction of the occurrence of instability phenomenal through GIS-based hazard zonation*. Geologische Rundschau, 86: 404-14.

Varnes, D.J. and IAEG, (1984). *Landslide hazard zonation: a review of principles and practice*. UNESCO, Darantiere, Paris, 61 pp.

Vinod, R.V., Sukumar, B., & Sukumar, A., (2003). *Transport Network Analysis Of Kasaragod Taluk, Kerala Using GIS*. Resources Analysis Division, Centre for Earth Science Studies, Akkulam, Thuruvikkal P.O, Thiruvananthapuram 695 031, INDIAN CARTOGRAPHER, 35-43.

Voskuil, R.P.G.A., (2008). *Landslide types, causes and identification*. E.ITC, ITC, Enscede.

Wahono, B. F. D., (2010). *Applications of Statistical and Heuristic Methods for Landslide Susceptibility Assessment (A case Study in Wadas Lintang, Wonosobo, Central Java Province, Indonesia)*. Thesis, International Institute for Geo information Science and Earth Observation, Enschede, The Netherlands, 80.

Yalcin, A,. & Bulut, F., (2007). *Landslide susceptibility mapping using GIS and digital photogrammetric techniques: a case study from Ardesen (NE-Turkey.*, Nat Hazards, 41:201–226.

Zezere J.L., Oliveira, S. C., Garcia, R. A. C., & Reis, (2007). *Landslide risk analysis in the area North of Lisbon (Portugal): evaluation of direct and indirect costs resulting from a motorway disruption by slope movements*. Landslides, 4:123–136.

Thompson, G.R & Turk, J, (1997). *Introduction to Physical Geology*. Brooks Cole Publisher. 396 pp.

USGS (July 2004), Landslide Type and Processes. Retrieved July 15th, 2011, from http://pubs.usgs.gov/fs/2004/3072/fs-20004-3072.html.

Kedaulatan Rakyat News (September 24th, 2010). Retrieved May 30th, 2011, from http://kr.co.id.

Antara News (May 31st, 2010). Retrieved May 30th, 2011, from http://antaranews.com.

Dictionary.com (2011). Network Analysis. Retrieved July 25th, 2011, from http://dictionary.reference.com/browse/network+analysis.

Oxford Dictionaries (2011). Network Analysis. Retrieved July 25th , from http://oxforddictionaries.com/definition/network+analysis?region=us.

APPENDICES

Appendix 1: Landslide Attributes on Segment 174 (2001-2010)

No	Coordinate		Year	Type of Slide	Run Out	Landslide Area
	X	Y			(m)	(m2)
1	**2**	**3**	**4**	**5**	**6**	**7**
1	405025	9149045	2001	Debris Slide	6.63	22.42
2	404983	9149133	2001	Debris Slide	5.49	23.41
3	405116	9148734	2001	Debris Slide	12.14	76.32
4	404996	9149103	2002	Debris Slide	6.36	20.26
5	405025	9149035	2002	Debris Slide	5.53	14.45
6	406010	9148064	2002	Debris Slide	12.16	65.37
7	405205	9148549	2003	Debris Slide	7.05	18.39
8	405207	9148532	2003	Debris Slide	5.41	11.87
9	404999	9149092	2004	Debris Slide	4.97	17.34
10	405208	9148523	2004	Debris Slide	6.56	10.68
11	406558	9148049	2005	Debris Slide	9.84	71.25
12	406298	9147996	2005	Debris Slide	8.97	37.29
13	405452	9148238	2005	Debris Slide	10.72	67.72
14	405447	9148224	2005	Debris Slide	11.43	47.33
15	406548	9147910	2007	Debris Slide	15.30	135.38
16	406262	9148040	2007	Debris Slide	4.64	15.46
17	404953	9149149	2007	Debris Slide	9.09	22.24
18	407790	9147286	2008	Debris Slide	6.83	54.04
19	406469	9148031	2008	Debris Slide	9.06	93.25
20	407711	9147425	2009	Rock Fall	8.28	73.43
21	407715	9147435	2009	Debris Slide	13.80	96.54
22	406852	9147918	2009	Debris Slide	31.38	494.11
23	406859	9147950	2009	Debris Slide	33.80	169.22
24	405212	9148476	2009	Debris Slide	6.62	22.90
25	405225	9148437	2009	Debris Slide	6.02	11.83
26	405227	9148425	2009	Debris Slide	5.57	24.83
27	405232	9148410	2009	Debris Slide	4.39	8.69
28	407669	9147447	2010	Rock Fall	11.94	63.32
29	407346	9147641	2010	Debris Slide	7.27	35.35
30	407150	9147887	2010	Debris Slide	2.60	10.97
31	406338	9148059	2010	Debris Slide	5.10	17.21
32	405455	9148296	2010	Debris Slide	7.94	23.41
33	405463	9148159	2010	Debris Slide	5.54	18.64
34	405477	9148155	2010	Debris Slide	4.28	20.06

Appendix 1: Continue

1	2	3	4	5	6	7
35	406509	9148019	2010	Debris Slide	16.70	101.96
36	405047	9148834	2010	Debris Slide	7.77	18.46
37	405418	9148355	2010	Debris Slide	7.64	32.18
38	406408	9148085	2010	Debris Slide	3.68	5.66

Source: Data Analysis

Appendix 2: Fieldwork Activity

Fieldwork activity : A & B). 2 of 6 trafic density measurement was done simultaneuslly, C) Landslide morphometry measurement by uisng lacer ace, D) Micro slope measurement by using Suunto, E) Interviewing with key informant to identify landslide, and F) By using questionnaire to determine alternative route based on community perception (Eko Setya N,2011)

Appendix 3: Volume and Landslide Blockage on Segment 174

No	Coordinate		Year	Type of Slide	Estimation Based on Kebonharjo Village Office	
	X	Y			Volume(m3)	Blockage(days)
1	**2**	**3**	**4**	**5**	**6**	**7**
1	405025	9149045	2001	Debris Slide	12.70	0.64
2	404983	9149133	2001	Debris Slide	13.27	0.66
3	405116	9148734	2001	Debris Slide	43.25	2.16
4	404996	9149103	2002	Debris Slide	11.48	0.57
5	405025	9149035	2002	Debris Slide	8.19	0.41
6	406010	9148064	2002	Debris Slide	37.04	1.85
7	405205	9148549	2003	Debris Slide	10.42	0.52
8	405207	9148532	2003	Debris Slide	6.73	0.34
9	404999	9149092	2004	Debris Slide	9.83	0.49
10	405208	9148523	2004	Debris Slide	6.05	0.30
11	406558	9148049	2005	Debris Slide	40.38	2.02
12	406298	9147996	2005	Debris Slide	21.13	1.06
13	405452	9148238	2005	Debris Slide	38.37	1.92
14	405447	9148224	2005	Debris Slide	26.82	1.34
15	406548	9147910	2007	Debris Slide	76.72	3.84
16	406262	9148040	2007	Debris Slide	8.76	0.44
17	404953	9149149	2007	Debris Slide	12.60	0.63
18	406469	9148031	2008	Debris Slide	52.84	2.64
19	407711	9147425	2009	Rock Fall	41.61	2.08
20	406852	9147918	2009	Debris Slide	280.00	14.00
21	405212	9148476	2009	Debris Slide	12.98	0.65
22	405225	9148437	2009	Debris Slide	6.70	0.34
23	405227	9148425	2009	Debris Slide	14.07	0.70
24	405232	9148410	2009	Debris Slide	4.93	0.25
25	407669	9147447	2010	Rock Fall	35.88	1.79
26	407346	9147641	2010	Debris Slide	20.03	1.00
27	406338	9148059	2010	Debris Slide	9.75	0.49
28	405455	9148296	2010	Debris Slide	13.27	0.66
29	405463	9148159	2010	Debris Slide	10.56	0.53
30	405477	9148155	2010	Debris Slide	11.37	0.57
31	406509	9148019	2010	Debris Slide	57.80	2.89
32	405047	9148834	2010	Debris Slide	10.50	0.53
33	406408	9148085	2010	Debris Slide	3.21	0.16

Source: Spatial Analysis

Appendix 4: Spatial Probability Calculation

MU	MU Area (m2)	Area of landslide covering road (m2)				Area of landslide destroying road (m2)	Total area of landslide damaging road (m2)	Spatial Probability
		Number of Landslides						
		1	2	3	4		(3+4+5+6+7)	(8 : 2)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	4,217.37					54.04	54.04	0.0128
2	3,107.26						0.00	0.0000
3	678.97						0.00	0.0000
4	4,875.58						0.00	0.0000
5	353.17						0.00	0.0000
6	2,831.61	73.43	63.32				136.74	0.0483
7	3,108.84					96.54	96.54	0.0311
8	2,526.18						0.00	0.0000
9	5,853.38	35.35					35.35	0.0060
10	10,149.24						0.00	0.0000
11	10,779.75						0.00	0.0000
12	2,123.77						0.00	0.0000
13	450.24						0.00	0.0000
14	3,580.15						0.00	0.0000
15	2,438.88						0.00	0.0000
16	1,274.53						0.00	0.0000
17	506.83						0.00	0.0000
18	15,302.49					10.97	10.97	0.0007
19	5,197.99						0.00	0.0000
20	2,500.44	494.11					494.11	0.1976
21	3,594.60					169.22	169.22	0.0471
22	1,137.07						0.00	0.0000
23	15,011.50	135.38					135.38	0.0090
24	2,228.86						0.00	0.0000
25	1,780.59						0.00	0.0000
26	2,235.14						0.00	0.0000
27	468.04						0.00	0.0000
28	1,308.89						0.00	0.0000
29	1,723.01						0.00	0.0000
30	1,474.64						0.00	0.0000
31	13,960.32	71.25	93.25	101.96			266.46	0.0191
32	3,756.95						0.00	0.0000

Appendix 4: Continue

1	2	3	4	5	6	7	8	9
33	1,373.89						0.00	0.0000
34	14,084.05						0.00	0.0000
35	5,545.64						0.00	0.0000
36	3,828.37						0.00	0.0000
37	20,941.13	37.29	15.46	17.21	5.66		75.62	0.0036
38	2,856.22	65.37					65.37	0.0229
39	1,017.29						0.00	0.0000
40	5,076.39						0.00	0.0000
41	5,200.81						0.00	0.0000
42	2,691.05						0.00	0.0000
43	5,404.35						0.00	0.0000
44	352.71						0.00	0.0000
45	779.81						0.00	0.0000
46	1,382.51						0.00	0.0000
47	133.55						0.00	0.0000
48	1,577.66						0.00	0.0000
49	6,034.60	20.06	18.64			32.18	70.88	0.0117
50	8,334.88	47.33	67.72	23.41			138.46	0.0166
51	456.39						0.00	0.0000
52	2,059.40						0.00	0.0000
53	6,557.45						0.00	0.0000
54	732.09						0.00	0.0000
55	1,996.09						0.00	0.0000
56	410.22						0.00	0.0000
57	690.17						0.00	0.0000
58	7,081.77	8.69	24.83	22.90	10.68		67.11	0.0095
59	3,206.62	11.83	11.87				23.70	0.0074
60	940.07	18.39					18.39	0.0196
61	5,137.77						0.00	0.0000
62	1,830.78						0.00	0.0000
63	2,628.67						0.00	0.0000
64	1,376.78						0.00	0.0000
65	4,470.72						0.00	0.0000
66	9,771.59	76.32	18.46				94.78	0.0097
67	1,541.13						0.00	0.0000
68	7,131.63						0.00	0.0000
69	5,221.01	14.45	22.42	17.34	20.26		74.47	0.0143

Appendix 4: Continue

1	2	3	4	5	6	7	8	9
70	1,299.99						0.00	0.0000
71	234.00	23.41					23.41	0.1001
72	2,893.02						0.00	0.0000
73	1,319.41	22.24					22.24	0.0169
74	760.91						0.00	0.0000
75	1,551.94						0.00	0.0000
76	1,336.87						0.00	0.0000
77	120.37						0.00	0.0000

Source: Data Analysis

Appendix 5: Temporal Probability Calculation

MU	N	t	λ (N/t) (2 : 3)	Temporal Probability Return Period 1	3	5
1	**2**	**3**	**4**	**5**	**6**	**7**
1	1	10	0.1000	0.0952	0.2592	0.3935
2	0	10	0	0	0	0
3	0	10	0	0	0	0
4	0	10	0	0	0	0
5	0	10	0	0	0	0
6	2	10	0.2000	0.1813	0.4512	0.6321
7	1	10	0.1000	0.0952	0.2592	0.3935
8	0	10	0	0	0	0
9	1	10	0.1	0.0952	0.2592	0.3935
10	0	10	0	0	0	0
11	0	10	0	0	0	0
12	0	10	0	0	0	0
13	0	10	0	0	0	0
14	0	10	0	0	0	0
15	0	10	0	0	0	0
16	0	10	0	0	0	0
17	0	10	0	0	0	0
18	1	10	0.1000	0.0952	0.2592	0.3935
19	0	10	0	0	0	0
20	1	10	0.1000	0.0952	0.2592	0.3935
21	1	10	0.1000	0.0952	0.2592	0.3935
22	0	10	0	0	0	0
23	1	10	0.1000	0.0952	0.2592	0.3935
24	0	10	0	0	0	0
25	0	10	0	0	0	0
26	0	10	0	0	0	0
27	0	10	0	0	0	0
28	0	10	0	0	0	0
29	0	10	0	0	0	0
30	0	10	0	0	0	0
31	3	10	0.3000	0.2592	0.5934	0.7769
32	0	10	0	0	0	0
33	0	10	0	0	0	0

Appendix 5: Continue

1	2	3	4	5	6	7
34	0	10	0	0	0	0
35	0	10	0	0	0	0
36	0	10	0	0	0	0
37	4	10	0.4000	0.3297	0.6988	0.8647
38	1	10	0.1000	0.0952	0.2592	0.3935
39	0	10	0	0	0	0
40	0	10	0	0	0	0
41	0	10	0	0	0	0
42	0	10	0	0	0	0
43	0	10	0	0	0	0
44	0	10	0	0	0	0
45	0	10	0	0	0	0
46	0	10	0	0	0	0
47	0	10	0	0	0	0
48	0	10	0	0	0	0
49	3	10	0.3000	0.2592	0.5934	0.7769
50	3	10	0.3000	0.2592	0.5934	0.7769
51	0	10	0	0	0	0
52	0	10	0	0	0	0
53	0	10	0	0	0	0
54	0	10	0	0	0	0
55	0	10	0	0	0	0
56	0	10	0	0	0	0
57	0	10	0	0	0	0
58	4	10	0.4000	0.3297	0.6988	0.8647
59	2	10	0.2000	0.1813	0.4512	0.6321
60	1	10	0.1000	0.0952	0.2592	0.3935
61	0	10	0	0	0	0
62	0	10	0	0	0	0
63	0	10	0	0	0	0
64	0	10	0	0	0	0
65	0	10	0	0	0	0
66	2	10	0.2000	0.1813	0.4512	0.6321
67	0	10	0	0	0	0
68	0	10	0	0	0	0
69	4	10	0.4000	0.3297	0.6988	0.8647
70	0	10	0	0	0	0

Appendix 5: Continue

1	2	3	4	5	6	7
71	1	10	0.1000	0.0952	0.2592	0.3935
72	0	10	0	0	0	0
73	1	10	0.1000	0.0952	0.2592	0.3935
74	0	10	0	0	0	0
75	0	10	0	0	0	0
76	0	10	0	0	0	0
77	0	10	0	0	0	0

Source: Data Analysis

N = total number of landslide occurred a time t

λ = average rate landslides occurrence

t = time

Appendix 6: Calculation of Debris Clean up Cost

MU	Volume of Landslide Covering Road (m^3)	Standard Cost of Debris Clean up (Rp/m3)	Total Cost of Debris Clean up (Rp) (2 x 3)
1	2	3	4
1		23,854	0
2		23,854	0
3		23,854	0
4		23,854	0
5		23,854	0
6	77.49	23,854	1,848,397
7		23,854	0
8		23,854	0
9	20.03	23,854	477,882
10		23,854	0
11		23,854	0
12		23,854	0
13		23,854	0
14		23,854	0
15		23,854	0
16		23,854	0
17		23,854	0
18		23,854	0
19		23,854	0
20	280.00	23,854	6,679,120
21		23,854	0
22		23,854	0
23	76.72	23,854	1,829,992
24		23,854	0
25		23,854	0
26		23,854	0
27		23,854	0
28		23,854	0
29		23,854	0
30		23,854	0
31	151.02	23,854	3,602,407
32		23,854	0
33		23,854	0

Appendix 6: Continue

1	2	3	4
34	0.00	23,854	0
35		23,854	0
36		23,854	0
37	42.85	23,854	1,022,245
38	37.04	23,854	883,587
39		23,854	0
40		23,854	0
41		23,854	0
42		23,854	0
43		23,854	0
44		23,854	0
45		23,854	0
46		23,854	0
47		23,854	0
48		23,854	0
49	21.93	23,854	523,120
50	78.46	23,854	1,871,625
51		23,854	0
52		23,854	0
53		23,854	0
54		23,854	0
55		23,854	0
56		23,854	0
57		23,854	0
58	38.03	23,854	907,091
59	13.43	23,854	320,423
60	10.42	23,854	248,544
61		23,854	0
62		23,854	0
63		23,854	0
64		23,854	0
65		23,854	0
66	53.75	23,854	1,282,121
67		23,854	0
68		23,854	0
69	42.20	23,854	1,006,594
70		23,854	0

Appendix 6: Continue

1	2	3	4
71	13.27	23,854	316,501
72		23,854	0
73	12.60	23,854	300,635
74		23,854	0
75		23,854	0
76		23,854	0
77		23,854	0

Source: Data Analysis

Appendix 7: Calculation of Road Construction Cost

MU	Asphalt Damage (m^2)	Upper Foundation Layer				Lower Foundation Layer				Laston (Asphal)				Grand Total
		t (m)	v (m^3)	Rp /m3	Total Cost (Rp)	t (m)	v (m^3)	Rp /m^3	Total Cost (Rp)	t (m)	v (m^3)	Rp /m^3	Total Cost (Rp)	(Rp)
1	10.58	0.10	1.06	288,593	305,215.96	0.2	2.12	240,284	508,248.72	0.05	0.53	1,739,951	920,086.09	1,733,550.76
7	25.26	0.10	2.53	288,593	728,985.92	0.2	5.05	240,284	1,213,914.77	0.05	1.26	1,739,951	2,197,558.11	4,140,458.80
18	2.03	0.10	0.20	288,593	58,512.23	0.2	0.41	240,284	97,435.16	0.05	0.1	1,739,951	176,387.53	332,334.93
21	14.47	0.10	1.45	288,593	417,594.07	0.2	2.89	240,284	695,381.90	0.05	0.72	1,739,951	1,258,854.55	2,371,830.52
49	3.88	0.10	0.39	288,593	111,974.08	0.2	0.78	240,284	186,460.38	0.05	0.19	1,739,951	337,550.49	635,984.96

Source: Data Analysis

Appendix 8: Road Damage Cost Recapitulation

MU	Road Damage Cost		Total (Rp)
	Debris Cleanup Cost (Rp)	Road Constructions Cost (Rp)	
1	2	3	4
1	0	1,733,550.76	1,733,550.76
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	1,848,396.68	0	1,848,396.68
7	0	4,140,458.80	4,140,458.80
8	0	0	0
9	477,882.45	0	477,882.45
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	332,334.93	332,334.93
19	0	0	0
20	6,679,120.00	0	6,679,120.00
21	0	2,371,830.52	2,371,830.52
22	0	0	0
23	1,829,991.51	0	1,829,991.51
24	0	0	0
25	0	0	0
26	0	0	0
27	0	0	0
28	0	0	0
29	0	0	0
30	0	0	0
31	3,602,407.21	0	3,602,407.21
32	0	0	0
33	0	0	0
34	0	0	0

Appendix 8: Continue

1	2	3	4
35	0	0	0
36	0	0	0
37	1,022,244.86	0	1,022,244.86
38	883,586.98	0	883,586.98
39	0	0	0
40	0	0	0
41	0	0	0
42	0	0	0
43	0	0	0
44	0	0	0
45	0	0	0
46	0	0	0
47	0	0	0
48	0	0	0
49	523,119.84	635,984.96	1,159,104.81
50	1,871,624.91	0	1,871,624.91
51	0	0	0
52	**0**	0	0
53	0	0	0
54	0	0	0
55	0	0	0
56	0	0	0
57	0	0	0
58	907,091.26	0	907,091.26
59	320,422.95	0	320,422.95
60	248,543.67	0	248,543.67
61	0	0	0
62	0	0	0
63	0	0	0
64	0	0	0
65	0	0	0
66	1,282,121.49	0	1,282,121.49
67	0	0	0
68	0	0	0
69	1,006,593.70	0	1,006,593.70
70	0	0	0
71	316,501.43	0	316,501.43

Appendix 8: Continue

1	2	3	4
72	0	0	0
73	300,635.40	0	300,635.40
74	0	0	0
75	0	0	0
76	0	0	0
77	0	0	0
Total			**32,334,444.29**

Source: Data Analysis

Appendix 9: Traffic Density on Point Measurement I (Source : Fieldwork Analysis)

Point Measurement	Days	Vehicles Type	Entrance					Exit				
			Time					Time				
			6.30-7.30	9-10	12.30-1.30	2-3	4-5	6.30-7.30	9-10	12.30-1.30	2-3	4-5
I	1	Motor Cycle	13	6	8	5	25	16	2	10	7	14
		Car	6	5	3	7	8	2	2	4	1	3
		Truck		4	5	2	3	2		3	2	4
	2	Motor Cycle	9	8	9	5	12	15	3	17	9	12
		Car	5	3	2		5	2	3	2	2	
		Truck		1	2	5	1	2		4	3	3
	3	Motor Cycle	12	10	5	8	10	24	5	7	11	13
		Car	5	2	5	1		6	4	2	1	
		Truck		3		2	3	2		2	2	
	4	Motor Cycle	22	9	6	9	9	18	3	6	5	17
		Car	6	1	4	3	6	7	3		1	3
		Truck		3	4	1	2	2		3	3	
	5	Motor Cycle	25	12	14	10	15	22	13	17	11	14
		Car	5	2	6	2	6	4	2	1	2	2
		Truck	3		3		2	2		2		1
	6	Motor Cycle	21	7	12	9	17	19	2	9	9	11
		Car	7		3	3	6	3	2		2	2
		Truck	1		3	2				3	3	2
	7	Motor Cycle	19	6	16	10	18	17	8	14	8	15
		Car	6	2	5	3	6	2	2	3	3	2
		Truck	3	3	4	2	3	1		2		2

Appendix 10: Traffic Density on Point Measurement II (Source : Fieldwork Analysis)

Point Measurement	Days	Vehicles Type	Entrance					Exit				
			Time					Time				
			6.30-7.30	9-10	12.30-1.30	2-3	4-5	6.30-7.30	9-10	12.30-1.30	2-3	4-5
II	1	Motor Cycle	20	12	22	13	14	19	10	22	18	26
		Car	3	3	6	3	7	2	3	5	3	4
		Truck	2		3						3	
	2	Motor Cycle	18	11	19	12	13	21	10	22	18	24
		Car	2	1	5	2	7	2	3	5	2	2
		Truck	3		3						3	
	3	Motor Cycle	22	14	17	10	15	24	9	20	19	21
		Car	2		3	2	5	1	2	4	1	3
		Truck										
	4	Motor Cycle	25	10	16	9	12	27	8	18	16	19
		Car	1		5	1			1	2	2	2
		Truck									2	
	5	Motor Cycle	19	8	11	7	8	20	7	16	14	12
		Car	2		4	1			1	1	2	1
		Truck										
	6	Motor Cycle	16	9	10	9	8	19	9	19	16	14
		Car	2		4	1			1	1	3	
		Truck	1		2						3	
	7	Motor Cycle	18	10	15	10	10	17	9	21	17	15
		Car	1		5	2		1	2	3	3	1
		Truck	1		3						4	

Appendix 11: Traffic Density on Point Measurement III (Source : Fieldwork Analysis)

Point Measurement	Days	Vehicles Type	Entrance					Exit				
			Time					Time				
			6.30-7.30	9-10	12.30-1.30	2-3	4-5	6.30-7.30	9-10	12.30-1.30	2-3	4-5
III	1	Motor Cycle	12	9	10	8	9	11	8	8	10	13
		Car	4	2	3	1	3	3		2	1	3
		Truck	0		1					0		1
	2	Motor Cycle	11	6	8	5	9	13	6	6	9	11
		Car	4	1	2			2		1	1	1
		Truck			0							0
	3	Motor Cycle	11	8	9	8	10	15	6	7	8	10
		Car	3	3	3	2	4	2		2	1	3
		Truck										
	4	Motor Cycle	10	5	9	7	6	12	6	8	8	10
		Car	1	1	2	2	3	1		2	1	3
		Truck			0							0
	5	Motor Cycle	7	5	7	6	7	11	5	6	8	9
		Car	2	2	3	1	2	1		3	2	2
		Truck			1					1		0
	6	Motor Cycle	8	7	9	7	8	11	6	6	9	12
		Car	3	2	2		1	2		2	1	2
		Truck			0							0
	7	Motor Cycle	9	8	11	7	7	9	7	7	9	11
		Car	3	1	1	1	2	3		2		1
		Truck										

Appendix 12: Traffic Density on Point Measurement IV (Source : Fieldwork Analysis)

Point Measurement	Days	Vehicles Type	Entrance					Exit				
			Time					Time				
			6.30-7.30	9-10	12.30-1.30	2-3	4-5	6.30-7.30	9-10	12.30-1.30	2-3	4-5
IV	1	Motor Cycle	11	10	18	9	14	13	9	14	13	17
		Car	3	2	4	2	3	5	5	8	3	1
		Truck										
	2	Motor Cycle	11	8	16	8	10	12	9	13	12	15
		Car	3	2	3	2	4	4	3	7	2	
		Truck										
	3	Motor Cycle	12	9	17	8	9	12	10	12	10	14
		Car	2	1	3	1	3	4	2	5	2	3
		Truck										
	4	Motor Cycle	11	7	15	6	11	10	7	9	9	10
		Car	2	2	2	1	2	2	2	3	1	2
		Truck	1							1		
	5	Motor Cycle	9	7	17	6	12	12	6	8	8	9
		Car	1	1	2	2	1	2	1	2	1	2
		Truck										
	6	Motor Cycle	10	5	18	7	9	13	7	10	7	9
		Car	1	2	2	2	1	2	1	2	2	3
		Truck										
	7	Motor Cycle	10	8	17	7	7	11	7	11	9	11
		Car	1	2	3	2	2	2	1	3	1	3
		Truck										

Appendix 13: Traffic Density on Point Measurement V (Source : Fieldwork Analysis)

Point Measurement	Days	Vehicles Type	Entrance Time					Exit Time				
			6.30-7.30	9-10	12.30-1.30	2-3	4-5	6.30-7.30	9-10	12.30-1.30	2-3	4-5
V	1	Motor Cycle	12	9	10	7	9	10	8	9	7	9
		Car	3		2				2		1	1
		Truck	2				2		0	2		
	2	Motor Cycle	13	8	10	7	11	11	7	9	6	8
		Car	2		2				3		2	2
		Truck	2				1			2		
	3	Motor Cycle	11	8	9	6	10	8	7	9	8	8
		Car	1						1			1
		Truck	1				1			1		
	4	Motor Cycle	12	7	10	11	11	9	8	8	8	10
		Car	4		3				3		2	2
		Truck										
	5	Motor Cycle	10	7	9	9	9	8	6	7	6	8
		Car	2		2				1		1	
		Truck										
	6	Motor Cycle	9	7	8	8	9	8	6	7	7	7
		Car	1		2				1		1	
		Truck	1				1			1		
	7	Motor Cycle	10	9	9	7	7	9	8	8	7	8
		Car	1		1				2			1
		Truck	1				1			1		

Appendix 14: Traffic Density on Point Measurement VI (Source : Fieldwork Analysis)

Point Measurement	Days	Vehicles Type	Entrance					Exit				
			Time					Time				
			6.30-7.30	9-10	12.30-1.30	2-3	4-5	6.30-7.30	9-10	12.30-1.30	2-3	4-5
VI	1	Motor Cycle	10	8	13	9	11	9	7	10	8	14
		Car	2		3	3	3	2		3	2	
		Truck	1		2		2			3		3
	2	Motor Cycle	10	8	11	6	11	9	9	11	6	12
		Car	1		2	2	2			4	2	
		Truck	2		2		1			3		1
	3	Motor Cycle	11	9	10	8	12	10	8	9	6	11
		Car			2	2	2	1		3	1	1
		Truck	1		3		2			2		3
	4	Motor Cycle	9	8	11	7	10	9	7	10	7	12
		Car	1		1	1	1			4	2	
		Truck	0		2		1			1		2
	5	Motor Cycle	8	7	10	6	9	10	8	9	6	11
		Car								1		
		Truck	2		2							
	6	Motor Cycle	7	7	8	6	9	6	7	8	5	10
		Car	2		3	2	3	2		3	2	
		Truck	1		1		1			1		2
	7	Motor Cycle	9	8	9	7	8	8	8	9	5	12
		Car	1		2	2	3	2		2	1	
		Truck	1		2					2		2

Appendix 15: Questionnaire

QUESTIONNARE

ANALYZING AND ESTIMATING LANDSLIDE RISK IMPACT TO ROAD

(A CASE STUDY IN SAMIGALUH DISTRICT, KULON PROGO REGENCY, YOGYAKARTA PROVINCE)

Researcher	:	Eko Setya Nugroho
University	:	Geoinformation for Spatial Planning and Risk Management, Double Degree MSc Programme Gadjah Mada University – Twente University

This information is used only for the purposes of research

Name of Respondent	:	……………………………………………………
Address	:	……………………………………………………
Age	:	……………………………………………………
Gender	:	……………………………………………………
Status	:	……………………………………………………
Job	:	……………………………………………………
Types of vehicles owned	:	……………………………………………………

1. Optimum Road toward Bali Desa Kebonharjo

a. In 2009, the biggest landslide which caused road blockage for 14 day occurred near Mr. Gunadi's shop. So the rider from **the east direction** who would reach **Balai Desa Kebonharjo** (public facility) couldn't across this way and tend to find the alternative road. Which alternative road will you choose? (the alternative roads map enclosed).

☐ Pringtali – Balai Desa ☐ Gebang – Balai Desa

☐ Pringtali – Dangsambuh ☐ Gebang - Dangsambuh

Note: the box is filled by using number based on the scale priority, smaller number indicates more prioritized

b. What reason do you choose this alternatives road (as main priority)?......................................

2. Optimum Road toward SDN Kebonharjo

a. In 2009, the largest landslide which caused road blockage for 14 day occurred near Mr. Gunadi's shop. So the rider from **the west direction** who would reach **SDN Kebonharjo** (public facility) couldn't across this way and tend to find the alternative road. Which alternative road will you choose? (the alternative roads map enclosed)

- ☐ Dangsambuh - Gebang
- ☐ Dangsambuh – Pringtali
- ☐ Balai Desa – Gebang
- ☐ Kleben - Gebang

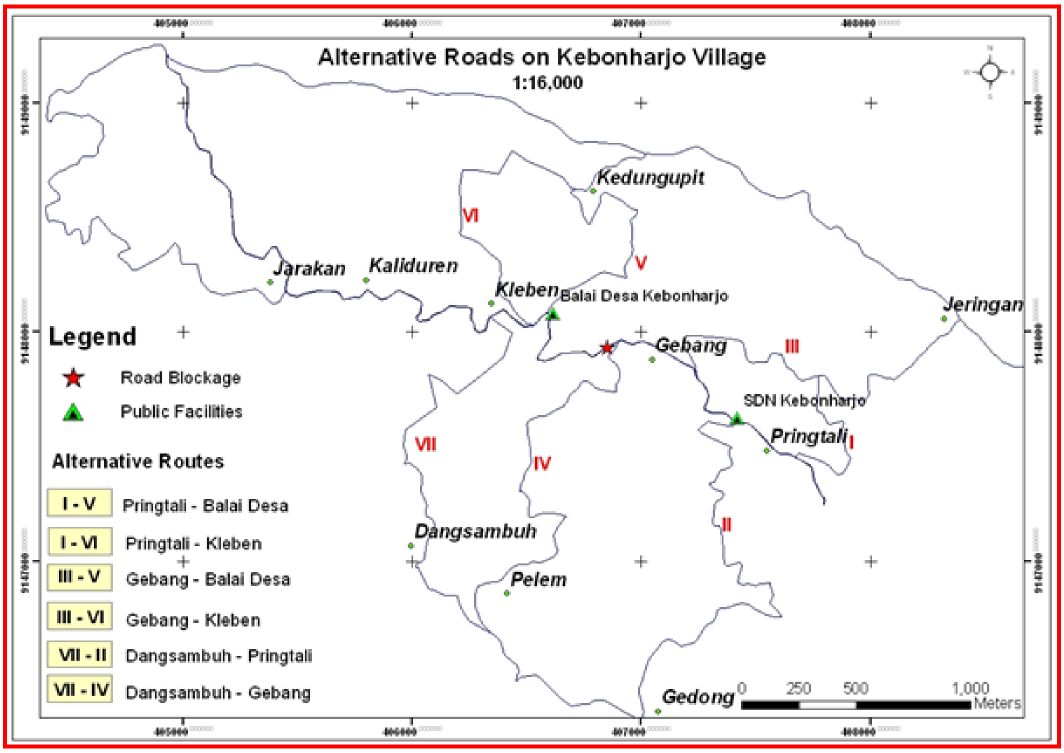
Note: the box is filled by using number based on the scale priority, smaller number indicates more prioritized

b. What reason do you choose this alternatives road (as main priority)?......................................

3. Fuel Consumption

How long distance (Km) can be travelled for your vehicle fuel consumption every 1 liter?

- Motorcycle :…… Km
- Car :…… Km
- Truck :…… Km


Alternative Roads on Kebonharjo Village
1:16,000
Legend
Road Blockage
Public Facilities
Alternative Routes
I - V
Pringtali - Balai Desa
I - VI
Pringtali - Kleben
III - V
Gebang - Balai Desa
III - VI
Gebang - Kleben
VII - II
Dangsambuh - Pringtali
VII - IV
Dangsambuh - Gebang
Kedungupit
Jarakan
Kaliduren
Kleben
Balai Desa Kebonharjo
Gebang
Jeringan
SDN Kebonharjo
Pringtali
Dangsambuh
Pelem
Gedong
VI
V
III
VII
IV
I
II
0
250
500
1,000
Meters