THESIS

OPTIMUM ROUTE EVALUATION OF PERMANENT SETTLEMENTS FOR ACCESSING TO PUBLIC FACILITIES AFTER MERAPI 2010 ERUPTION IN SLEMAN REGENCY

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DISCLAIMER

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Yogyakarta, 11 March 2013

Alfi Nur Rusydi

ABSTRACT

Permanent settlements were built to accommodate living needs of local people since they lost their settlement caused by Merapi 2010 eruption. The accessibility problems appeared since repairing infrastructures and public facilities after disaster occurred, especially route roads network connected from settlement to given public facilities was still unfinished. Optimum route evaluation was needed to find out which route that could be accessed effectively and be revitalized using model influenced by constraints, such as road length, travel time, route steepness, road quality, and traffic condition. Evaluation was done in several permanent settlements that had accessibility problems such as Batur, Gondang, Singlar, Glagahmalang, Banjarsari, Pagerjurang and Karangkendal. Butuh market and Pakem market were public facilities needed to be accessed by local people living in Batur and in Gondang, whereas Pakem market was needed to be accessed by them living in Pagerjurang and Karangkendal. Local people in Singlar, Banjarsari, and Karangkendal had route problem to access sub district office of Cangkringan.

Research was done by road network analysis using Geographic Information System (GIS) and Remote Sensing (RS) completed with interviewing and participation mapping with local people. Research results shown that optimum routes did not mean they being safe from volcanic hazard, although they had shorter road length and travel time, less steep route, better road quality, and quieter traffic. Most optimum routes of Batur, Gondang, Singlar, Banjarsari, and Glagahmalang passing Gendol river were located on the higher hazardous prone area of volcanism event. Therefore, the best optimum route was chosen on the routes that were far from Gendol river which was main channel for pyroclastic flow and lahars. Meanwhile, the best optimum route from Pagerjurang to Pakem market was located on the route which has lighter traffic condition. In weekend, the traffic of those routes would be heavier than on weekday because of holiday. Traffic would also be heavier in the day than in the morning because of rush hours.

Keyword: *Merapi volcano, optimum route, permanent settlement, public facilities, network*

INTISARI

Hunian tetap (Huntap) dibangun untuk mengakomodasi kebutuhan hidup penduduk local karena mereka kehilangan tempat tinggalnya dikarenakan erupsi Merapi 2010. Masalah aksesibilitas muncul karena perbaikan infrastruktur and fasilitas umum setelah bencana terjadi, khususnya jaringan jalan yang menghubungkan dari hunian tetap ke fasilitas umum tertentu masih belum selesei. Evaluasi rute optimal diperlukan untuk menemukan rute mana yang dapat diakses secara efektif dan dapat revitalisasi menggunakan srbuah model yang dipengaruhi oleh pembatas-pembatas, seperti panjang jalan, waktu tempuh, kemiringan rute, kualitas jalan, dan kondisi lalu lintas. Evaluasi dilakukan di beberapa hunian tetap yang mempunyai masalah aksesibilitas, seperti Batur, Gondang, Singlar, Glagahmalang, Banjarsari, Pagerjurang, dan Karangkendal. Pasar Butuh dan pasar Pakem adalah fasilitas umum yang dibutuhkan untuk diakses oleh penduduk local yang tinggal di Batur dan di Gondang, sedangkan pasar Pakem dibutuhkan untuk diakses oleh mereka yang tinggal di Pagerjurang dan Karangkendal. Penduduk local di Singkar, Banjarsari, dan Karangkendal mempunyai masalah rute untuk mengakses ke kantor kecamatan Cangkringan.

Penelitian dilakukan dengan analisis jaringan jalan yang menggunakan Sistem Informasi Geografi (SIG) dan Penginderaan Jauh (PJ) yang dilengkapi dengan wawancara dan pemetaan bersama dengan penduduk local. Hasil penelitian menunjukkan bahwa rute-rute optimal tidak berarti bahwa mereka aman dari bahaya gunungapi, walaupun mereka mempunyai panjang jalan yang lebih pendek, waktu tempuh yang lebih singkat, kemiringan rute yang tidak terlalu curam, kualitas jalan yang lebih baik, dan lalu lintas yang lebih tenang. Sebagian besar rute optimal Batur, Gondang, Singlar, Banjarsari, dan Glagahmalang, yang melewati sungai Gendol terletak pada area cenderung berbahaya tinggi terhadap peristiwa gunungapi. Oleh karena itu, rute optimal terbaik dipilih pada rute-rute yang jauh dari Sungai Gendol yang merupakan saluran utama bagi aliran awan panas dan lahar. Sementara itu, rute terbaik dari Pagerjrang dan Karangkendal ke pasar Pakem terletak pada rute-rute yang mempunyai lalu lintas lebih tenang. Pada akhir pecan, lalu lintas pada rute-rute tersebut menjadi lebih padat daripada pada hari kerja disebabkan hari libur. Lalu lintas akan menjadi lebih padat saat siang hari daripada pagi hari disebabkan jam-jam sibuk.

Keyword: *Gunungapi Merapi, rute optimal, hunian tetap, fasilitas publik, analisis jaringan*

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ABBREVIATIONS AND GLOSSARY

BAPPENAS	: Badan Perencanaan Pembangunan Nasional (Indonesia's National Development Bureau for Development Planning)
BAPPEDA	: Badan Perencanaan Pembangunan Daerah (Indonesia's Regional Development Bureau for Development Planning)
BNPB	: Badan Nasional Penanggulangan Bencana (Indonesia's National Bureau for Disaster Response)
BPPTK	: Balai Penyeledikan dan Pengembangan Teknologi Kegunungapian (Indonesian Agency for Investigation and Technological Development on Volcanism)
BPBD	: Badan Penanggulangan Bencana Daerah (Indonesia Agency for Regional Disaster Response)
RBI	: Rupa Bumi Indonesia (map of Indonesia's land use and administrative boundary)
DFID	: Department for International Development
DEM	: Digital Elevation Model
IRP	: International Recovery Platform
UNDP	: United Nations Development Programme
UTM	: Universal Transverse Mercator
Dirt road	: an unpaved road made from native material of the land surface
Sub district	: an administrative region consists of several villages with authority level below a regency

Chapter 1. Introduction

This chapter describes the background of the research, problem statement, research objectives, research questions, benefit of the research, scope and limitations and thesis structure.

1.1. Background

One of the elements at risk affected by 2010 Merapi eruption was human settlement. As public known, settlement is one of human basic needs, besides foods and clothes. Merapi 2010 eruption destructed a lot of settlements including infrastructures. It caused a lot of local people suffering from loss of their settlements. To cope with that problem, Government and other stakeholders planned to build temporary settlements and other infrastructures (see Figure 1-1) for temporarily accommodating their needs for living before permanent settlements were realized.

Figure 1-1. Temporary settlement (BPBD, 2011)

Figure 1-2. Permanent settlement (BPBD, 2012)

Now, permanent settlements (see Figure 1-2) have been built partly and some of them were still under construction (Kompas news, 2012). Since the construction and other infrastructures including roads are still unfinished, providing accessible public facilities become more sensitive issue to be considered for dealing with how people can access easily and effectively to those facilities to fulfill their daily needs. Besides functioned as path to transport commuters, goods, and vehicles, road was functioned also as rescuing path during emergencies like disasters (Anbazhagan, Srinivas, & Chandran, 2012). To optimization existing road network in effectiveness of accessibility to public facilities, optimum route evaluation is really needed since transport route is one of important socio economic factors of a settlement, besides size of settlement and proximity to other villages (Entwistle et al, 2008). Thereby, this research will focus on the optimum route from their permanent settlements to specified places that people need to access.

1.2. Problem Statement

The first surveying had been done on 20-22th October 2012 for updating accessibility problems in permanent settlements located in Sleman Regency. It was done by informal interviewing to key persons and some local people in each location of permanent settlement.

By interviewing to key persons and some local people, what the places that people need to access dealing with travel distance, road condition, and importance of those places to their daily activities had been investigated (see Figure 1-3). That interviewing reflected also existing accessibility problems as represented in Table 1-1.

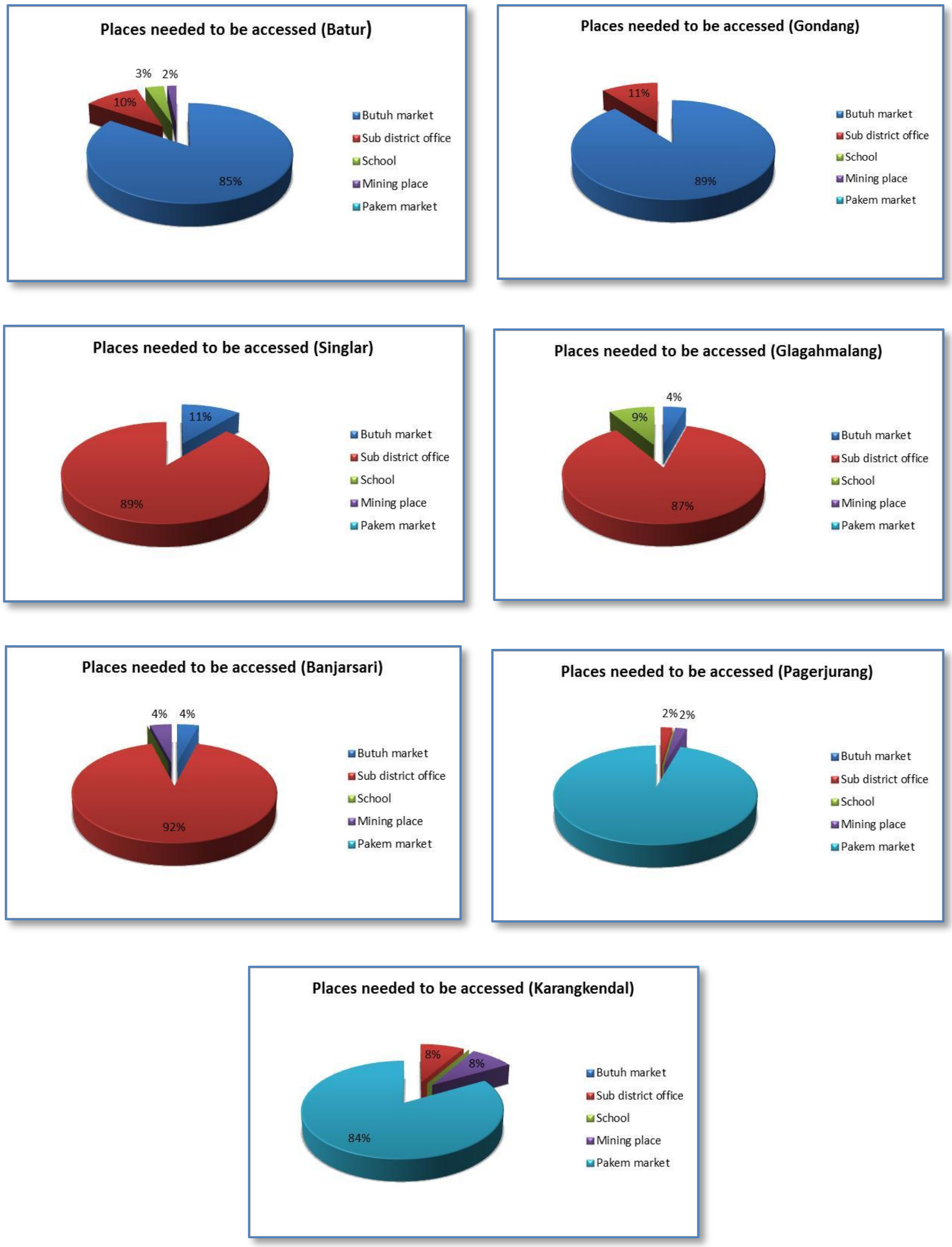

Figure 1-3. Places needed to be accessed by local people in permanent settlements of Cangkringan sub district (Field surveying, 2012)

Table 1-1. Research problem

No	Name of permanent settlement	Places that people need to access	Problems
1.	Batur; Gondang 2 and Gondang 3;	Access to market	1. No representative near market located around the settlement. Near market which is Cokrokembang market still being desolate place caused by insufficient crop supply from farmland located in upper areas that were destructed by Merapi eruption of 2010. 2. Therefore, most people prefer to go to the further and more crowded market which is Butuh market. It provides more complete goods than Cokrokembang market and has lower prices. 3. Many damaged road segment connecting from settlement to Butuh market because of pyroclastic flows, lahars and overload of volcanic sand carried by trucks makes that route being difficult to be accessed
2.	Kepuharjo; Karangkendal	Access to market	1. Market typically accessed by people is Pakem market, however, it is located further from the settlements 2. The market can be accessed by two routes. 3. The first route (going across local government office of Umbulharjo village) was easy to be accessed but in Saturday and Sunday, it became difficult to be accessed due to more crowded traffic dominated by touring bus 4. The second route can be alternative route despite of worse road condition caused by trucks carrying volcanic sand. Even, it is further route to the destination
3.	Singlar; Glagahmalang; Banjarsari	Access to local government's office of Cangkringan sub district	1. The closest route connecting settlement to Cangkringan sub district's office was damaged because of pyroclastic flows, lahars, and overload of truck carrying volcanic sand 2. If rain comes, road became muddy so that it would be more difficult to be accessed. Other routes available had much further distance so that the travel time would be much longer.

(Source: Field surveying, 2012)

These problems deal with how people to access effectively to those access-needed places. It related to how a given route can be optimum to be accessed by them. Unsolved condition causes disturbance of their daily activities since those place provide basic goods (for instance, foods provided by market). This research tried to solve these accessibility problems for the proper living over there.

Accessing to the market is most accessibility problem of most new settlement. Easy access to the market being one of preferences of new settler in a given location of settlement, besides flat area, water resources available, security, and sociability (Entwistle et al, 2008).

No updated road network analysis for accessing to public facilities caused difficult accessibility of permanent settlement. Most road condition of post Merapi 2010 eruption in Cangkringan sub district changed being worse caused by that eruption. Those roads became limited access and only given vehicles type that could access well. Updated road network analysis was needed to make easier accessibility for local people. How to updated road network in specified analysis could be easier by using geo-informatics analysis. Geo-informatics analysis started from road data input, continued to GIS network analysis and route evaluation by overlaying it with detailed hazard map were effective tools to find where the best optimum route would be find out.

1.3. Research Objectives

This research tried to find optimum routes out over preferred routes by local people. Routes network modeling was implemented spatially and temporarily to decide the best accessible route in various times and days. Possible hazardous roads were evaluated also by means detailed volcanic hazard map of Merapi overlaid that road network. The detailed objectives were carried out through three specific objectives which are:

1. To identify preferred routes that are accessed by local people from their permanent settlement to place they need to access by participation mapping together with local people
2. To extract optimum routes from preferred routes network by analysis of varying costs, such as road length, neutral travel time, road steepness, road quality, traffic factor, and influenced travel time by traffic
3. To evaluate optimum routes prone to volcanic hazard zone by overlaying with detailed volcanic hazard map of Merapi

1.4. Research Questions

Research questions discussed in this research are represented in Table 1-2.

Table 1-2. Research Questions

No	Research Objectives	Research Questions
1	To identify preferred routes that are accessed by local people from their permanent settlement to place that they need to access by participation mapping together with local people	1. Where is preferred route by local people from their permanent settlement to place that they need to access?
2.	To extract optimum routes from preferred routes network by analysis of varying costs, such as road length, neutral travel time, road steepness, road quality, traffic factor, and influenced travel time by traffic	2. Where are optimum routes by various costs (road length, neutral travel time, road steepness, road quality, traffic factor and travel time influenced by traffic)?
		3. How is variation of route traffic condition by times and days?
		4. How is variation of optimum routes influenced by variation of route traffic condition?
		5. When can people get easiest access to go to the place that they need to access?
		6. Which is best optimum route (has minimum cost/contraints)?
3.	To evaluate optimum routes prone to volcanic hazard zone by overlaying with detailed volcanic hazard map	7. Which are the road segments prone to hazardous route based on hazard zone analysis of Merapi?

1.5. Research Benefits

This research provided information of the preferred routes, optimum routes and evaluation of those routes connecting from permanent settlement to public facilities related to hazard zone of Merapi volcano. This research was also useful for local government, local community, and other stakeholders for several purposes as follows:

1. Revitalizing optimum route of permanent settlement in Merapi volcano.
   As part of resilience, people need an optimum route that can be accessed to important place to fulfill their basic needs. Without that, their resilience is not going on well. The improved resilience is needed to rebuild a normal life condition as well as that in pre-disaster occurrence.
2. Recommendation in decision making to rebuild infrastructures of permanent settlement in Merapi volcano
   Route evaluation can be valuable suggestion for Government or stakeholders to mature their planning to rebuild infrastructures. It can avoid unsatisfied living felt by inhabitants.
3. Livelihood sustainability of inhabitants can be kept.
   By means of good spatial planning of permanent human settlement, livelihood consisted of capabilities, assets, and activities (DFID, 1999) of community can be kept. Livelihood can support their economic condition as their resilience in post-disaster.
4. Contributing for further research related to human settlement in pre, during, or post-disaster occurrence.

This research can be used as another consideration to improve any concepts, method, analysis techniques, and research results related to human settlement in pre, during or post-disaster occurrence, especially about volcanic disaster.

1.6. Scope and Limitations

1.6.1. Scope

This research discussed routes that were typically accessed by local people to facilities that they need to access. That route was called as preferred routes. Those routes were analyzed by including several influencing factors to extract a model of optimum route spatially and temporarily. Since the routes belongs to Merapi volcano area, so by means updated hazard zone of Merapi, those routes were evaluated to get optimum route that can be accessed safely by local people, so that in the future, the routes can be revitalized for dealing with increasing sustainable spatial accessibility of permanent settlement.

1.6.2. Limitation

Limitations were used to focus this research on what things that were need to be discussed. Some limitations included research focus and source of input data as follows:

1. The focused research area was located only in permanent settlements that have accessibility problem. At least, there are 13 permanent settlements placed in surroundings area of Merapi volcano. In this research, only 7 permanent settlements that were analyzed
2. The source of base road as input data for road network model was from preferred routes since the focus of this research is preferred routes by local people, so that not all roads located in Merapi volcano were involved in that network.

1.7. Research Structures

This research consisted of eight chapters which were described specifically in this following section:

Chapter 1-Introduction
This chapter described the background of the research, problem statement, research objectives, research questions, benefit of the research, scope and limitations and thesis structure.

Chapter 2-Literature Review
The literature provided theoretical background of this research including concept of accessibility, definition of optimum route, human settlement, location of human settlement, preference of human settlement, resettlement, volcanoes, Merapi volcano, Merapi 2010 eruption, policy and planning for post-disaster rehabilitation and reconstruction in Yogyakarta, Importance of developing route network, participation community in disaster preparedness and risk reduction, role

of Geographic Information System (GIS) analysis in finding optimum route, role of Remote Sensing (RS) analysis in finding optimum route, network analyst, and network dataset, traffic analysis in Geographic Information System (GIS), and Digital Elevation Model (DEM) analysis.

Chapter 3-Study Area
This chapter provided overview of research area which was located in the permanent settlement built after Merapi 2010 eruption. The parts overviewed in this chapter included condition of Merapi volcano, location of permanent settlement completed with current condition of those settlements.

Chapter 4-Research Methodology
The method used in this research was provided in this chapter including data, software, tools/equipment, data collecting, data analysis, and analysis of results. The flow of this research was figured into research framework.

Chapter 5- Network modeling of optimum route
This chapter provided spatial information of preferred routes by local people used to access facilities they need to access and an optimum routes model derived from those preferred routes. A model was controlled spatially and temporarily by influencing factors (costs/constraints), such as road length, neutral time, route steepness, traffic factors, and travelling time influenced by traffic.

Chapter 6-Evaluation of optimum route by means hazard zone of Merapi volcano
This chapter discussed optimum route evaluation related to volcanic hazard types and areas prone to hazard which road segments are located in. The perceptions of local people and local government related to road condition in post-Merapi 2010 eruption were also included. This part also analyzed whether an optimum route was located in safe area or in hazardous area.

Chapter 7-Conclusion and recommendation
The recommendation was provided to give reference for local government, local community, other stakeholders and researchers in doing future research focusing on Merapi volcano.

Chapter 2. Literature Review

The literature provides theoretical background of this research including concept of accessibility, definition of optimum route, human settlement, location of human settlement, preference of human settlement, resettlement, volcanoes, Merapi volcano, Merapi 2010 eruption, policy and planning for post-disaster rehabilitation and reconstruction in Yogyakarta, Importance of developing route network, participation community in disaster preparedness and risk reduction, role of Geographic Information System (GIS) analysis in finding optimum route, role of Remote Sensing (RS) analysis in finding optimum route, network analyst, and network dataset, traffic analysis in Geographic Information System (GIS), and Digital Elevation Model (DEM) analysis.

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2.1. Concept of accessibility

Accessibility is effort at reasonable cost, in reasonable time, and with reasonable ease done by people to get key services (Social Exclusion Unit of UK Government (2003) after Poole (2003)). Accessibility is also defines as ease of a given location that can be reached from other locations (Goodall, 1987 after Farrow and Nelson, 2001). There are four elements of accessibility which are: (Poole, 2003)

1. A transport that connects between an origin and destination location
2. A landuse that spatially depicts distribution of activities at destination
3. A temporal component that illustrates time limitation to reach destination
4. An individual component, reflecting the needs, abilities, and opportunities of individuals

Accessibility was also viewed as reference of opportunity and function of deterrence. Opportunity means availability that individual can reach destination, whereas deterrence means cost to reach destination, such as distance and time (Poole, 2003). Accessibility can be modeled such as calculating access, calculation of capacity constraints per location, distance to closest facility, improved access for the population, and optimum location (HSRC (2008) after Widyaningrum (2009)). Spatial accessibility means the effort to reach a given location from other locations by considering spatially (site, routes, distance, time, and direction) the condition of those locations

2.2. Definitions of Optimum Route

Optimum route is meant as not only the fastest route, but also reliable route (Akay, Wing, Sivrikaya, & Sakar, 2012). Brainard et al. (1996) explained that optimum route can be viewed by several perspectives of usefulness of GIS in finding that route such as: (1) route for shortest time only; (2) route that can be accessed by motor and dual-carriageway encouragement; (3) retired route from abundant population of people; (4) safety route (minimum accident). Generally, route can be optimum if there is minimum the sum of route parameters (route costs) influencing that route (Zhan, F. B, 1997).

Optimum route in this research is meant by considering several influencing factors such as: (1) the shortest travel time; (2) the shortest road length; (3) the flattest road (since the research area is volcanic area consisting of many steep roads); (4) the quietest traffic (minimum traffic jam); (5) the most secure road from volcanic hazards). Combination of those optimum routes generated by these factors is used to determine the best route. Therefore, the best route is meant as the best of optimum route.

2.3. Human Settlement

Human settlement is a part of environment that is in outside of preserve area, both in urban area and rural area which the function is as living place or settlement and activity place that is support human life and livelihood (Law No.4 of 1992 article 1). Yunus (1987, 1989) explained also that human settlement is all both artificially and naturally form within all its completeness that are used by human both individually and in group. This form is used as either temporary living place or permanent living place for human's life.

Human settlement has five elements which are nature (soil, air, animal, and plant), shells, networks, human, and community (Doxiadis, 1971). Nature is a major part which shells (house, building, and et cetera) are created as settlement within various other activities and network (road, utility network). Nature plays role as facilitator for relationship between those elements. Therefore, human settlement is combination between human, community, nature, and artificial element (Doxiadis, 1971).

2.4. Location of human settlement

Location depends on space (Tarigan, 2009). Location does not exist without space. Location depicts position of space (can be determined by latitude and longitude). Location often concern with name or character of a given place so that it can be distinguished between one location and another location.

Location has two elements which are site and situation. Site is location of place within its specified characteristics and resource, whereas situation is relationship of one location to another location (Daldjoeni, 1997). Location of human settlement is selected based on ease of accessibility for inhabitant to reach working place and service centers (Sastra and Marlina, 2006). This statement can be interpreted through several further explanations as follows:

1. Between location of human settlement and working place and service centers are connected by public infrastructures
2. Location of human settlement and working place and service centers has accessibility of public transport that can be used by all people in a community living in that area.

Mirhad (1983) explained that planning of human settlement should consider factors as follows:

1. Not hazardous area, such as flood area, earthquake area, volcanic eruption, or thunderstorm area.
2. Easy accessibility without significant obstacles

3. Easy to get and use fresh water for drinking, electricity, waste drainage, and *et cetera*
4. Easy to reach working place
5. Far distance from polluted factory, garbage, and waste; and
6. Noise free

2.5. Preference of human settlement

Turner (1968) explained that there are four dimensions about selection of settlement by inhabitants which are:

1. Location
   Suitability between characteristics of location and capability of livelihood (economic and life cycle), and distance to working place.
2. House's ownership
   Capability of inhabitants to own a house can be influence factor to select location for settlement
3. Life cycle dimension
   People want to get much more things related to their settlement, if they have much more money or income.
4. Income
   Economic condition of people influences how they can survive to live in a given location of settlement

Turner's explanation above illustrates that there is relationship between income and preference of inhabitants about location of settlement. Priority of basic needs will decrease together with increasing of income, and this priority will be substituted by secondary or tertiary needs. Closeness of distance from house to working place also becomes a factor to select location of settlement. This priority will decrease together with increasing of income, because further distance to working place can be reached if someone has much more income. Demand of house's ownership will increase together with increasing of income (related to prestigious). The limitation of resources, such as land for settlement and difference of economic condition of inhabitants become a main problem to fulfill those preferences, so that strategy or policy related settlement cannot satisfy definitely to inhabitants.

2.6. Resettlement

Resettlement is needed optionally if the location of settlement is located in the area which is too hazardous. Permanent settlement located in Merapi volcano after 2010 Merapi eruption belongs resettlement that is done by government to cope community who lose their settlement because of that eruption. In the process of resettlement, there are reasons that should be avoided, so resettlement can be done successfully (Jha et al, 2010). Those reasons are explained as follows:

1. Unsuitable site selection

The location selected is not best for people because in some cases, the location is selected because that location is owned by government or it is fastest available site.

2. Distance from livelihood and social network.
   Unsustainable settlement can be caused by long distance from important resources, market, and social-network of relation.
3. Socio-culturally inappropriate layout.
   Failure of resettlement can be caused by inappropriate housing design, layout, and construction.
4. Lack of community participation
   Participation of community is needed to increase sense of ownership and responsibility, so that resettlement can be successful.
5. Under budgeting of relocation cost
   The relocation cost is divided into two kinds of cost which are hard cost and soft cost. Cost for infrastructure and housing construction is involved as hard cost, whereas cost for training, facilitation, social assistance, and temporary public services is involved as soft cost. Both costs have to be calculated.

The Sphere Project (2004) explained that the standard a new settlement for affected people. The covered floor area per person should be at least 3.5 m2 to ensure that people have dignified accommodation and to provide room for their main household activities and livelihood support activities. There are reasons related to shelter recovery as follows (IRP & UNDP, 2010; The Sphere Project, 2004):

1. Shelter recovery transitions.
   There are five phases of shelter in planning of shelter recovery transitions as shown in Figure 2-1.

Figure 2-1. Phase of shelter recovery (IRP 2010, modified by Author)

2. Site selection.
   There are two approaches of site selection which are staying on existing site and relocation. If the staying on existing site is taken as decision in site selection, it has to be considered whether that site can be inhabited safely by affected people or not. The advantage of this approach is burden of service provision will be reduced. Relocation can also be taken, if that site is still hazardous area, but first approach is more preferred by affected people because existing site is associated with livelihood, history, culture, community, family, spiritually, and much more. There are prerequisites of resettlement which are shown in Table 2-1.

Table 2-1. Prerequisites of site selection

Provision of facilities	The existence of and access to adequate and appropriate cultural and religious facilities
	Adequate and accessible medical and public health services
	Suitable and sufficient educational facilities
	Access to safe and affordable food and drinking water
	Access to affordable standard utility services (power, communications, sanitation)
Connection of community	The existence of a community structure and physical layout that residents find agreeable and which alienates no group or household
	Physical access to other community
Continuity of livelihood	Access to and availability of appropriate livelihood opportunities (including agricultural land for agrarian communities)
	The provision of training and counseling to provide life and livelihood transitions
	The ability to ensure and maintain security
	The maintenance of existing community, family, and social networks

(IRP & UNDP, 2010)

3. Project implementation method.
   The process relates the managing construction project, including structural design, materials selection, source of labor, and technical expertise. That process can be divided into 4 categories which are:
   a. Owner/community-driven project implementation
   b. Government/donor/NGO-driven project implementation
   c. Contractor-driven project implementation
   d. Hybrid implementation (mixed between two or all other implementations). Mostly, hybrid implementation is selected because it can maximize the best capacity of the actors involved in the project implementation
4. Building design
   In the process of design, hazard resistance, local aspect in appearance, function, and material chose should be considered.
5. Legal implications
   The shelter reconstruction is influenced by legal framework of affected area and it need proof of ownership of land and property. Mostly, after disaster occurred, that proof is lost , so that the affected people cannot present it.
6. Technical assistance/expertise.
   The houses should be built in safe and sustainable manner. Therefore, technical assistance/expertise is needed in building those houses.
7. Construction materials
   The specification of construction materials should able to mitigate against future natural disaster. The reasons used in choosing construction materials are quality, cost and appropriateness, local knowledge of material, local availability, impact on local markets, and environmental impact of the materials.
8. Construction labor

It should consider food for work, cash for work, and owner labor. They are called as three mechanism of compensation for construction labor.

9. Upgrading and maintenance
   For long-term needs, the people should upgrade the shelter or aspect of the design. They should also repair using appropriate tools and materials.
10. Maintaining live, livelihoods, and community character.
    The factors that should be considered are design and functionality, location, and availability and quality of services. To keep sustainable economic activities of affected people, the land availability and access for cultivation and grazing; the location and access to market areas; and the availability of and access to local services that may be essential to given economic activities should also be considered.
11. Safety and privacy
    The settlement needs an adequate separation between the groups, such as women and children. They are more potential to be attacked and have more personal safety. Adequate personal privacy and safety can be created based on groups of related family, well-planned access routes through the building or structure, and materials to screen personal and household space.

In the process of resettlement, explanation shows how important to consider spatial accessibility and social accessibility in order to ensure sustainable live of affected people in post-disaster. As disaster responsibility, government plan to build temporary settlement for short term and to build permanent settlement for long term then. Permanent settlement (see Figure 2-2) is the settlement for a human or group of human that is functioned during unlimited time, whereas temporary settlement is the settlement for a human or group of human that is functioned during limited time (BPBD, 2011). This research focuses on the permanent settlement as the matter that will be researched.

Figure 2-2. Temporary settlement (left side) and permanent settlement (right side) (BPBD DIY, 2011)

2.7. Volcanoes

Volcanoes as major part of Earth and one of most important natural hazard do not appear everywhere on the Earth's surface (McCall, 2005). Distribution of volcanoes depends on the location which plate tectonic being active. Activities of plates tectonic include colliding of each plate and spreading of seafloor (midocean ridge). Both activities of those plates generate upwelling magma containing certain Earth materials and minerals. Depositing much more both materials and minerals could form a cone shape being a first proliferation of volcanoes. Tilling (2003) explained also that volcano is a mountain or hill as a result of accumulation of materials obtained from openings of Erath surface. Those openings refer to volcanic vent.

One of activities of volcanoes is called as eruption which is an ejection of materials that rises above volcanic vent (Tilling, 2003). Eruption can be various forms such as lava, pyroclastic flow, and volcanic ash. High temperature of ejected materials, however, reached to Earth's surface, had made volcanic eruption becoming one of volcanic hazards giving potentially damaging so far.

Thomson and Turk, 1997 had classified volcanoes based on shape, size, type of magma, and style of activity, see the Table 2-2.

Table 2-2. Classification of volcanoes

Type	Form	Size	Type of Magma	Style
Basalt plateau	Flat to gentle slope	100.000 to 1.000.000 km2 in area; 1 to 3 km thick	Basalt	Gentle eruption from long fissures
Calderas	Cataclysmic eruption leaving a circular depression called a caldera	Less than 40 km in diameter	Granite	Very violent
Cinder	Moderate slope	100 to 400 m high	Basalt or andesite	Ejection of pyroclastic materials
Shield volcanoes	Slightly slope 6° to 12°	Up to 9000 m high	Basalt	Gentle, some fire fountains
Strato or composite volcanoes	Alternative layers of flows and pyroclastic	100 to 3500 m high	Variety types of magma and ash	Often violent

(Thomson and Turk, 1997)

2.8. Merapi Volcano

Merapi volcano (see Figure 2-3) known as the most active volcano in the world (Gerstenecker et al, 2005, (Voight, Constantine, Siswowidjoyo, & Torley, 2000) has changed in its eruption being explosive eruption since in 2010. In that time, compared with eruption in 1872, producing pyroclastic materials are around 100 million m3, even tremendous explosive eruption of Merapi produces much more pyroclastic materials which are around 140 million m3 (Kompas, 2010). The eruption has also thrown those materials up to 8 kilometers (Tribunnews, 2010) and 17,090 people were evacuated (BNPB, 2010). The 2010 Merapi's eruption took victims about 386 people, most of them which are around 198 people fell victims to pyroclastic flow.

Figure 2-3. Merapi volcano (www.wayantulus.com/foto-gunung-merapi-meletus, 2010)

Merapi has explosive episodes of 8-16 years intervals generating dome-collapse pyroclastic flow and destroying pre-existing dome (J. C. Thouret, Lavigne, Kelfoun, & Bronto, 2000). Rivers that their upstream are located in Merapi volcano are Apu, Trising, Pabelan, Senowo, Lamat, Blongkeng, Putih, Bebeng, Krasak, Boyong, Kuning, Gendol, Woro., Krasak, Teleng, and Gandul. In 2006, Gendol river and its valley is the most affected channel by pyroclastic flow, because that flow mostly moves through Gendol valley. (J.-C. Thouret et al., 2010).

Merapi flanks are lived by high dense population of people (Gerstenecker et al, 2005), because in this area, a lot of benefit potencies can be explored, such as sand mining, economic activities, tourism object, high productive land for agricultural, and comfortable for human living with the beautiful scenery and fresh air. On the other side, those areas are still to be volcanic hazardous area due to Merapi eruption. Not all communities understand clearly and scientifically about Merapi hazards and actual volcanic processes (Lavigne et al., 2008), so their preparedness and coping capacity to face these hazards are still at low level which there are still many victims and losses caused by Merapi hazard.

2.9. Merapi 2010 Eruption

Merapi 2010 eruption occured on 26th of October 2010 and 5th of November 2010 has intensity which was far higher than any Merapi eruptions before. Tremendous eruption of Merapi has changed thhe morphology of Merapi (Ikaputra et al. 2011, after Putri, 2011). The southern flank has been opened by that eruption, so the future eruption (especially pyroclatic flow as primary damage) is predicted to move southward. Yogyakarta city are located to the south of Merapi.

The total death toll was 340, the estimated total loss was IDR 4 Trillion and 200.000 persons were evacuated. Severely damaged houses in Yogyakarta were about 2.636. Medium damaged houses were 156, and slightly damaged houses were 632. In Central Java, there were 551 severely damaged houses, 950 medium damaged houses, and 2204 slightly damaged houses (Bappeda, 2010). The chronology of Merapi 2010 eruption is represented in Table 2-3.

Table 2-3. Chronology of Merapi 2010 eruption

Date	Geological Agency Decision / Danger zone	Events and danger zone
20th of September 2010		Merapi alert level was increased from Normal to Waspada
21st of October 2010		Merapi alert level was increased to Siaga
25th of October 2010	2048/45/BGL.V/2010 10 km from the peak of Merapi	Merapi alert level was increased to Siaga. Evacuation was started. Priority of evacuation is given to women, children and elderly. Seven evacuation barracks were prepared in Glagaharjo, Kepuharjo, Umbulharjo, Hargobinangun, Purwobinangun, Girikerto and Wonokerto. Sleman government prepared means of transportation for the evacuation.
26th of October 2010		Merapi erupted. Forty persons were death. People who resided in KRB were evacuated.
3rd of November 2010		Pyroclastic flow happened for 1.5 hours and reached 9km from river bank of Gendol River.
5th of November 2010	2317/45/BGL.V/2010 20 km from the peak of Merapi	Merapi erupted again. Death toll reached 222 persons.
19th of November 2010	2377/45/BGL.V/2010 10 km from the peak of Merapi in west area and 15 km in East area of Boyong River	From 12 am, the save zones for refugee in Sleman regency were 15 km from the peak of Merapi on east area of Boyong River, 10 km from the peak of Merapi on west area of Boyong River; in Magelang Regency was 10 km from the peak of Merapi; and in Klaten Regency was 10 km from the peak of Merapi
3rd of December 2010	3120/45/BGL.V/2010 2.5 km from the peak of Merapi, especially in temporary KRB III in sub-district of Cangkringan, Ngemplak, Pakem, and Sleman Regency	Merapi alert level was decreased to Siaga, but there was still threat from cold lahars

(Bappeda, 2010, modified by Author)

2.10. Policy and Planning for Post-disaster Rehabilitation and Reconstruction in Yogyakarta

There are three kinds of planning of 2006 for post disaster rehabilitation and reconstruction in Yogyakarta which are (Hadi, 2008):

1. Recovery and systematic approach
2. Action plan for rehabilitation and reconstruction
3. Institutional framework for post-disaster rehabilitation and reconstruction

Government has two important roles in this planning which are not only in implementation, but also in monitoring those processes of planning. The processes can be seen in Figure 2-4. For recovery and systematic approach (point 1), policies that will be done are (Hadi, 2008):

1. Housing and settlement recovery: It emphasizes on how houses can be rebuild and the society life can be reform after disaster occurred
2. Public infrastructure recovery: Public infrastructure should be recovered to revitalize social life and local economy
3. Local economy revitalization: It emphasizes to activate social economic life to reach sustainable livelihood of society. Providing employment opportunities should be included to solve unemployment problems.

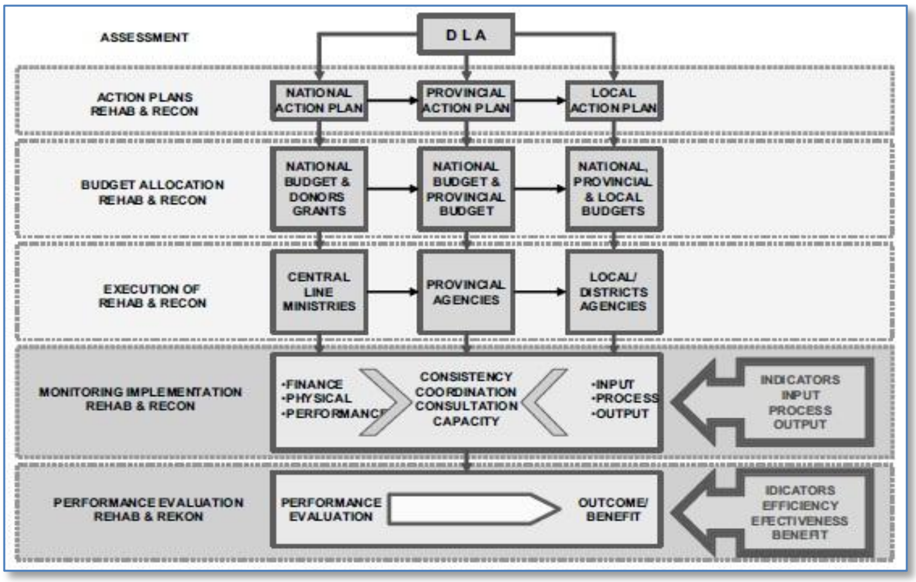


Figure 2-4. Reconstruction planning and monitoring process (Hadi, 2008)

Explanation above indicates that settlement being one important aspect that has to been included in post-disaster rehabilitation and reconstruction. Rebuild permanent settlement for local people who lose their settlement due to Merapi eruption should be completed with recovery of public infrastructure. A good plan for building public infrastructures located in surrounding location where new permanent settlement built can help local people to recover their social economic life quickly. It will be called a better plan if the location can also be accessed easily by them.

For action plan of rehabilitation and reconstruction (point 2), the processes are started from estimated damage continued by need assessment (see Figure 2-5). Need assessment process is detailed as follow (Hadi, 2008):

1. Generate base line data from Statistics agencies and other sources
2. Doing assessment stage which are
    a. Preparation previous assessment at national level which includes data collecting, data optimizing, data updating, and data verifying.
    b. Field surveying for additional data collection

c. Data updating and data verifying which includes well coordination and consultation between national, provincial, and local government. Assistance from expert should also be included to assess need and possible impacts. Meanwhile, by parcipatory process, community can take role in monitoring and verifying assessment processes.
d. Doing process
3. Coordination in financial plan that will be included in formulation the recovery plan.

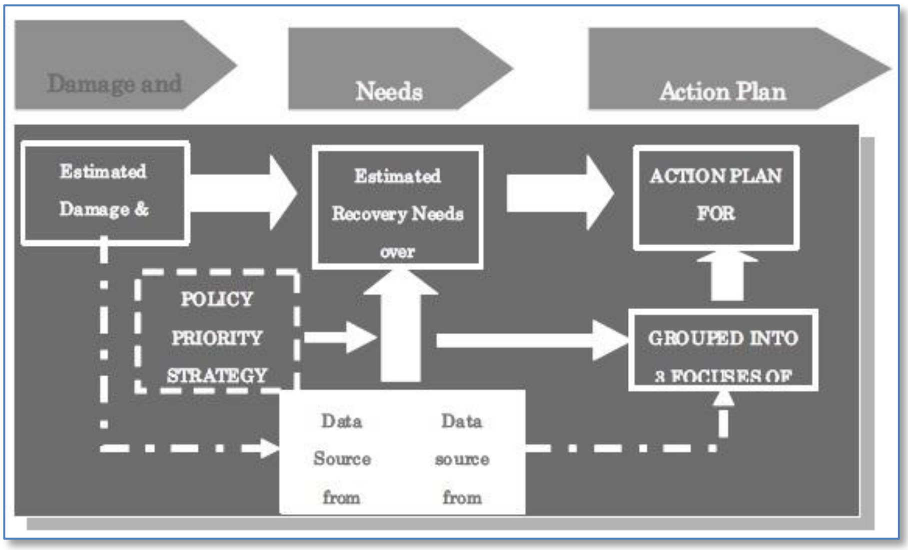


Figure 2-5. Need assessment and action plan approach (Hadi, 2008)

Thus, the research focusing on accessibility of route from permanent settlement should include need assessment first for which indicates what the public facilities that should be accessed by local people. It is important since there are damaged public facilities caused by volcanic eruption, so that they have to been reinvestigated to solve accessibility problems suffered by local people who live in new permanent settlement

National action plan provided by BAPPENAS includes three important elements which are (Hadi, 2008):

1. National policy and strategy in recovery process. Both emphasizes housing and settlement recovery, public infrastructure recovery, and local economy revitalization
2. Formulate financial plan since all processes need sufficient fund (see Figure 2-6). The financial plan can be carried out by well coordination of budgeting between central government, provincial government, and local government. Financing scheme can be seen in Figure..
3. Activities and responsibility from parties. They can support those policies under supervision and coordination of government.

	Funded by private/ company/ community	Funded by community/ private with government support	Government Expenditure with support from community	Funded by Government Expenditure
Housing and settlement		Physical rehabilitation		
Public Infrastructure		Physical rehabilitation : electricity Water and sanitation telecom	Physical rehabilitation : market-place, government building, cultural heritage, health, education, public facilities	Physical rehabilitation: road, bridge, irrigation
Economic recovery	Financial stimulation, and regulatory support : economic sector in general	Financial stimulation and regulatory support : SME		

(Government expenditure/government support include support from donors)

Figure 2-6. Financing scheme for rehabilitation and reconstruction (Hadi, 2008)

It indicates that this research cannot neglect the role of government in determining optimum route from permanent settlement to public facilities. That role was placed in government perspective related to where the better routes that are recommended to be accessed by local people. The main consideration in this perspective was volcanic hazard evaluation of Merapi volcano.

2.11. Importance of Developing Route Network

Road network is one important part in region planning (Tawfik, Nagar, & Anya, 2008) since it accommodates growth of population and economy (Nijagunappa, Shekhar, Gurugnanam, Raju, & De, 2007). Population growth and economy should be facilitated by better road network to keep both being sustainable. In the hazardous area, road network is more important that should be considered in planning, especially for evacuation path. Akay et al (2012) give a good example about how important road network in increasing response to forest fire. A better road network indicated with identifiable optimum route will much more help forest fighter to cope forest fire problem in Kahramanmaras Forestry Regional Directorate in the Mediterranean region of Turkey where the research done. Developing road network functioned as evacuation for livestock during volcanic crisis in Chile is also researched well by Wilson et al (2012). They research evacuation road for human and livestock evacuation since both are essential aspects in volcanic risk management (Wilson et al., 2012). Besides that, the optimum route indicated by shortest route (shortest or least costs) should be considered by most organizations (Erden & Coskun, 2006).

Similar with previous research above, a good manageable road network should be developed effectively. In this research, the developing road network indicated by identifiable optimum route focused on accessing to public facilities since there are many research related to road network to investigate evacuation path from volcanic hazard. Finding optimum route will help local people to travel effectively to public facilities needed to be accessed since the condition after Merapi 2010 eruption was mostly changed.

2.12. Participation Community in Disaster Preparedness and Risk Reduction

Hadi (2008) stated that one of roles that can be done by community in disaster preparedness and risk reduction is to develop multi-hazards risk assessment maps. Therefore, involving community's roles in determining safety route from volcanic eruption was important to do since they had local knowledge about where the likely hazardous areas located and where the hazardous route that should not be accessed. To do so, participation mapping with community was involved in this research.

2.13. Role of Geographic Information System (GIS) Analysis in Finding Optimum Route

GIS analysis is more effective to find optimum route or other network analysis. Accessibility measurement including route network can also be modeled by GIS road network, besides transportation planning, retail market analysis, service allocation, and more (Lwin & Murayama, 2012). Lepofsky and Abkowitz (1993) explained that in finding effectively optimum route, transport parameters represented in map and statistical data of population can be integrated into this system. Huang et al. (2004) stated that GIS can be used in quantifying criteria (costs) of route specifically to extract optimum route. Research about route planning done by Li and Leung (2011) taking place in Hongkong use costs such as travel time, incident probability, route risk, off-road population at risk, needs of people, and economy impacts coming from industrial, commercial, and transport facilities (Li & Leung, 2011). Akay et al. (2012) also use GIS as a tool to find the fastest and safest travel route from forest fire areas. By GIS, a network analyst in ArcGIS 9.2 software was used to determine that route (Akay et al., 2012). It was completed to include several spatial data such as road network, land use classes, and fire sensitivity levels. These data was combined as data layers in GIS by using topographic maps, forest management maps, and fire sensitivity maps.

Network analyst tool in GIS (see Figure 2-7) is a tool that widely used to solve the spatial problem related to route network. It processes to find optimum route by building network database constructed by arcs and intersection points of arcs (nodes). Then, the further step is processing map layers by considering network database to get possible optimum routes between features (Akay et al., 2012). Optimum routes meant as shortest route that has least costs (length and speed) can be analyzed by CAD analysis using Dijkstra algorithm (Erden & Coskun, 2006). Optimum route or trace can also be investigated by including Digital Elevation Model integrated into GIS (Núñez Mc Leod & Rivera, 2013). This research tries to find it out through Artificial Intelligence system based on Evolutionary Computation.

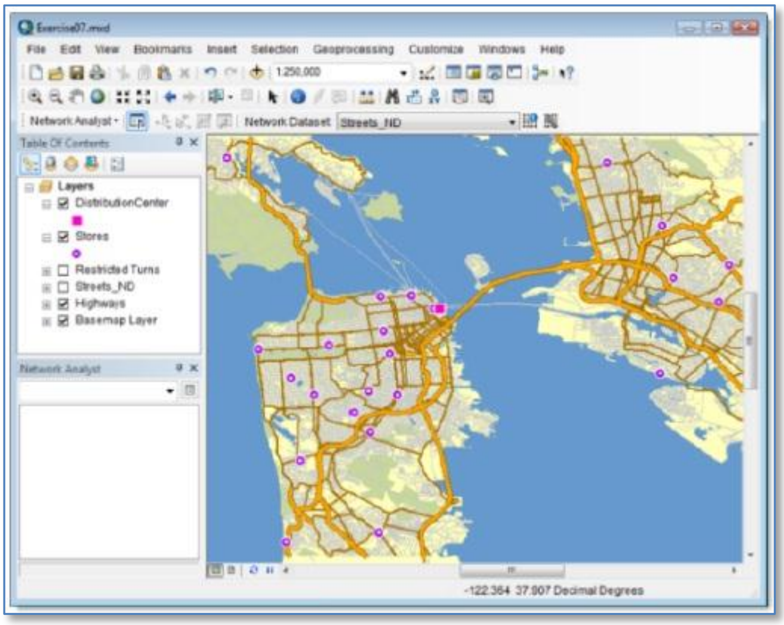


Figure 2-7. Interface of routes analysis by using Geographic Information System (ESRI, 2010)

Finding process of optimum route in GIS is mostly based on algorithm implied to the computer and graph theory field without considering characteristics of features. Considering those characteristics such as features attributes, road network attributes, and combination several feature-based methods in GIS can be used to give additional process in finding optimum route (Zhang & Yi, 2012). For example, weather condition can be part that should be considered in determining optimum route (Litzinger, Navratil, Sivertun, & Knorr, 2012). They use parameter of weather information to improve route planning. They assume that driving during heavy rain will be slower since visibility being poor and it makes more dangerous condition than doing that during normal weather condition.

In this research, by using Network analyst in GIS, optimum route was identified. The different with previous research explained above is that starting route investigated was extracted from preferred route. Preferred route can be obtained by interviewing and participatory mapping with local people. This research tried to find optimum route dynamically by day and by time. The role position of network analyst tool was on the processing variables as costs that influence in finding optimum route. Meanwhile, Nijagunappa (2007) used network analysis after the route had been extracted by interpreting and digitizing satellite imagery, not from local people's perspective.

Characteristics of features considered in this research were road quality and volcanic hazard zone. A better road quality would be easier to be accessed than a bad road. Since one influence factor of road quality in the research area was volcanic hazard, so that analysis of volcanic hazard was also included. Assumption used in this part was that a given path would be more optimum to be accessed if the condition surrounding it was safe from volcanic hazard.

2.14. Role of Remote Sensing (RS) Analysis in Finding Optimum Route

Another tools in GIS used in this research is image processing handled by ENVI software. The tools of supervised classification will be used to investigate road quality along the route. Research done by Akay et al (2012) does not include this tool to investigate road quality. They just take secondary data from government about road quality differentiated by road status. Use of satellite imagery is also different with the previous research.

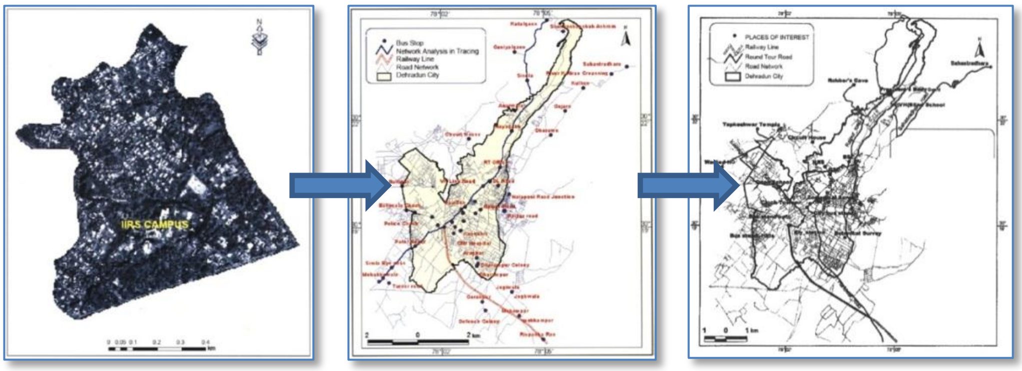


Figure 2-8. Road network extraction from high spatial resolution satellite imagery (Nijagunappa et al., 2007)

Nijagunappa (2007) use IKONOS image to find route out that has to take by visual interpretation and digitizing of road network since this image has high spatial resolution to look road feature up (see Figure 2-8). In this research, satellite imagery used was GeoEye image and Worldview image of 2011 and 2010, respectively. Besides visual interpretation and digitizing, both images were used to identify road quality by supervised classification since the damaged featured caused by volcanic hazard could be investigated more detail than IKONOS image.

2.15. Network Analyst

A network is interconnections of elements that can be viewed as a system, such as lines connected by points. The important thing of a network is connectivity and navigation. Connectivity and navigation are useful to guide where direction of travelling over network as shown in Figure 2-9 (ESRI, 2007). Connectivity influence whether points can be linked or not.

Network analyst is useful in various purposes as follows: (ESRI, 2006 after Karadimas, 2007).

1. Business : distribution to customer by considering drive time
2. Education: determining routes of school bus
3. Environmental health: effective routes for inspecting health
4. Public safety: emergency routes because of incident
5. Public works: optimal routes or working services
6. Retail: closest store depends on customer location

7. Transportation: accessibility of transit system of a certain kind of transportation.

Figure 2-9. Road network (ESRI, 2010)

Network analyst is very useful to analyze accessibility spatially. In this research, the network analyst was started through building network database which represents roads connecting settlements to place that people need to access. There are five kinds of network analyst as follows (ESRI, 2008)

1. Finding the best route
   This analysis tries to find where a traveling route is efficient from one place to another place (see Figure 2-10 and Figure 2-12). The process involves cost attributes as impedance.
2. Finding the closest facility
   Analysis of closest facility will try to determine where facility located around a given place is closest (see Figure 2-11). The best route from that place to closest facility will also be created.
3. Finding service area
   Service area means an area covering all accessible roads that are located within particular impedance as shown in Figure 2-11. This analysis will evaluate how accessible an area is. In this research, analysis of service area is used to know whether facility located around the settlement is accessible in providing service to that settlement.
4. Creating an OD cost matrix
   OD cost matrix is a table containing network impedance from one place to another place as destination. This analysis will rank origin-destination connections based on minimum network impedance in ascending order.
5. Solving a vehicle routing problem
   This analysis tries to give high level of customer service by determining routes which have cost as low as possible.

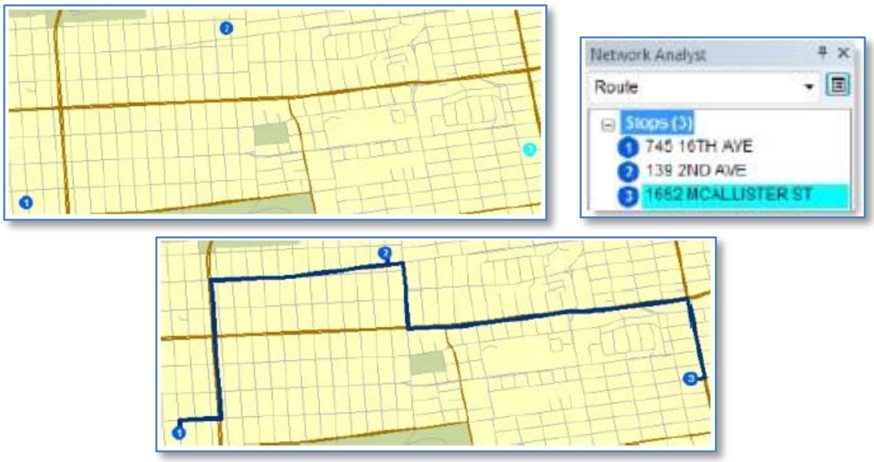


Figure 2-10. Finding the best route (the shortest route length and travel time) (ESRI, 2010)

Edgar Dijkstra (1959) explained that network analyst software operates in finding the best routes by using algorithm of shortest path (Orlin, 2003 after Karadimas, 2007). This algorithm calculates a path from a starting node to all other nodes (directed or undirected) to get optimal path. Optimal path here means the path that is computationally manageable (Olivera 2002 after Karadimas et al., 2007).

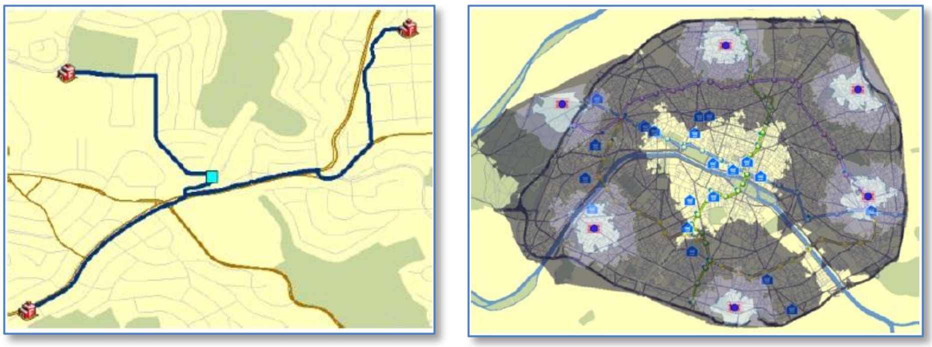


Figure 2-11. Finding the closest facility (left side) and finding service area (right side) (ESRI, 2010)

Figure 2-12. Modeling the best route (continuous destinations) (ESRI, 2010)

The algorithm is illustrated from a node called as a starting point to move to another node called as distance point. Some distance values will be assigned by

Dijkstra’s algorithm to get shortest path by tracing back predecessors (bold arrows). The further illustration of Dijkstra’s algorithm is explained as follows:

1. Every node is assigned as a distance values. Our initial node will be set as zero and for all other nodes as infinity
2. All nodes will be marked as unvisited. Initial node will be set as current
3. For current node, all its unvisited neighbors will be considered and calculation of their distance will be done from the initial node
4. Overwrite the distance will be done if this distance is less than the previous distance that is recorded (infinity in the beginning, zero for the initial node).
5. All neighbors of the current mode will be marked as visited node (and not will be checked ever again) if they have been considered. It is final and minimal for a visited node’s distance that is recorded.
6. Smallest distance will be set for unvisited node as the next “current node” and step 3 will then be continued.

2.16. Network Dataset

Network analyst cannot be done if network dataset is not available. Therefore, in the first step of network analyst, network dataset must be created as shown in Figure 2-13 and Figure 2-14.

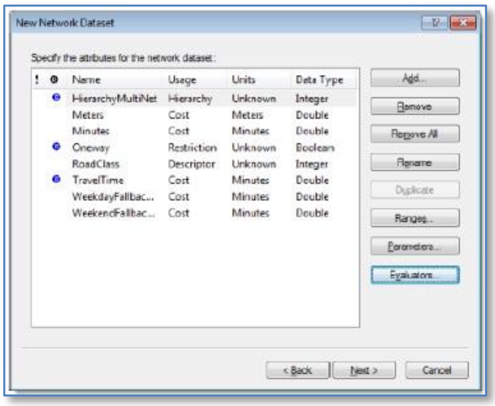


Figure 2-13. Creating network dataset (ESRI, 2010)

In this research, network dataset contained condition of roads connecting to each other. Network dataset involved travel impedance for each segments, defining directions and one-way streets, and managing restricted turns. ESRI (2005) explained that network dataset must have poly-line geometry in which the line features to other line features at coincident endpoints or at all coincident vertices. Layers included in network dataset are explained as follows:

1. Travel impedance
   Travel impedance means the cost of traveling that can be distance, time, fuel consumption, and cost, *et cetera* (ESRI, 2005).
2. Restriction

Restriction can be measured as directions and turns. Turn contains the information which path that is allowed to turn or not. Direction shows whether the path is one-way street or two-way streets

3. Time
   Time shows the information how long a path can be tracked (in minutes or hour). Time determine which route that can be efficient to track.

ESRI (2008) explained that there are five steps to create a network datasets, as follows:

1. Preparing the features dataset and sources
   This step involves arranging of all feature classes being sources in one feature datasets.
2. Preparing the sources for appropriate roles inside the network dataset.
   Field attributes containing distance, travel time, and so on will be added and it is named based on the impedance unit (represented in Table 2-4).

Table 2-4. Field names based on cost unit

Cost unit	**Field Name** **FT = TF** **From – To = To - From**	**Field Name** **FT ≠ TF** **From – To ≠ To - From**
Seconds	SECONDS	FT_ SECONDS and TF_ SECONDS
Minutes	MINUTES	FT_ MINUTES and TF_ MINUTES or FT_ DRIVETIME and TF_ DRIVETIME or FT_ IMPEDANCE and TF_ IMPEDANCE or FT_ TRAVELTIME and TF_ TRAVELTIME
Hours	HOURS	FT_ HOURS and TF_ HOURS
Milimeters	MILIMETERS	FT_ MILIMETERS and TF_ MILIMETERS
Centimeters	CENTIMETERS	FT_ CENTIMETERS and TF_ CENTIMETERS
Meters	METERS	FT_ METERS and TF_ METERS
Kilometers	KILOMETERS	FT_ KILOMETERS and TF_ KILOMETERS
Inches	INCHES	FT_ INCHES and TF_ INCHES
Yards	YARDS	FT_ YARDS and TF_ YARDS
Feet	FEET	FT_ FEET and TF_ FEET
Miles	MILES	FT_ MILES and TF_ MILES
Nautical Miles	NAUTICAL MILES	FT_ NAUTICALMILES and TF_ NAUTICALMILES
Non-time/non-distance units, such as monetary units	COST or UNITS	FT_ COST and TF_ COST FT_ UNITS and TF_ UNITS

(ESRI, 2008)

a. For instance, if the impedance unit is in time, so it should be named as MINUTES for its field attribute. If it is in direction of travel, the name can be given into two kinds of name which are FT_Minutes and TF_Minutes. FT refers to From To and TF refers to To From). It is done based in direction of digitizing.
b. If the impedance unit includes one-way analysis, so the name will be 'One-Way' or 'OneWay'.

3. Preparing turn feature classes and adding turn information
   This field contains how much time needed to turn in a given place or turn restriction for the vehicle to pass

Table

Lines

ObjectID	Shape	Name	OriginID	DestinationID	DestinationRank	Total_Drivetime
1	Polyline	Warehouse #1 - AU PRINTEMPS HAUSSMANN	1	2	1	8.562172
2	Polyline	Warehouse #1 - GALERIES LAFAYETTE HAUSSMANN	1	3	2	8.816077
3	Polyline	Warehouse #2 - SAMARITAINE	2	11	1	2.335185
4	Polyline	Warehouse #2 - ESPACE EXPANSION FORUM DES HALLES	2	9	2	2.67174
5	Polyline	Warehouse #2 - BAZAR DE L'HOTEL-DE-VILLE	2	12	3	3.568861
6	Polyline	Warehouse #2 - GALERIE CARROUSEL DU LOUVRE	2	10	4	4.466963
7	Polyline	Warehouse #2 - LE MARCHE SAINT GERMAIN	2	14	5	7.042571
8	Polyline	Warehouse #2 - GALERIE DES TROIS QUARTIERS	2	7	6	7.441952
9	Polyline	Warehouse #2 - GALERIES LAFAYETTE HAUSSMANN	2	3	7	8.564864
10	Polyline	Warehouse #2 - LE BON MARCHE	2	15	8	8.627457
11	Polyline	Warehouse #2 - AU PRINTEMPS HAUSSMANN	2	2	9	9.274025
12	Polyline	Warehouse #2 - MAINE-MONTPARNASSE	2	18	10	9.974127
13	Polyline	Warehouse #3 - PRINTEMPS NATION	3	16	1	4.442888
14	Polyline	Warehouse #4 - ITALIE 2	4	20	1	5.628731
15	Polyline	Warehouse #4 - CENTRE COMMERCIAL MASSENA 13	4	21	2	6.300414
16	Polyline	Warehouse #4 - GAITE	4	19	3	8.578264
17	Polyline	Warehouse #5 - S.C.I. BEAUGRENELLE	5	17	1	2.428298
18	Polyline	Warehouse #5 - GALERIE COMMERCIALE PASSY PLAZA	5	13	2	7.046085
19	Polyline	Warehouse #6 - LES BOUTIQUES DU PALAIS DES CONGRES	6	1	1	3.868477
20	Polyline	Warehouse #6 - GALERIE SAINT DIDIER	6	8	2	6.098853
21	Polyline	Warehouse #6 - ARCADES DU LIDO	6	4	3	8.649069
22	Polyline	Warehouse #6 - GALERIE DU CLARIDGE	6	5	4	8.793894
23	Polyline	Warehouse #6 - GALERIE COMMERCIALE PASSY PLAZA	6	13	5	8.857523
24	Polyline	Warehouse #6 - ELYSEE 26	6	6	6	9.773061

24 (0 out of 24 Selected)

Lines

Figure 2-14. Network database (ESRI, 2010)

4. Create the network dataset
   In the process of creating of this dataset, the naming of network, identifying network sources, setting up the connectivity, identifying elevation data, *et cetera* will be considered.
5. Build the network dataset
   In this step, the process includes creating network elements, establishing connectivity, and assigning values to the defined attributes.

2.17. Traffic Analysis in Geographic Information System

ESRI (2010) emphasizes that traffic is an important aspect that should be included in network analysis. It affects travel time taken by vehicles passes through a given road since it relates congestion of that route. The more congestion there is, the longer travel time will be taken. Therefore, to analyze the shortest time of a route as occurred in reality like, traffic is always included in network database, then the network analyst tool in GIS software will run it through a specific process.

According to Figure 2-15, there is a simple example depicting how the shortest route can be changed at different time of the day since there is influence coming from traffic. In the morning (left side picture) shows that traffic of the route to the city is dense/heavy, whereas it to the sub urban area is quiet/light, so that the shortest travel time to the sub urban area can be reached at this time. Meanwhile, in the day or evening (right side picture), route traffic to the city is light, and it to the sub urban is changed to be heavy, so that accessing to the sub urban will be more difficult since travel time being longer. Analysis road network show that besides highway, there is alternative serpentine road for which has light traffic. Thus, if one wants to go to sub urban, it is recommended to access through that road since travel time will be shorter.

Figure 2-15. Traffic change at different times being influencing factor in network analysis (ESRI, 2010)

ESRI (2010) explained that in traffic analysis, free-flow travel time should be involved to be compared with travel time induced by traffic consisting of different types of transportation (truck, car, and motorcycle). Free-flow time or neutral travel time is travel time that a given vehicle passes a route without any impedance from other vehicles (see Figure 2-16). Free-flow time typically can be measured by function of segment length and speed limit or observed (observation here means average speed of vehicle that pass without any other vehicles present.

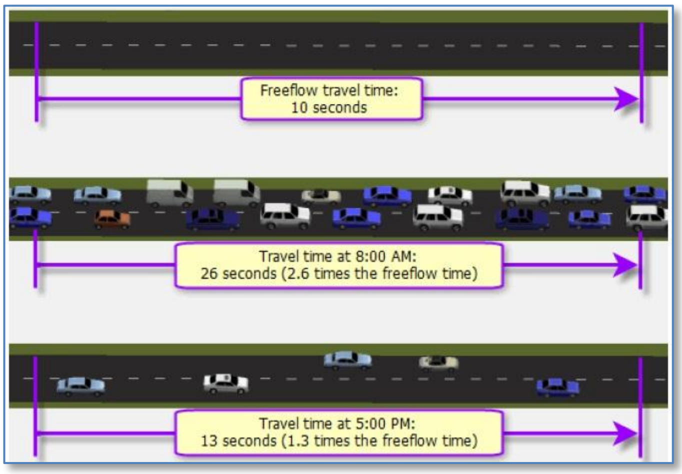


Figure 2-16. Free-flow time or neutral travel time compared with travel time induced by other vehicles (ESRI, 2010)

According explanation above, ESRI (2010) allow implicitly that both neutral travel time and travel time induced by other vehicles can be observed directly in the field since to get more accurate result of travel time. It is important to improve network database that will be built.

2.18. Digital Elevation Model (DEM) Analysis

Digital Elevation Model (DEM) is powerful analysis and representation of terrain (http://www.kgis.org). It works by calculating elevation data for each pixel and trying to visualize real terrain-like as shown in Figure 2-17. Result of DEM analysis depends on how detail cell size of an image that elevation data placed in. Figure shows how DEM analysis works.

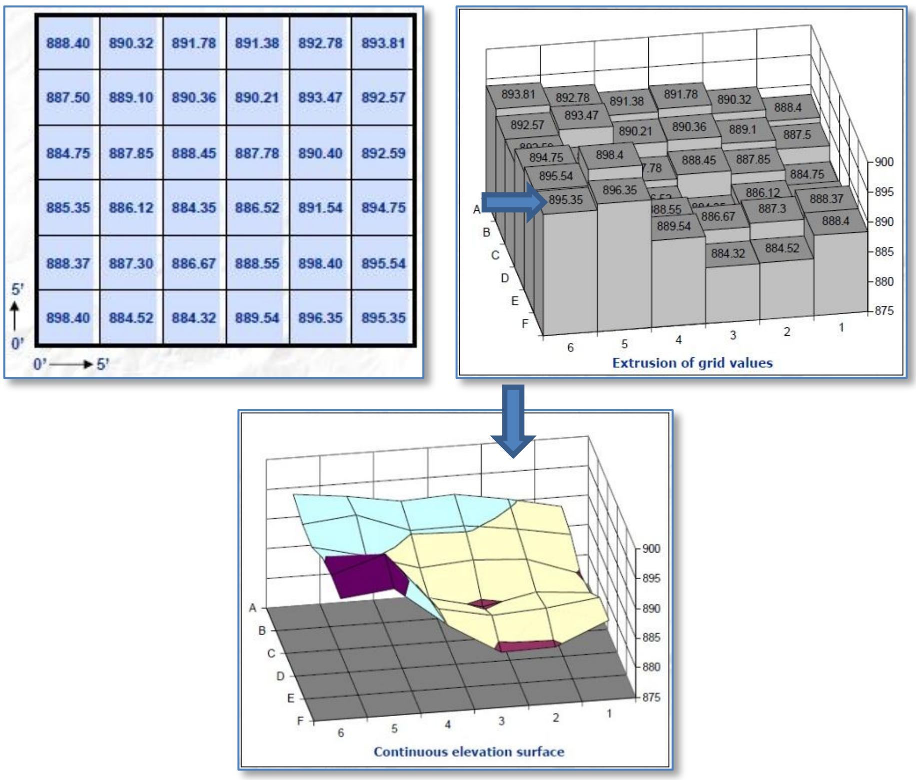


Figure 2-17. How DEM analysis works (http://www.kgis.org).

Analyses of Digital Elevation Model (DEM) typically involve hillshade analysis, slope analysis, aspect analysis, area analysis, profile graph analysis, flow direction analysis, profile curvature analysis, plan curvature analysis, and Topography Position Index (TPI). Each analysis is explanation much more as follows (http://www.kgis.org):

1. Hillshade analysis: analysis of sun's illumination, so that it can visualize realistic image of the landscape (see Figure 2-18). It is able to give information such as where sun does not shine.

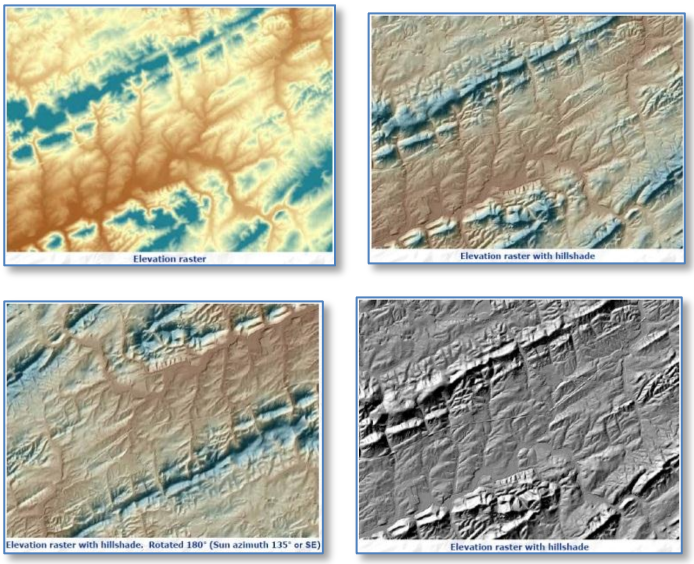


Figure 2-18. Hillshade analysis: (a) elevation raster; (b) and (d) elevation raster with hillshade; (c) elevation raster with hillshade (rotated 180° or sun azimuth 135° or South East) (http://www.kgis.org)

2. Slope analysis: Analysis of the steepness of a terrain which the higher slope value, the steeper the terrain (see Figure 2-20). Triangulated Irregular Network (TIN) is derived from DEM data to generate slope parameters both in percent (slope of 100 percent is vertical) and degree (slope of 90 degree is vertical). Formula to count slope as shown in Figure 2-19:

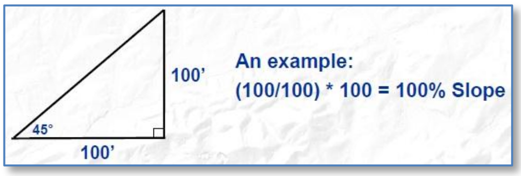


Figure 2-19. Formula to measure slope steepness (http://www.kgis.org)

Percent (%) slope = (Rise/Run) * 100

For which slope approaches ∞ as the angle reaches 90°

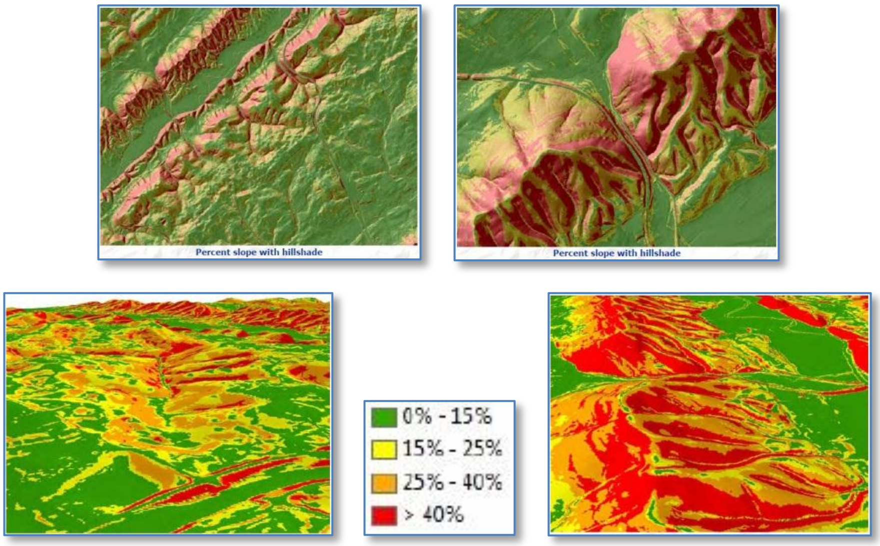


Figure 2-20. Slope analysis: (a) percent slope with hillshade; (b) variation in color result from hillshade (c) and (d) percent slope viewed in 3-dimensions; (source: http://www.kgis.org)

3. Aspect analysis: to analysis direction of slope (0-360 degree, clockwise from north) (see Figure 2-21). For volcanic hazard analysis, aspect analysis is useful for identifying downslope direction of pyroclastic flow and where areas likely to be hit by spreading out of pyroclastic flow.

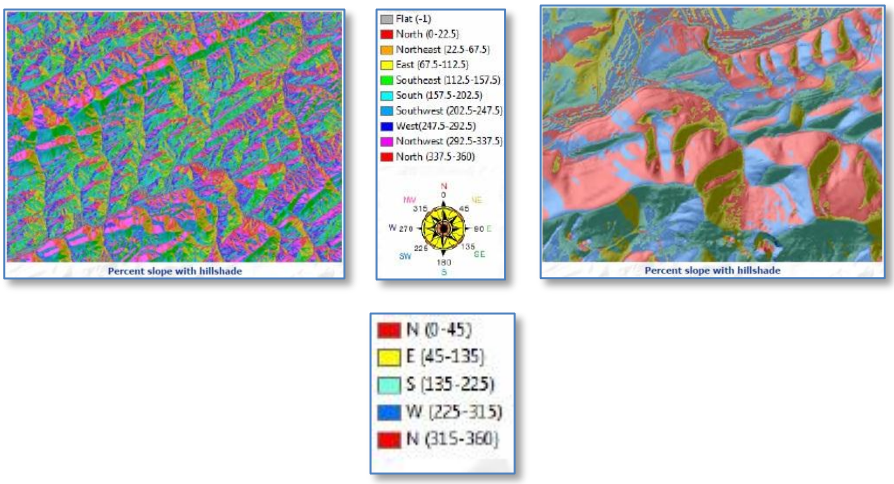


Figure 2-21. (a) and (b) slope aspect analysis (http://www.kgis.org)

4. Viewshed analysis: Analysis that identifies area that can and cannot be seen by an observation point (see Figure 2-22). It aims to answer, for instance, where a building will be visible if it is located at a given location. Line of sight is the one of viewshed analysis that is functioned to see a target by a single observation point.

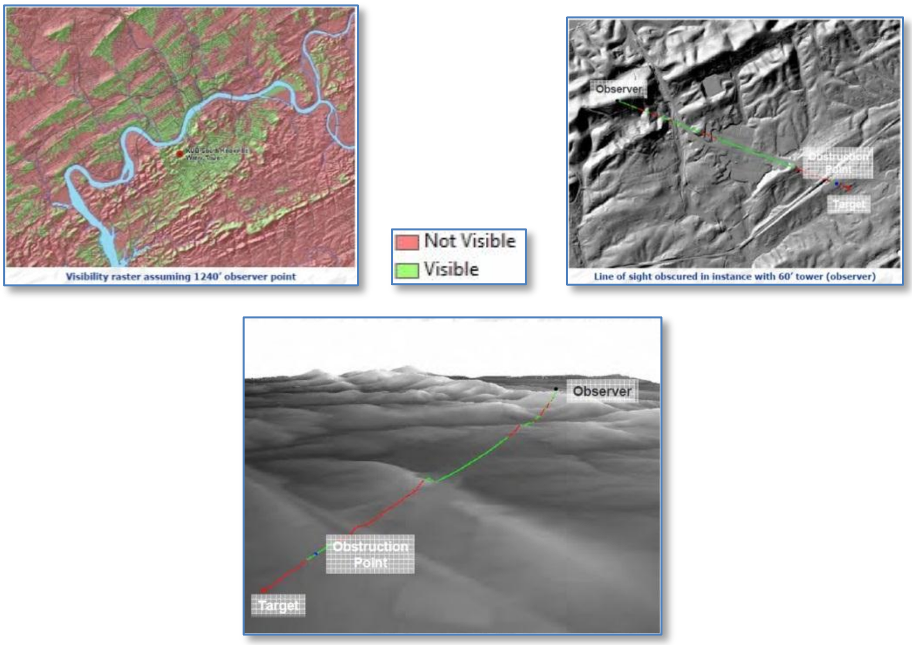


Figure 2-22 Viewshed analysis: (a) visibility raster assuming 1240 observer point; (b) and (c) line of sight obscured in instance 60 tower (observer) (source: http://www.kgis.org)

5. Profile graph analysis: to depict break of slope because it also contribute to spread pyroclastic flow out from the river channel. It can be useful for identifying where areas having break of slope that indicate pyroclastic flow to be extended.
6. Flow direction analysis: to predict the direction of flow over the given areas. Determining direction of route can be done by using reversed DEM as well as research about flood evacuation route planning (Kim, Kuwahara, & Kumar, 2011). Reversed DEM analysis as shown in Figure 2-23 analysis allows the route direction to avoid low land and turn to high land as safer area from flood.

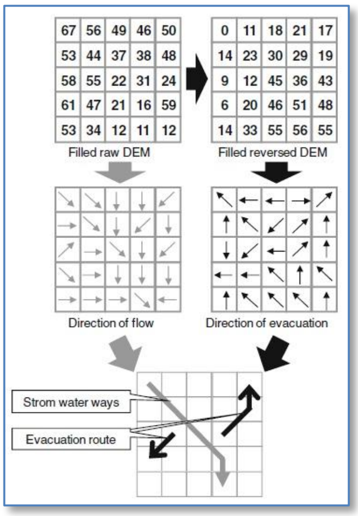


Figure 2-23 Normal DEM analysis and reversed DEM analysis in determining flood evacuation route (Kim et al., 2011)

7. Profile curvature analysis: this analysis means calculation of slope of slope to descript the shape of slope as being either concave or convex (sees Figure 2-24 and Figure 2-25). Curvature analysis is useful to determine acceleration and deceleration. For pyroclastic flows mechanism, concave slope means up acceleration of spreading out of pyroclastic flow, whereas convex slope means down acceleration (deposition) of that flow.

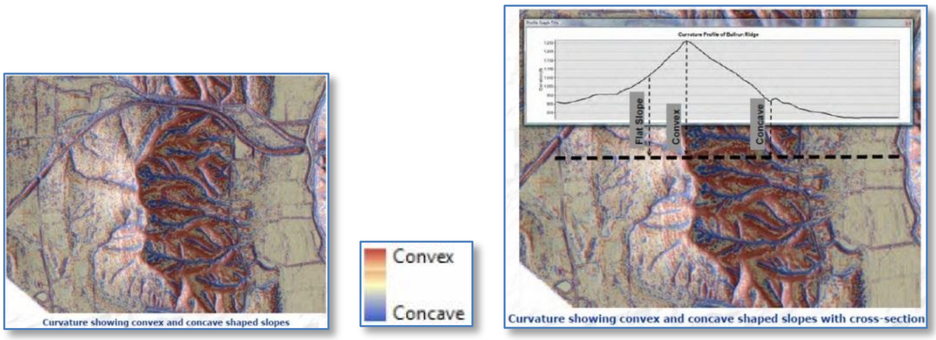


Figure 2-24. Curvature analysis: (a) curvature showing convex and concave shaped slope; (b) curvature showing convex and concave shaped slope with cross-section (http://www.kgis.org)

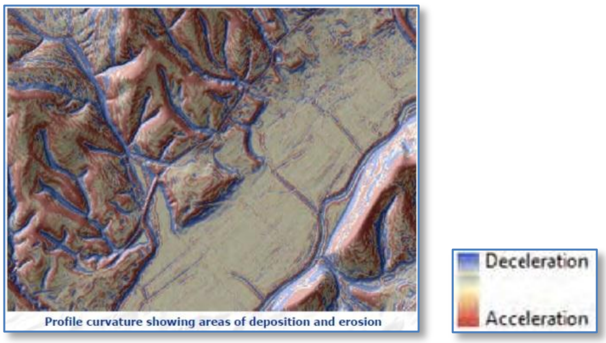


Figure 2-25. Curvature analysis: profile curvature showing areas of deposition and erosion (http://www.kgis.org)

8. Plan curvature analysis: this analysis describes perpendicular to the direction of the slope as being either convergence or divergence (see Figure 2-26). Convergence slope means that flow will tend to be accumulated, whereas divergence slope means that flow will tend to extended or distributed

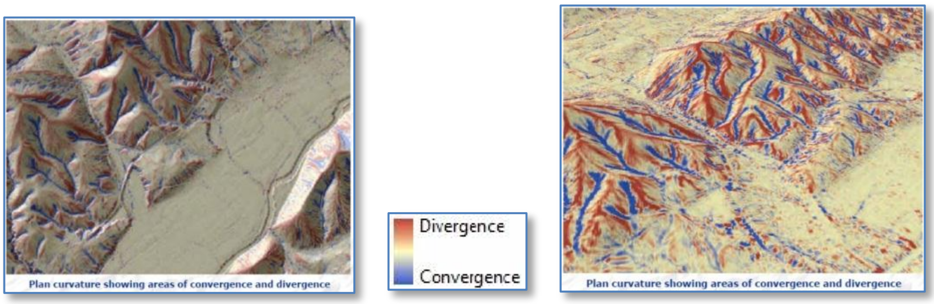


Figure 2-26. Curvature analysis: (a) and (b) plan curvature showing areas of convergence and divergence (:http://www.kgis.org)

9. Topography Position Index (TPI): TPI analysis tries to compare elevation of all given points on the map to the mean elevation of an area surrounding that point (see Figure 2-27 and Figure 2-28). This analysis can determine topography as being ridge, valley, or flat. If TPI is positive, it means that slope is ridge whereas if TPI is negative, the slope is valley. If TPI equals zero, topography is flat. It is useful for identifying the presence of dike which can prevent the behind area from spreading out of pyroclastic flow. The presence of dike is represented as ridge.

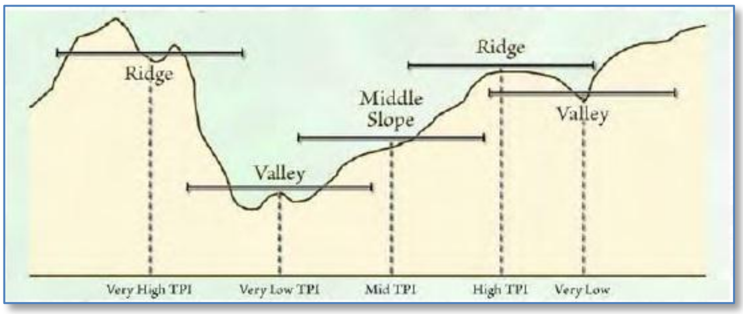


Figure 2-27. Topography Position Index (TPI) (source:http://www.kgis.org)

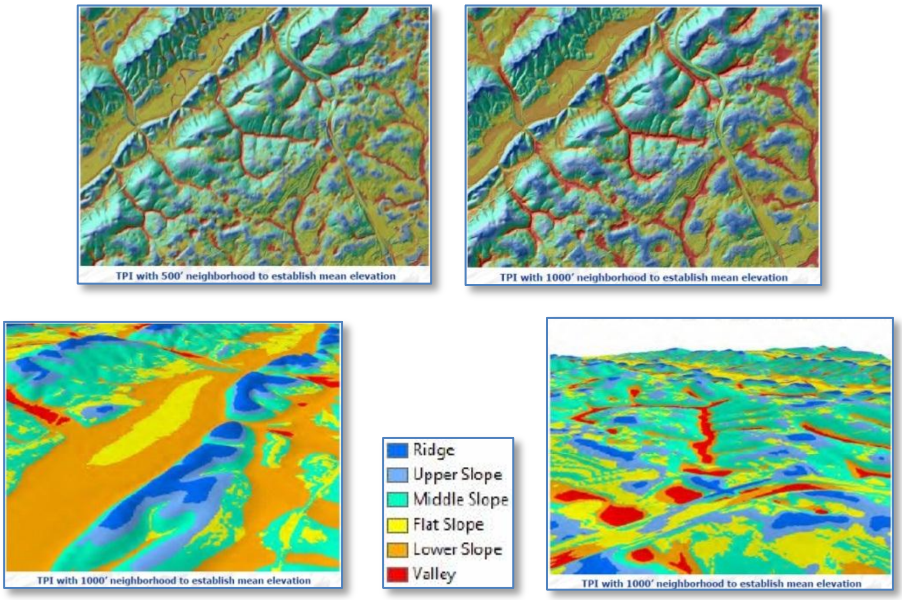


Figure 2-28. Curvature analysis: (a) TPI with 500 neighborhood; (b) TPI with 500 neighborhood; (c) and (d)) TPI with 1000 neighborhood to establish mean elevation (http://www.kgis.org)

Digital Elevation Model became important part for analysis in this research, although the focus was on optimum route as vector-based analysis. To optimize process of finding optimum route, DEM extraction as raster-based analysis was needed, especially in volcanic hazard analysis. Hazard element could be one of influence factor or cost of optimum route. Besides that, most road network of research area was located on steep area of volcano, so that slope analysis was really needed in finding process of that route.

Chapter 3. Study Area

This chapter provides overview of research area which is located in the permanent settlement built after Merapi 2010 eruption. The parts overviewed in this chapter include condition of Merapi volcano, location of permanent settlement completed with current condition of those settlements.

3.1. Merapi Volcano

Merapi volcano is located Central Java which near to subduction zone between Eurasia plate and Indo Australia plate. It is one of andesitic stratovolcano that has volcanic activities as follows (Gerstenecker et al, 2005):

1. Development of permanent lava dome
2. Pyroclastic flows signed by lava dome collapses
3. Lahars occurrence that is mostly triggered by rain season

Pyroclastic flows make Merapi volcano being feared volcano (Voight, Sukhyar, & Wirakusumah, 2000), and even it has been populated by high density population of people (Newhall et al., 2000). Therefore, Merapi eruption becomes one of natural hazard that may still take a lot of victims and damaging.

3.2. Permanent Settlement

This research focused on the permanent settlements which are located in upper Merapi flank since facilities over there are not as many as those that are located in lower Merapi flank. Locations of permanent settlement are represented in Table 3-1 and Table 3-2, whereas destination places are represented in Table 3-3.

Table 3-1. Location of permanent settlement as research area

No	Location	Initial number of households	Number of households have been relocated (per 17/02/2012)	Village
1.	Karangkendal	315	81	Umbulharjo
2	Batur	841	184	Kepuharjo
3	Pagerjurang		307	
4.	Singklar	826	65	Glagaharjo
5.	Glagahmalang		68	
6.	Banjarsari		185	
7.	Gondang	406	89	Wukirsari
			38	

(BPBD DIY, 2011)

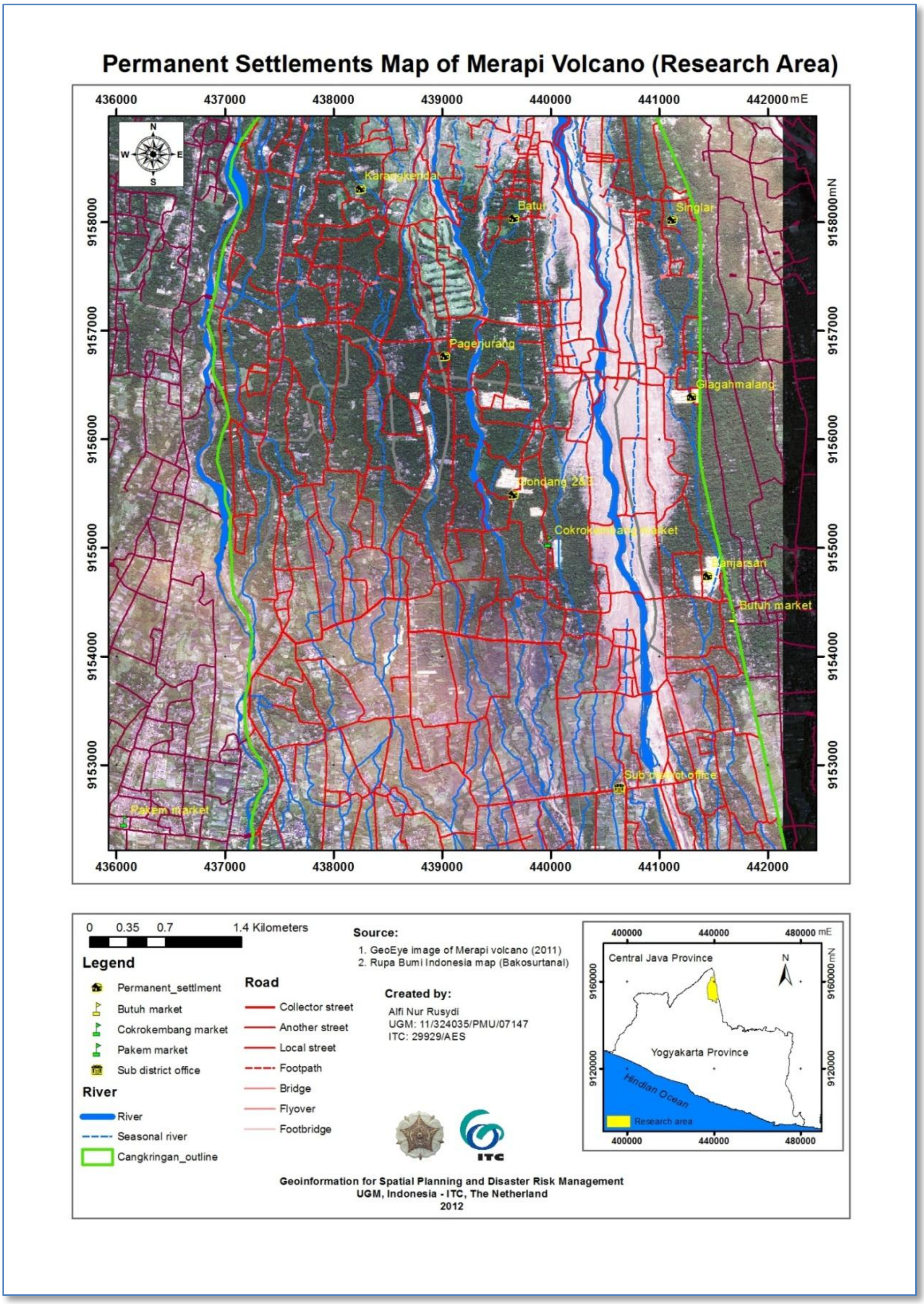


Figure 3-1. Location of permanent settlements of Sleman Regency

Table 3-2. Location of permanent settlement

No	Location	Figure	Coordinate	Elevation (meter above mean sea level)
1.	Karangkendal		X: 438244 Y: 9158307	776.3
2.	Batur		X: 439656 Y: 9158035	753.6
3.	Pagerjurang		X: 439021 Y: 9156764	661.3
4.	Singklar		X: 441111 Y: 9158018	749.3
5.	Glagahmalang		X: 441294 Y: 9156388	625
6.	Banjarsari		X: 441442 Y: 9154740	526.1
7.	Gondang		X: 439652 Y: 9155490	577.6

(Field surveying, 2012)

Table 3-3. Location of route's destination

No	Location	Figure	Coordinate	Elevation (meter above mean sea level)
1.	Butuh market		X: 441677 Y: 9154365	518.3
2.	Pakem market		X: 436071 Y: 9152477	433.5
3.	Cokrokembang market		X: 439977 Y: 9155056	561.4
4.	Sub district office of Cangkringan		X: 440627 Y: 9152784	432.6

(Field surveying, 2012)

Chapter 4. Research Methodology

The method used in this research was provided in this chapter including data, software, tools/equipment, data collecting, data analysis, and analysis of results. The flow of this research was figured into research framework.

4.1. Required data

Materials used in this research were divided into two kinds of data which were primary data and secondary data. Those data are listed in Table 4-1:

Table 4-1. Data Requirement

No	Data requirement	Kind of data	Source
1.	Worldview images and GeoEye images after Merapi 2010 eruption (recorded in 2011)	Secondary data	Faculty of Geography, UGM
2.	Rupa Bumi Indonesia Map (RBI) map scale 1:25.000	Secondary data	Bakosurtanal
3.	Hazard map of Merapi volcano in 2010	Secondary data	Indonesian National Board for Disaster Management (BNPB)
4.	Specification and quality of road	Secondary data	Regional Department of Public Working
5.	Preferred route	Primary data	Interviewing

4.2. Materials

Kinds of software used in this research are represented in Table 4.2.

Table 4-2. Kinds of software

No	Kinds of software	Function
1.	ENVI 4.5 version	Digital image processing
2.	ILWIS 3.x version	Raster-based analysis
3.	ArcGIS 10 version	Vector-based analysis
4.	SPSS 19 version	Statistical analysis
5.	Microsoft Office 2010 version	Report writing

Tools used in this research are represented in Table 4.3.

Table 4-3. Tools/equipment

No	Tools/equipment	Function
1.	Checklist and interviewing form (questionnaire)	Guide for data collecting during field work
2	Digital pocket camera	Taking pictures in the field
3	Mobile Global Positioning System (GPS)	Plotting location of human settlement and places that local people need to access
4	Rupa Bumi Indonesia (RBI) map	Guide for analysis of research areas and its surrounding

4.3. Data collecting

Data collecting were divided into three steps which were pre-field work, field work, and post field work. The detail steps done are explained as follows:

4.3.1. Pre-field work

Activities done are study of literatures, data collection, and preparation materials for field work. Kinds of literature studied are journals, text books, exercise modules, and some reports. Those literatures were used to design research problem, objectives, research questions, and proper methodology. In data collection, kinds of data collected were satellite imageries, maps, and report data including physical condition of study area. Preparation of software, surveying tools, checklists were included in preparation materials of field work.

4.3.2. Field work

In field work, the activity done was interviewing by using questionnaire (see Appendix A and B) to inhabitants and key persons to know where preferred travelling routes by them to places that are needed to access (see Figure 4.1). To know variation of traffic, a number of each kind of vehicle (motorcycle, car, and bus/truck) passing through a given road to the specified place (needed to access) were counted by hours (at 07.00-08.00 a.m. and at 12.00-13.00 p.m; these time are rush hours) and by day (Monday until Sunday).

Figure 4-1. Interviewing and participation mapping with local people (Field surveying, 2012)

Preferred routes by inhabitants were tracked to build network database. Name of road, length, width, slope/route steepness, quality of road, travelling time, and distance were involved into creating network database. Tracking of routes was done by hours and by days to know when the easiest route that can be access, so that people can decide when they should go easily to the place that they need to access through a given route. Interviewing with local government was also done to know what recommended routes and hazardous route based on government's views.

4.3.3. Post field work

Activities done in post field work were data processing and dissemination of result. Data containing numbers of motorcycles, cars, and bus/trucks passing that road was represented as a trend graphic of traffic by hours and by days. This result showed the highest traffic and the lowest traffic and kind of vehicle that dominates that traffic by time and by day. This traffic condition (number of vehicle and travelling time to the destination) was assumed as the influencing factor of optimum route.

Data was processed by network analyst in Geographic Information System (GIS) to perform preferred route by local people. It included creating network database to build optimum route analysis. In dissemination of result, those results represented in maps. Involving variation of traffic as influence factor gave variation of optimum route. The improved hazard map of Merapi was involved in determining the best route by overlaying analysis between hazard zone and optimum routes generated by variation of costs.

The research result was delivered to government to be discussed about heir response and what they will do in short term and long term related to route development in research area.

4.4. Data analysis

4.4.1. Network analysis

Network analysis was done to answer research questions number 2 up to number 6. To do network analysis, steps done are explained as follow:

1. Creating network database
   Network database was obtained from line features representing roads (in shapefile format) within several requirements which are:
   a. Arcs have to be connected. If not, the road will be meant as stopped road.
   b. Name of field containing roads condition have to follow standard name of network database.

   Network database created from digital road map completed with its attribute after road map verification in the field is done. The road conditions observed were kinds of road, route steepness and quality of road. The kinds of road could be known by doing map interpretation of RBI map. Specifications of road provided by Regional Department of Public Working were name of road, length, and width. The kinds of road used were:
   a. Artery road
   b. Collector road
   c. Local road
   d. Footpath/lane

   Quality of road was classified into 3 classes:
   a. Good (if the road was covered by asphalt cover, no crack on the road)
   b. Good enough (if the road was covered by asphalt, but there are small crack on the road)
   c. Bad (if the road was not covered by asphalt (typically covered by gravel and volcanic ash and sand), there were a lot of cracks on the road)
2. Optimum routes analysis

This analysis was tried to get effective routes from one object to another object by considering attribute of connecting lines (length or width), turns, and crosses. Analysis was done to get nearest routes (based on length) and quickest routes (time of journey of each segment, both From-To and To-From). The optimum routes analysis considered kinds of transportation that was typically used by inhabitants. For instance, optimum route of motorcycle was not always similar to optimum route of car. In the first surveying, most people prefer to use motorcycle to go to everywhere, so that in this research, kind of transportation used to get road attribute was motorcycle.

4.4.2. Traffic analysis

Vehicles passed through a given road segment were counted on each day of a week (from Monday until Sunday) at given hours which were in the morning at 07.00-08.00 a.m. and in the day at 12.00-13.00 a.m. Vehicles were counted for each 15 minutes at those times. For instance, in the morning at 07.00-08.00 a.m., vehicles were counted at 07.00-07.15 a.m.; 07.15-07.30 a.m.; 07.30-07.45 a.m.; and 07.45-08.00 a.m. To do so, traffic monitoring point was needed to count number of vehicles that passed a given route. Locations of traffic monitoring point were determined by considering road length and number of cross road. The longer road length and more number of cross road, the more traffic monitoring points were needed. Locations of traffic monitoring point were represented in Figure 4-2.

The graph depicting a number of vehicles passing a given route dynamically by hours and by days was needed for this analysis. Assumption used was the higher number of vehicle, the more difficult route to access. Number of vehicle was distinguished by kinds of vehicle which were motorcycle, car, and truck/bus. Bus/truck had much more contribution for difficulty of route to access because its size was bigger than car than motorcycle. Therefore, each kind of vehicle was given score. Higher score meant bigger contribution of vehicle in difficulty of route to be accessed. Score was multiplied by number of each vehicle to show how intense that vehicle influenced to the difficulty of route to be accessed. The score was represented in the Table 4-4.

Table 4-4. Scores of traffic contribution for each vehicle type

No	Kinds of vehicle	Score
1.	Motorcycle	1
2.	Car	2
3.	Bus/truck	3

Those scores were used to count traffic factor meant as a quietness index of route's traffic. The higher traffic factor, the more difficult a given route to be accessed since travel time would be longer. The higher traffic factor of a given route, the more possible traffic jam occurred. Traffic factor of a road segment used formula as follow:

Formula:

Traffic intensity = Σ (Score x Number of each vehicle)……………………… 1

Average traffic intensity at 07.00 a.m = Total traffic intensity of all road segments during Monday-Sunday (07.00 a.m)/ (Total number of road segments x number of days in a week)…….…………………………………………………………………..…….. 2

Average traffic intensity at 13.00 p.m = Total traffic intensity of all road segments during Monday-Sunday (13.00 p.m)/ (Total number of road segments x number of days in a week)……………………………………………………………………………….. 3

Traffic Factor at 07.00 a.m. = Traffic intensity/Average traffic intensity of 07.00 a.m…..……………………………………………………………………………. 4

Traffic Factor at 13.00 p.m. = Traffic intensity/Average traffic intensity of 13.00 p.m...………. 5

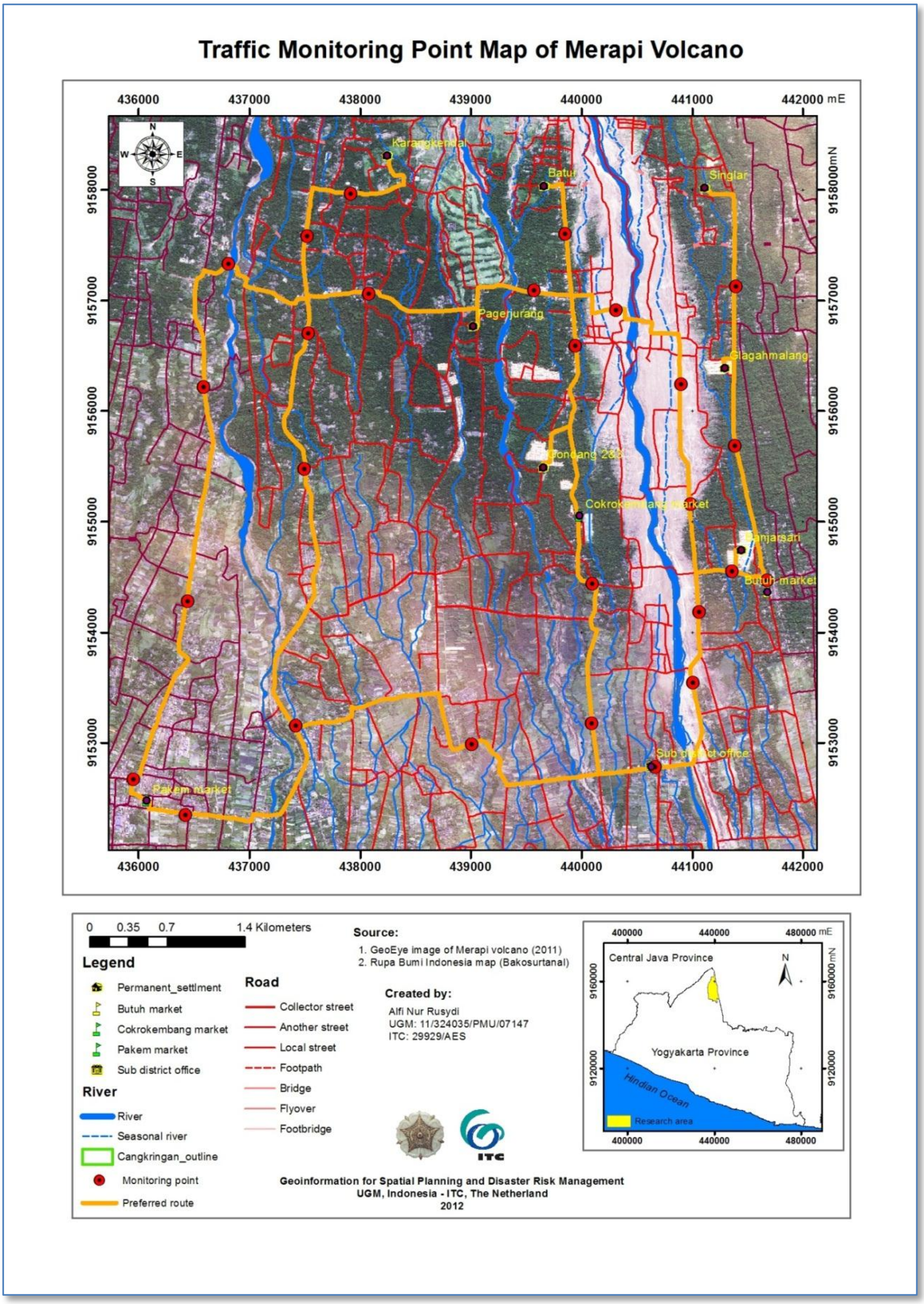


Figure 4-2. Location of traffic monitoring post

4.4.3. Measuring Travel Time

There was a formula of travel time which was measured based on road length and average speed of vehicle (Akay et al., 2012). It was varied by road type and road status. Parameters of road type influencing that travel time were asphalt, gravel and forest roads that were distinguished by road status which was good, medium, and poor. Specific formula of travel time was stated as function of length of path divided by speed of vehicle (Li & Leung, 2011). To measure travel time, they used several constraints factors such as fuel consumptions (operating cost). Travel time was also varied by different type of road since they assumed that different type of road (road status) would generate different travel time.

In this research, travel time of a route was measured directly by riding a vehicle through that route. Since research area is volcanic area mostly consisting of steep slope, so that the formula a by Akay (2012) could not be adapted in this research. That formula was valid only in flat area since there was no influence of slope. Influence of slope might obtain different result of travel time. Although road length was similar, travel time through a flat route was shorter than through a steep route. In the fact, a vehicle run much slowly in a steeper route than if it runthrough a flat route.

4.4.4. Sampling Technique

For interviewing with local people, samples as respondents were taken randomly by using site plan map and statistical data of permanent settlements (secondary data) (see Appendix C). Number of samples was 30% of settlement population (one house has one household) since this proportion is statistical standard proportion of sample, so that the samples are appropriate to be processed statistically (see Figure 4-5). Number of samples is represented in Table 4-5.

Table 4-5 Number of sample for interviewing with local people

Settlement	Population of Settlement	Number of samples
Batur	194	58
Gondang	93	28
Singlar	59	18
Glagahmalang	76	23
Banjarsari	162	49
Pagerjurang	301	90
Karangkendal	81	24

For interviewing with local government, the respondents interviewed were chairman of Road Construction Broad of Public Work Department of Yogyakarta Province, chairman of Road Construction Broad of Public Work of Sleman Regency, and Local Government of Cangkringan sub district (Sub district head, village heads, hamlet heads).

4.4.5. Supervised classification

Supervised classification was used to extract areas that dirt road probably located. (performed as areas, not as detailed line). Dirt road means an unpaved road made from native material of the land surface. In this research, only surrounding areas of dirt roads that were performed and classified, not detailed line of dirt roads itself. Training samples (Region of Interest/ROI) were taken first before performing the classification. Specification of training samples is represented in Table 4-6 and how process of classification is represented in Figure 4-6.

Table 4-6 specification of training samples

Name	ROI RGB value	ROI n-pixel	ROI Polygon	Area (Ha)	Color
Surrounding areas of dirt road	255, 0, 0	339384	9	8.485	Red
High dense vegetation	0, 255, 0	135578	6	3.389	Green
Rooftop	0, 0, 255	1519	3	0.037975	Blue
Paddy field	255, 255, 0	4058	5	0.101450	Yellow
Bareland	0, 255, 255	51936	2	1.298	Cyan
Water body	255, 0, 255	3206	4	0.080150	Magenta

4.4.6. Hazard map analysis

Detailed hazard map of Merapi was overlaid to the optimum route map to evaluate which road segments were prone to a given volcanic hazard type (see Figure 4-7). This evaluation was aimed to determine the best route that could be accessed by local people. Considering the preferred route by local people was also included to do that. Ideally, the hazardous route should be avoided in order to optimize safe route that connected from their permanent settlement to social economic public facilities.

4.4.7. Name of road segment

In this research, road segments were given named based on road class, road number in order (for each road class), and name of village (both name of village (from) and name of village (to); if a segment across two or more different village). This method was much easier and simpler to know road characteristics directly from road name than checking them in network database of GIS. List of road segmenta name was represented in Table 4.7. How to give name of road segment is shown as follow:

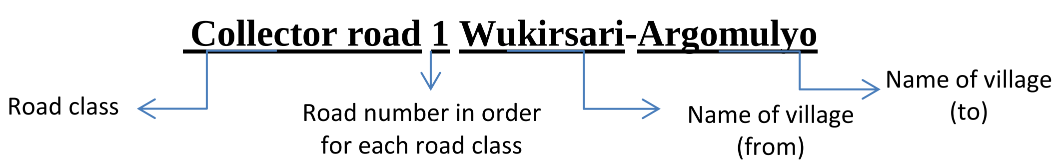


Table 4-7. Number of road segment

Number of road segment (based on map)	Road name	Road length (meters)
1	Another Road 1 Kepuharjo	185.4
	Local Road 1 Kepuharjo	1012.0
2	Collector road 1 Wukirsari-Argomulyo	1441.7
	Another road 2 Wukirsari	543.5
	Another road 1 Kepuharjo-Wukirsari	2570.9
	Another road 1 Wukirsari	536.2
3	Collector road 1 Argomulyo	480.8
	Local road 2 Argomulyo	312.1
4	Another road 2 Argomulyo	1029.7
	Another road 1 Argomulyo-Glagaharjo	755.3
5	Local Road 1 Argomulyo-Glagaharjo	631.2
	Another road 4 Glagaharjo	252.7
6	Local Road 1 Argomulyo	153.5
7	Local Road 1 Kepuharjo-Glagaharjo	252.5
	Local Road 2 Kepuharjo	1075.1
8	Local Road 1 Glagaharjo	2176.2
9	Another road 1 Glagaharjo	285.0
	Another road 3 Glagaharjo	3671.2
10	Another road 1 Kepuharjo	205.1
	Local Road 1 Kepuharjo-Umbulharjo	1604.9
11	Collector road 1 Wukirsari	1236.0
	Local Road 1 Umbulharjo-Wukirsari	2948.6
12	Collector road 1 Umbulmartani	60.2
	Collector road 1 Umbulmartani-Pakem Binangun	936.0
	Collector road 1 Wukirsari-Umbulmartani	1099.7
	Another road 1 Pakem Binangun	95.4
13	Local Road 1 Umbulharjo-Hargobinangun	1181.1
14	Collector road 1 Hargobinangun-Pakem Binangun	4971.4
	Another road 1 Pakem Binangun	162.0
15	Another road 1 Umbulharjo	360.6
	Another road 2 Umbulharjo	854.6
16	Local Road 1 Umbulharjo	978.8
17	Local Road 3 Kepuharjo	1036.5
18	Local Road 3 Argomulyo	831.4
	Local Road 1 Wukirsari	792.0
	Local Road 1 Argomulyo-Wukirsari	510.3
	Another road 3 Wukirsari	1427.7

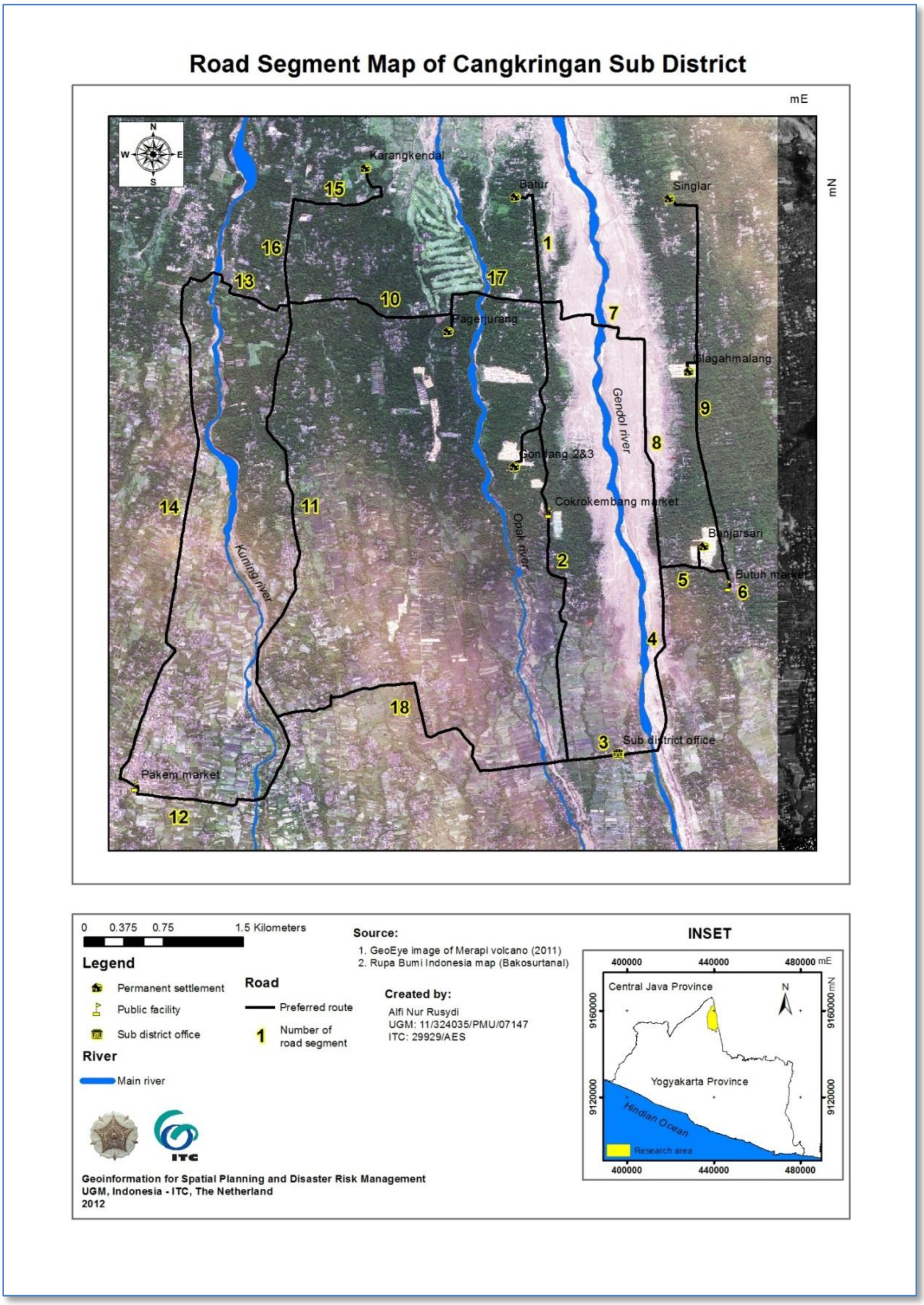


Figure 4-3. Road segment map of Cangkringan sub district

4.5. Analysis of results

Optimum route meant route that could be accessed quickly and easily (shorter travel time and shorter road length). Variation of traffic factor by days and by hours might influence optimum route change. Optimum route analyzed by involving traffic factor was addressed to know when the easiest optimum route could be accessed which had light traffic by hours and by days. The best routes were selected by considering minimum constraints such as road length, neutral time, route steepness, road quality, travel time controlled by traffic factor, and overlying it with detailed hazard map. The best route meant the most effective optimum route that could be accessed. The criteria of best route were:

1. Shorter road length
2. Shorter travel time (both in neutral time and travel time controlled by traffic factor)
3. Flat/Undulating/gently route
4. Better road quality
5. Quieter traffic condition
6. Safety route from volcanic hazard

All steps of research method are shown in Figure 4.4, Figure 4.5, Figure 4-6, and Figure 4.7.

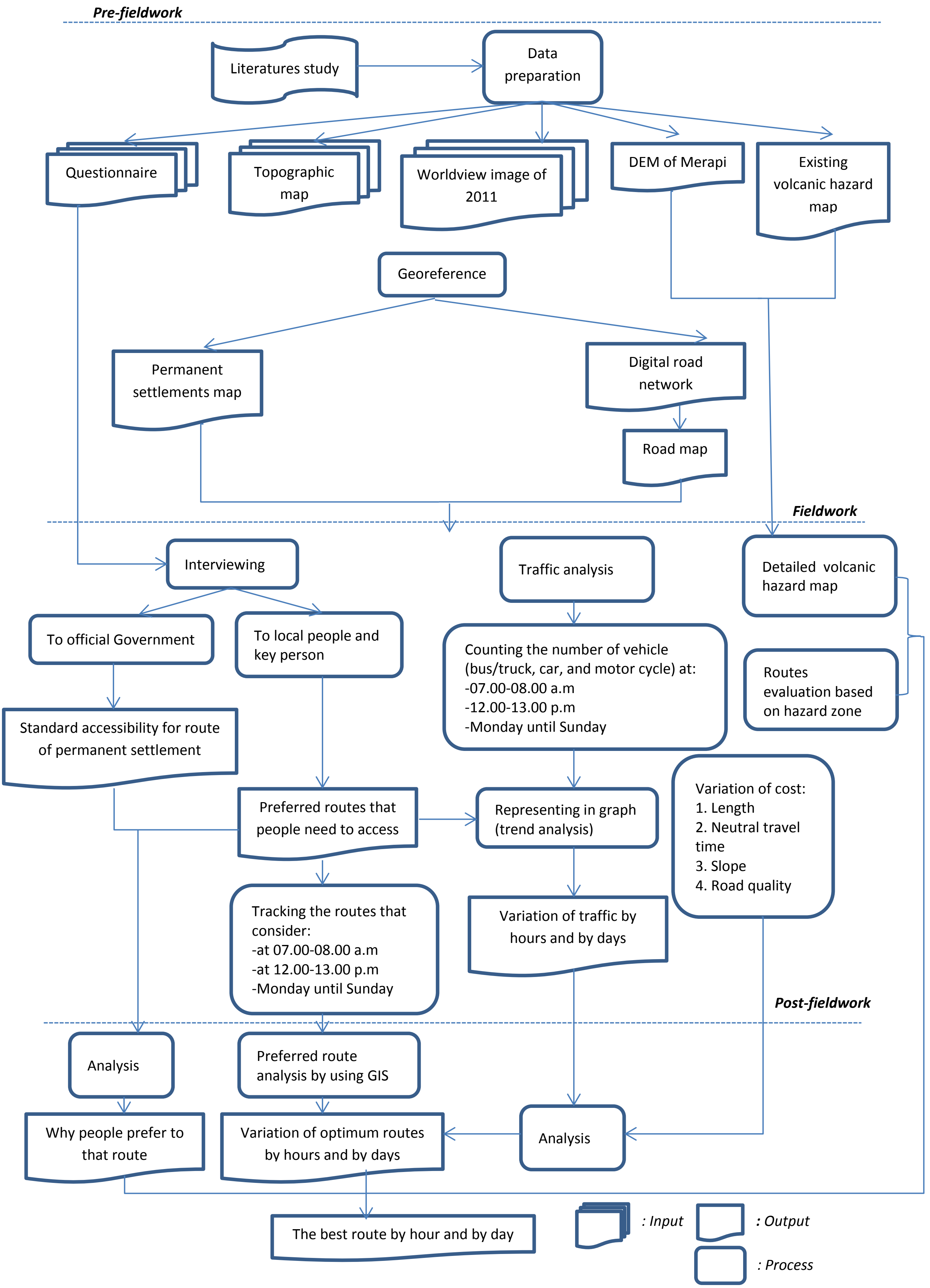


Figure 4-4. Flowchart of method

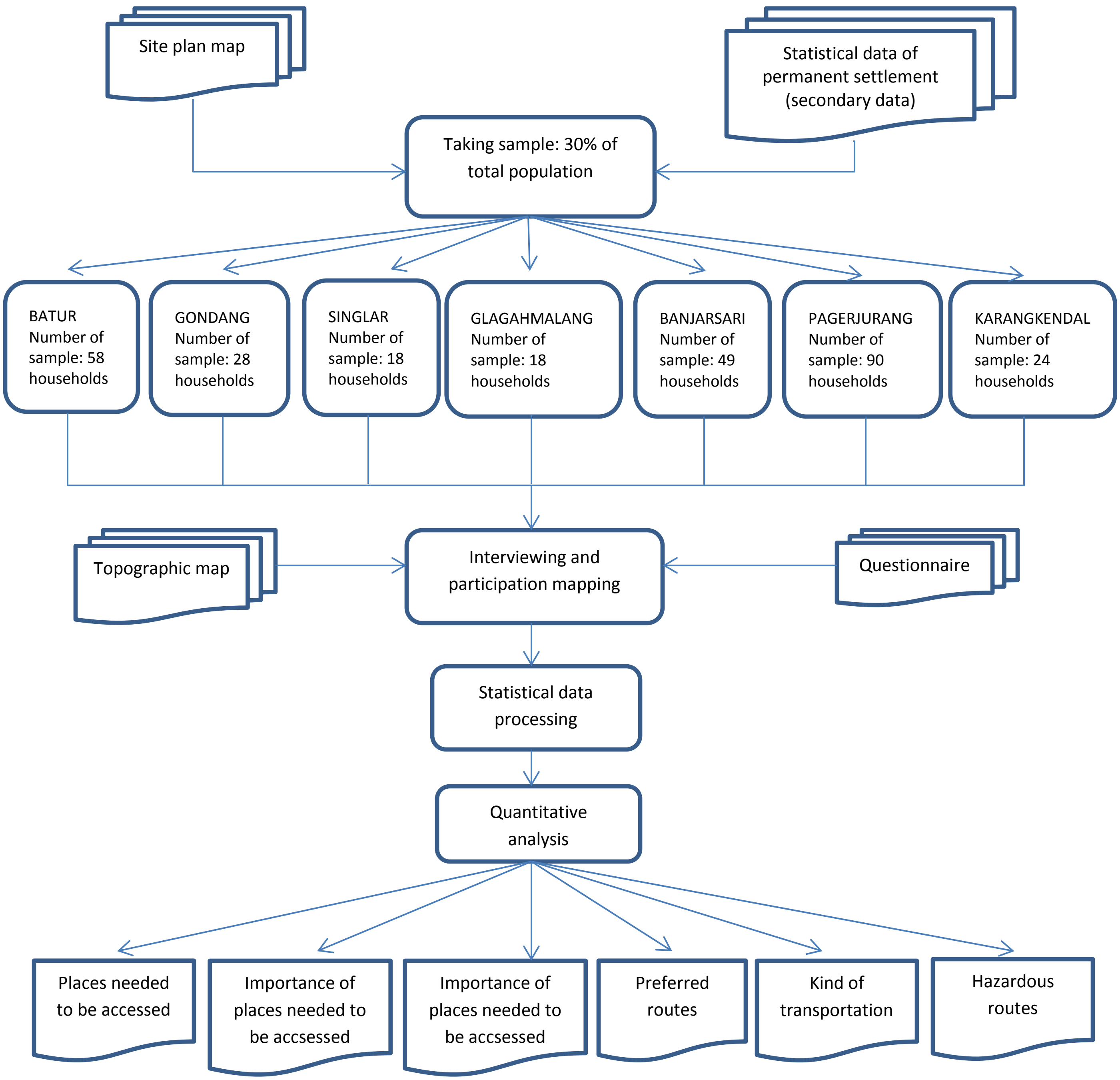


Figure 4-5. Flowchart of interviewing to local people

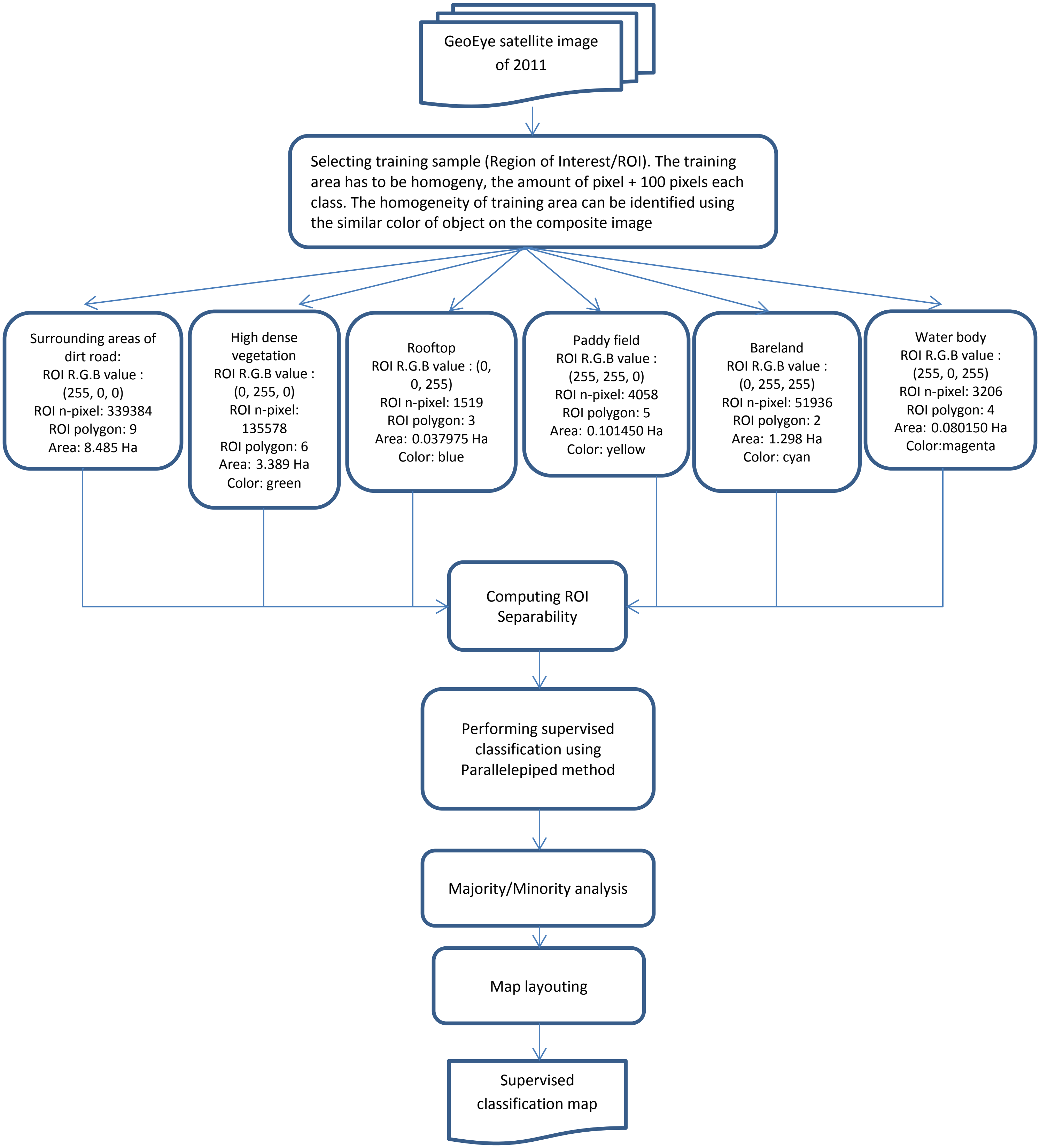


Figure 4-6. Flowchart of supervised classification

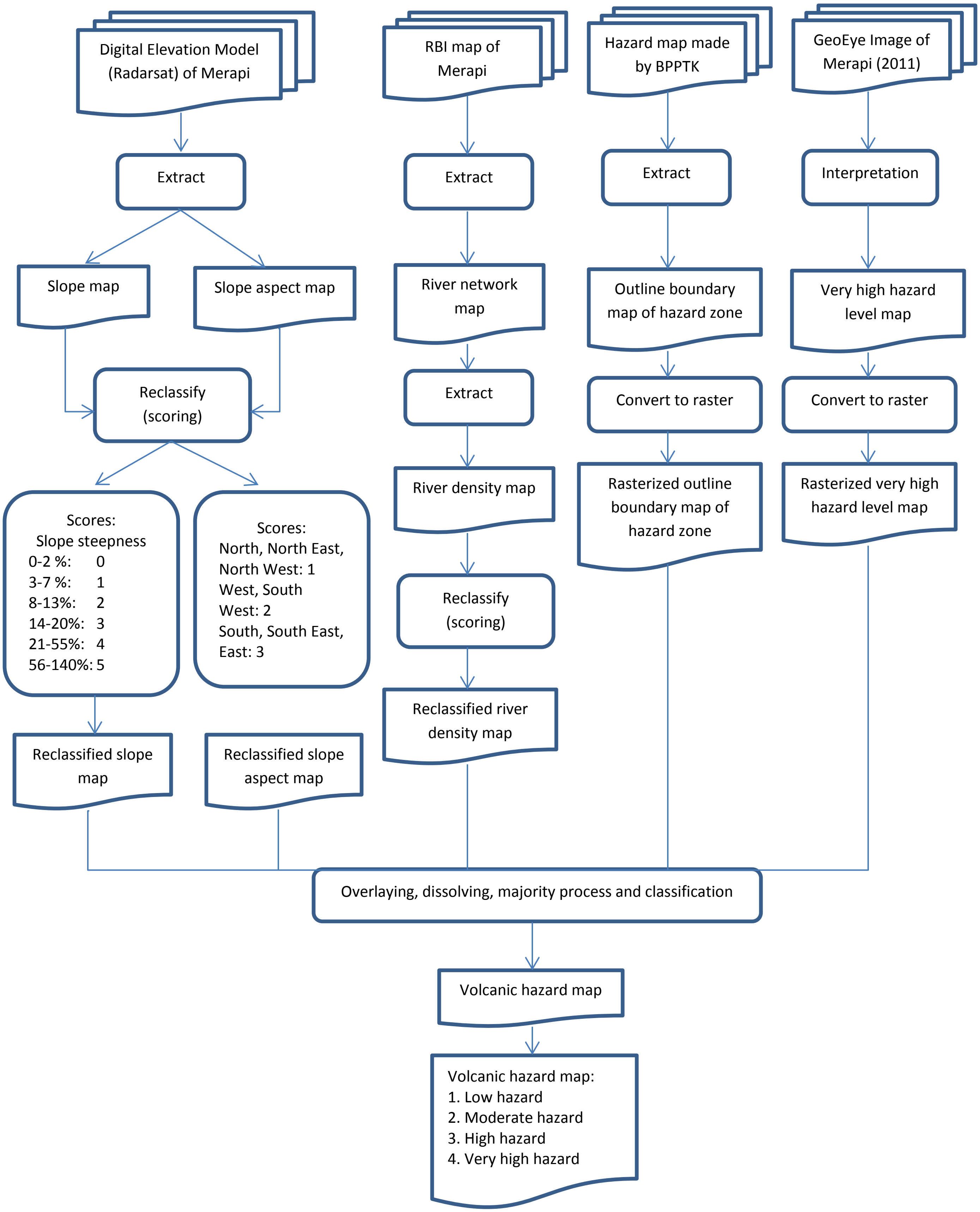


Figure 4-7. Flowchart of detailed volcanic hazard mapping

Chapter 5. Network modeling of optimum route

This chapter provides spatial information of preferred routes by local people used to access facilities that need to access and a model of optimum routes derived from those preferred routes. A model was controlled spatially and temporarily by influencing factors, such as road length, neutral time, slopes, traffic factors, and travelling time.

5.1. Preferred Route connecting to public facilities by local people

Typically, people movement is influenced by environmental constraints such as spatial aspects (Pan, Han, Dauber, & Law, 2007). Moreover, whatever they do are forced to face with both natural disaster and man-made disaster (Pel, Bliemer, & Hoogendoorn, 2012). Since volcanic eruption destructed a lot of infrastructures including roads used by most local people to travel anywhere, the accessibility became limited, so that they were forced to try to access given routes as their preference. Their preference might be effective in one side, but be ineffective in other sides. Therefore, overview of that preference was important in evaluating the effectiveness of accessibility.

5.1.1. Preferred route from permanent settlement of Batur and Gondang to Butuh market

There are two preferred routes available that connect from permanent settlement of Batur and Gondang to Butuh market (see Figure 5-5). Most local people travel to that market through both routes. In the Figure 5-1 and Figure 5-3, white color line indicates the first route, and the yellow color one is the second route. The first route was chosen by most local people, because of shorter road length, but it is worse road condition than the second route (see Figure 5-2 and Figure 5-4). Although most local people known that condition, but they seem still prefer to that route because of shorter road length than the second route (see Figure 5-6).

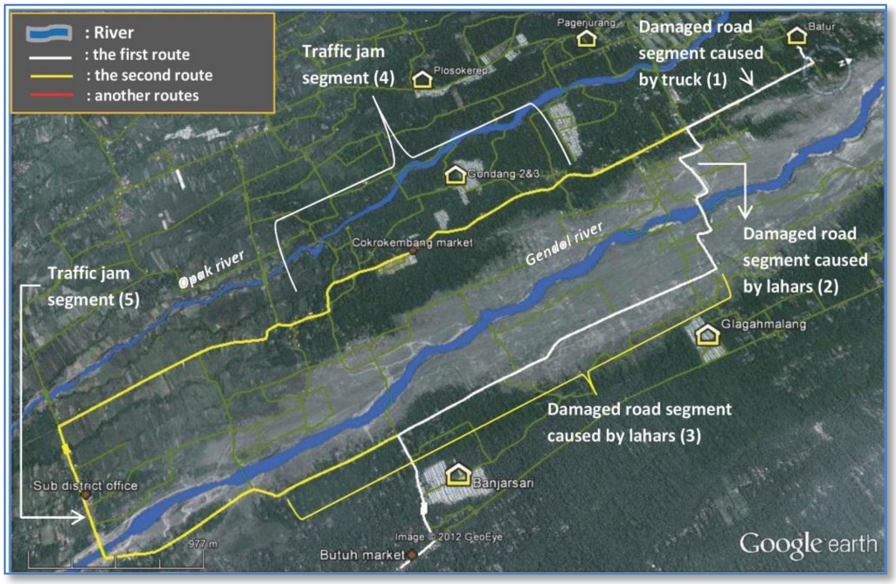


Figure 5-1. Preferred route from Batur to Butuh market

Figure 5-2. Damaged road caused by truck (1) Damaged road caused by lahars crossing Gendol river (2) (left side) and damaged road caused by lahars (3) (right side)

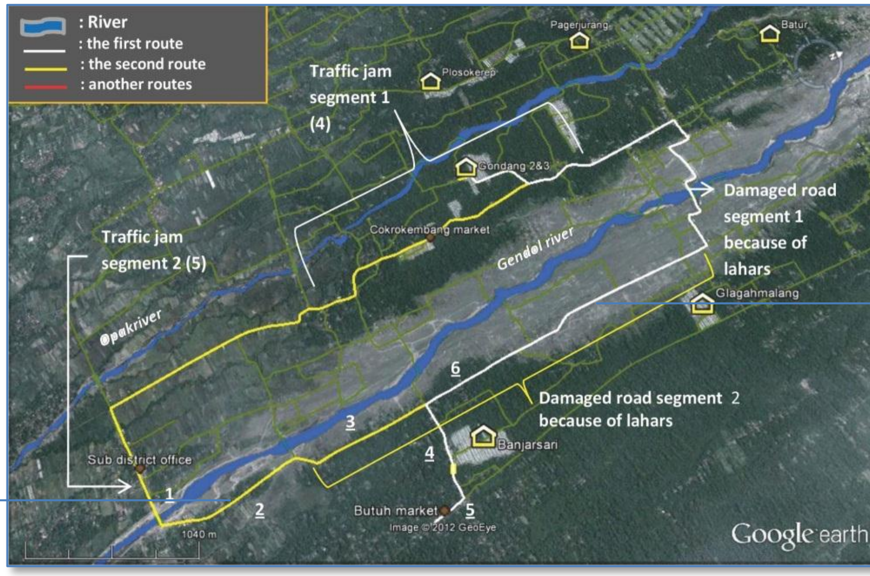


Figure 5-3. Damaged road of Gondang-Butuh market's route

Figure 5-4. Road condition of route from Batur and Gondang to Butuh market

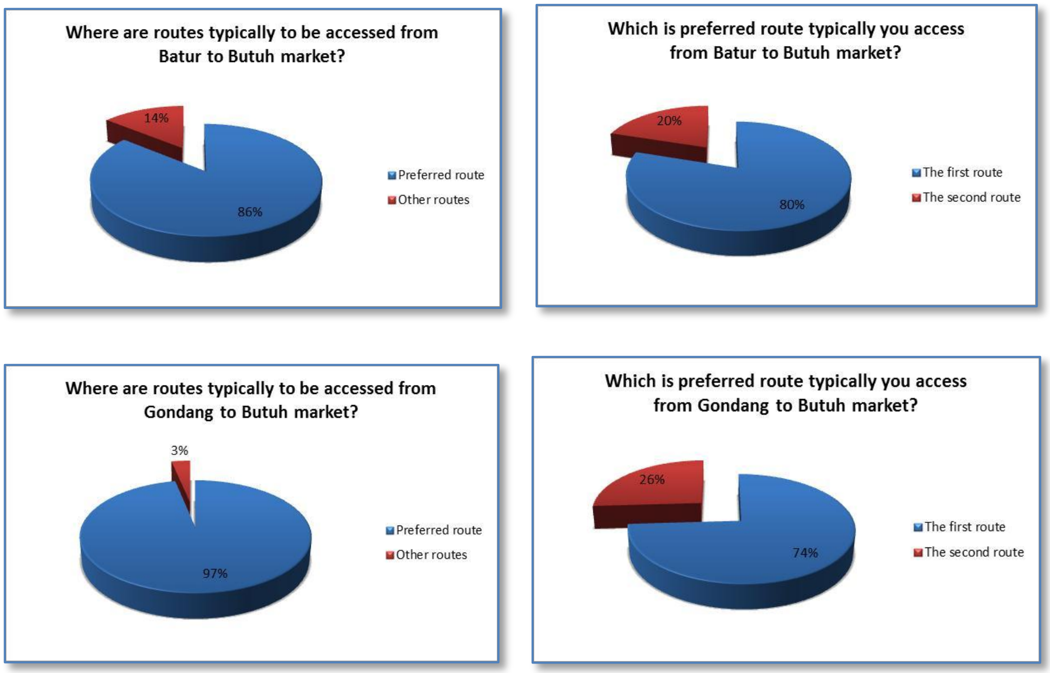


Figure 5-5. Perception of preferred route from Gondang to Butuh market by local people

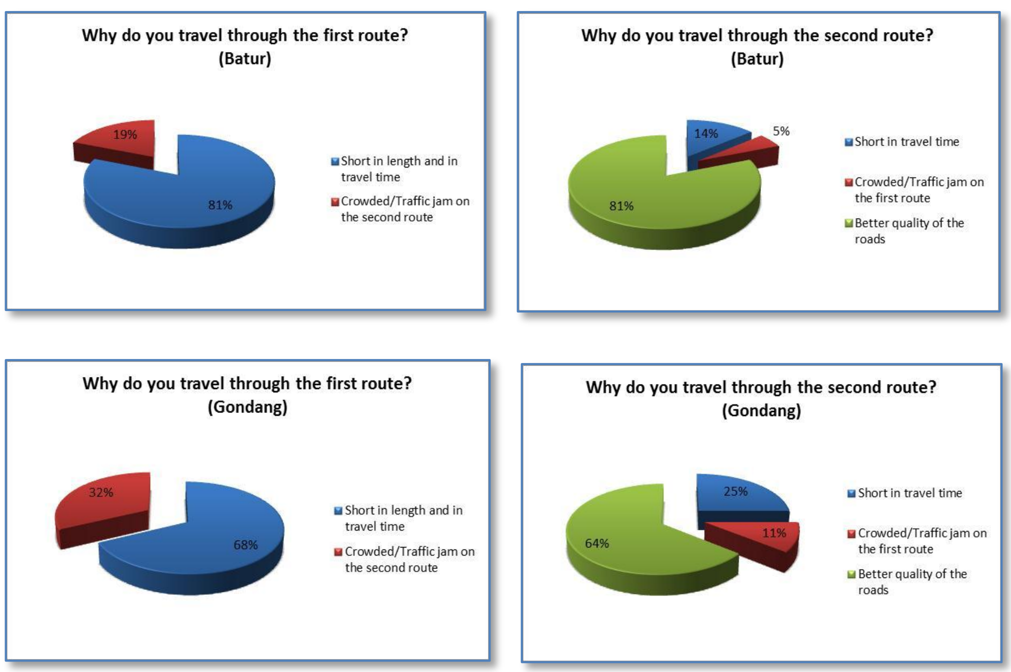


Figure 5-6. Reasons of accessing through preferred route from Batur and Gondang to Butuh market by local people

However, travel time of the first route is longer than the second route. Most road segments of it were seriously damaged and made vehicle speed being decreased.

Longer road segments and heavy traffic became reasons of why local people did not prefer to the second route. Sometimes, heavy traffic on it caused traffic jam, so that local people thought that the travel time would definitely be much longer. That jam often occurred in the turn roads. The road is narrow so that if the two trucks meet side by side, one truck has to stop waiting for a moment until another one goes first and the truck can pass then.

If heavy rain came, they shifted the preference to the second route. On the first route, water inundations from rain worsen the dirty roads (muddy roads) and made more difficult driving by most vehicles types. Vehicles speed would be much slower than in the normal condition. Only truck could cross over that road. Compared with road quality of the first route, the second route is much better. However, fortunately, since that route was also passed by a lot of trucks in the day, especially on given road segments (traffic jam (4) and traffic jam (5) as shown in Figure 6-1), it made it being more difficult to be accessed.

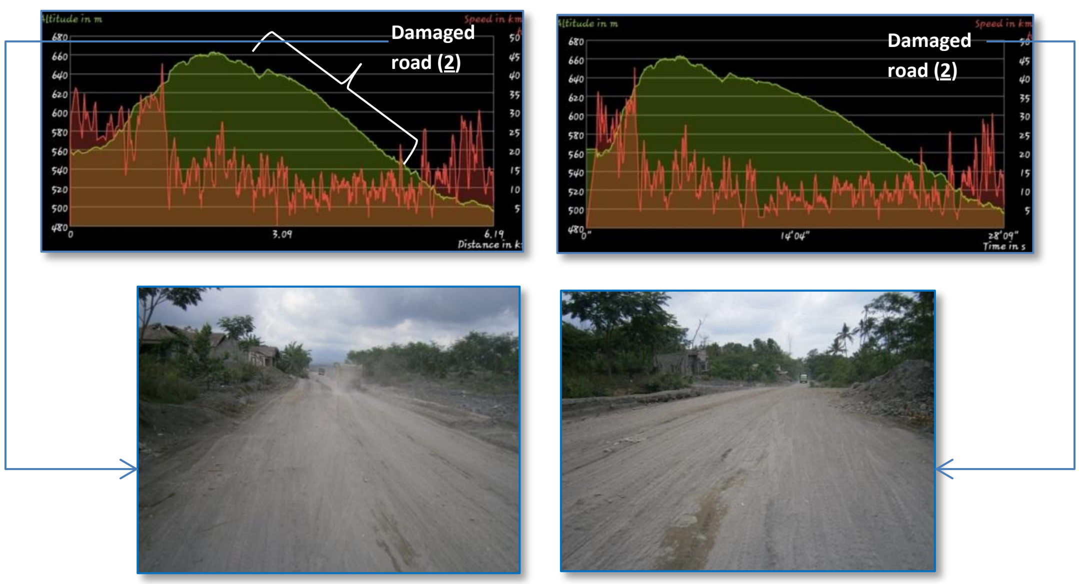


Figure 5-7. Average continuous travel speed of motorcycle from Gondang to Butuh market (road segment 2 in Figure 5-3)

The Figure 5.7 above shows how the damaged road segment decreased average continuous speed of motorcycle. In the normal condition, the speed increased on the down road because of gravity, whereas both graphs show the reverse condition. The rider seems reduced the speed intensively while the motorcycle passed on damaged road segment. After it had been passed, the average continuous speed of that vehicle would be back increased. It could be identified where the road segment of the first route likely contributed to the retardation of travel time.

Most traffic of the first route was dominated by truck carrying volcanic sand. If heavy traffic occurred, it will be difficult to be passed, especially if one goes by motorcycle and car. The effect of Merapi 2010 eruption caused more damaged and dirty roads (many cracks, pebbles, gravels, less asphalt covered). The presence of the traffic dominated by truck made the condition being worse. Cracks and holes could be found every side along the road.

Local people prefer to the first route if they go in the morning since the traffic is still light, especially from trucks. If rain comes, whatever in the morning or in the day, the local people prefer to the second route.

5.1.2. Preferred route from permanent settlement of Singklar, Glagahmalang, and Banjarsari

There was only one preferred route (see Figure 5-8) crossing Gendol river accessed by local people who live in the permanent settlement of Singklar, Glagahmalang, and Banjarsari to the Sub district office of Cangkringan (as shown in Figure 5-9).

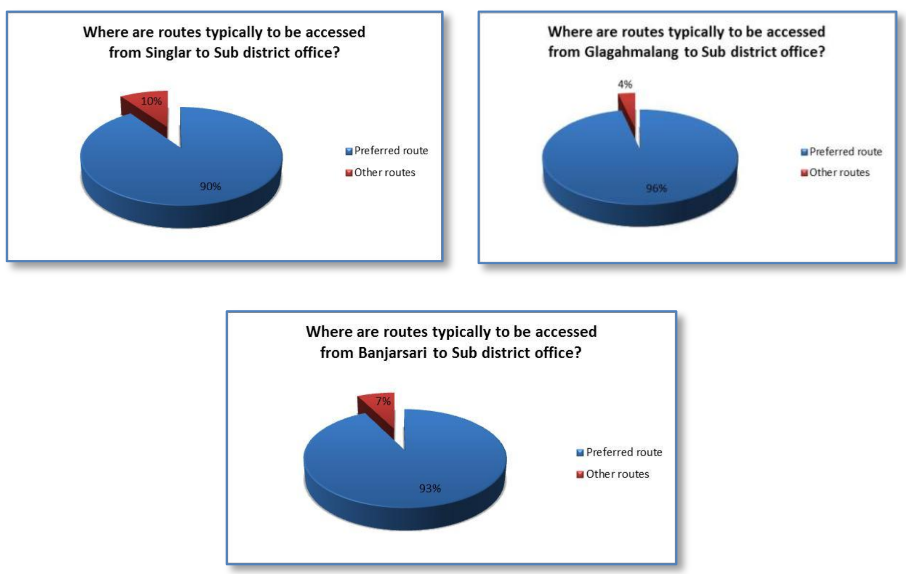


Figure 5-8. Perception of preferred route from Singlar, Glagahmalang, and Banjarsari to Sub district office by local people

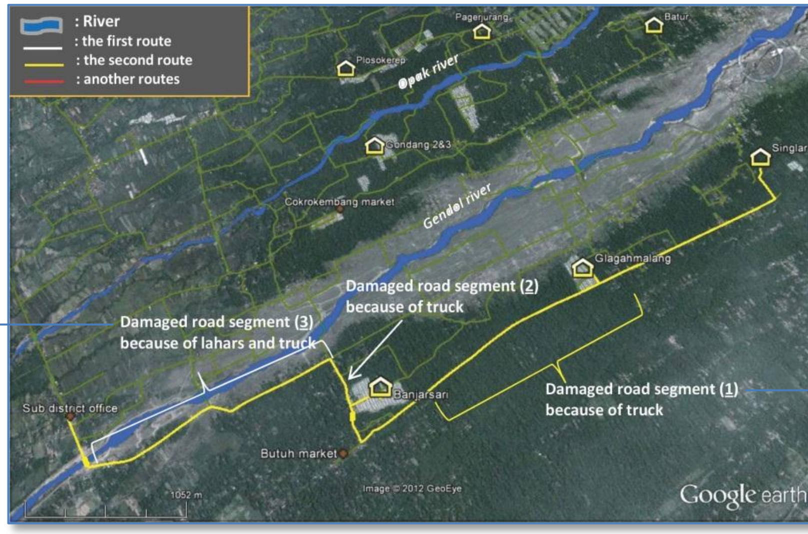


Figure 5-9. Damaged road segment from Singlar, Glagahmalang, and Banjarsari to Sub district office

Figure 5-10. Damaged road segment of Singlar, Glagahmalang, and Banjarsari to Sub district office in the field

All local people said that this route was the shortest path although it was less covered by asphalt, and for them who are not local people, of course, they will find it being difficult to be accessed (see Figure 5-10).

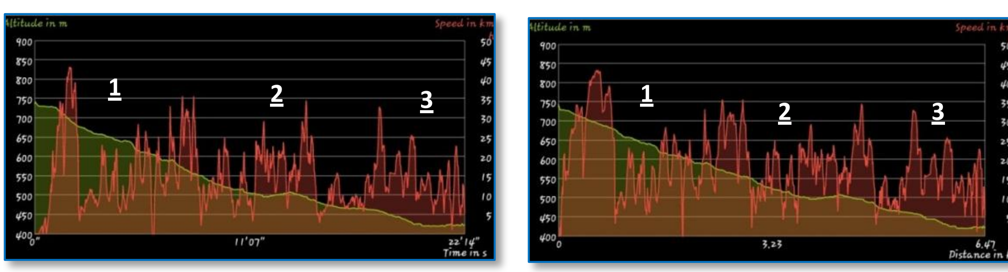


Figure 5-11. Average continuous travel speed of motorcycle from Singlar, Glagahmalang, and Banjarsari to Sub district office. Number 1, 2, and 3 were damaged road.

Graphs as shown in Figure 5-11 depicts that the curve of average continuous speed of motorcycle was more various indicating more various road condition. The road segment indicated with low average speed (no.1, 2, and 3) informs that there were cracks on the road and made the travel time being slower than it should be. Meanwhile, the better road quality (asphalt cover) of road segment was investigated by increasing that speed.

5.1.3. Preferred route from permanent settlement of Pagerjurang and Karangkendal

Two preferred routes were available that connect both settlements (Pagerjurang and Karangkendal) to the Pakem market. Both routes are shown in the Figure 5-12 and Figure 5-14 which white color line is the first route and the yellow one is the second route. In weekday (from Monday until Friday), most local people mostly prefer to the first route since its condition was better than the second route (see Figure 5-13 and Figure 5-15).

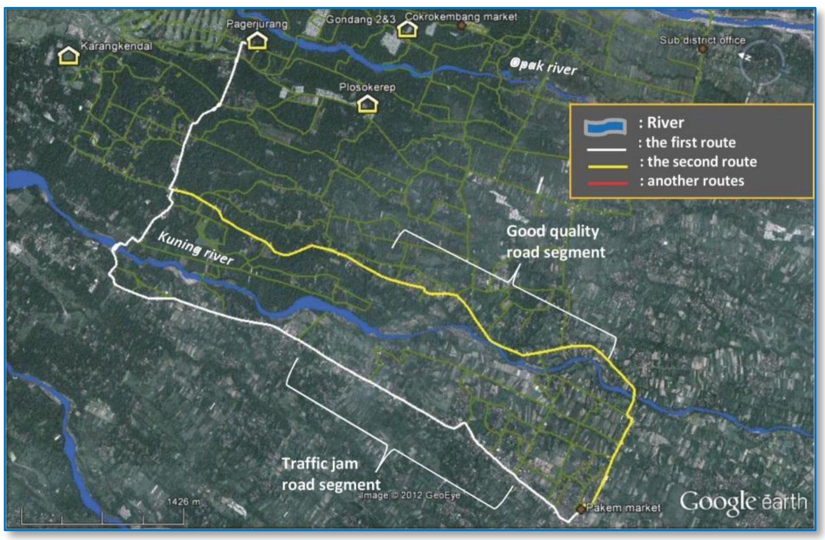


Figure 5-12. Preferred route from Pagejurang to Pakem market

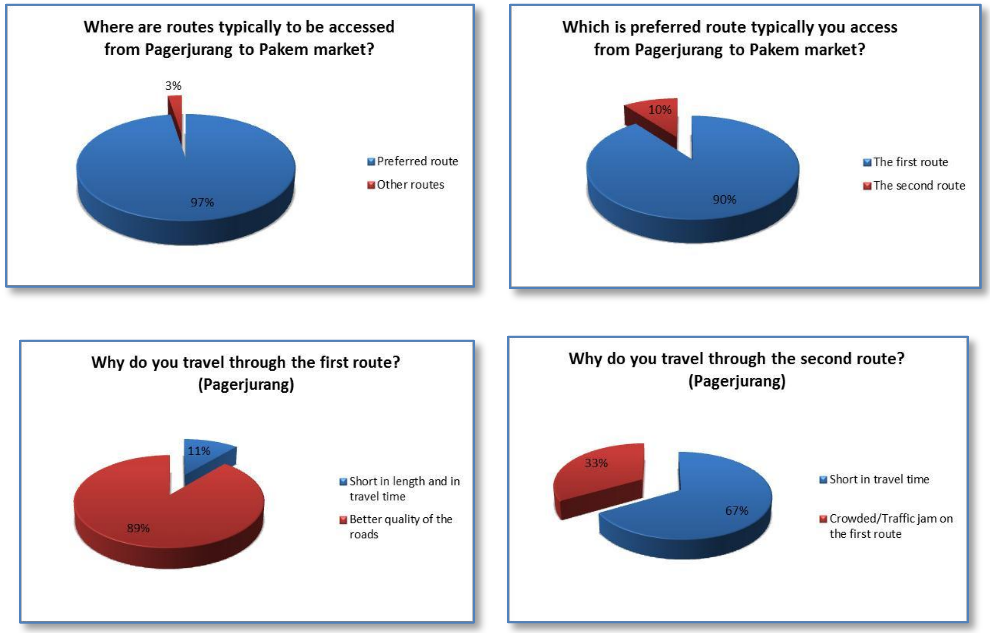


Figure 5-13. Perception of preferred route from Pagerjurang to Pakem market by local people

If weekend (Saturday and Sunday) came, traffic of the first route was more crowded dominated by tourism buses that travelled to the tourism object such as Kaliurang and Kaliadem. It forced them to shift their preferred path to the second route (see Figure.5-13). Although the road condition was worse (cracks and thinner asphalt covers), travel time was shorter than the first route.

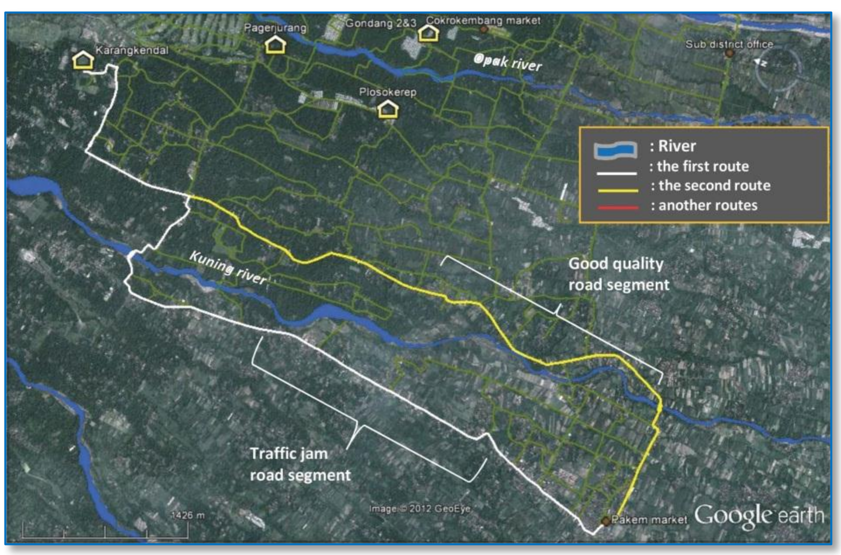


Figure 5-14. Preferred route from Karangkendal to Pakem market

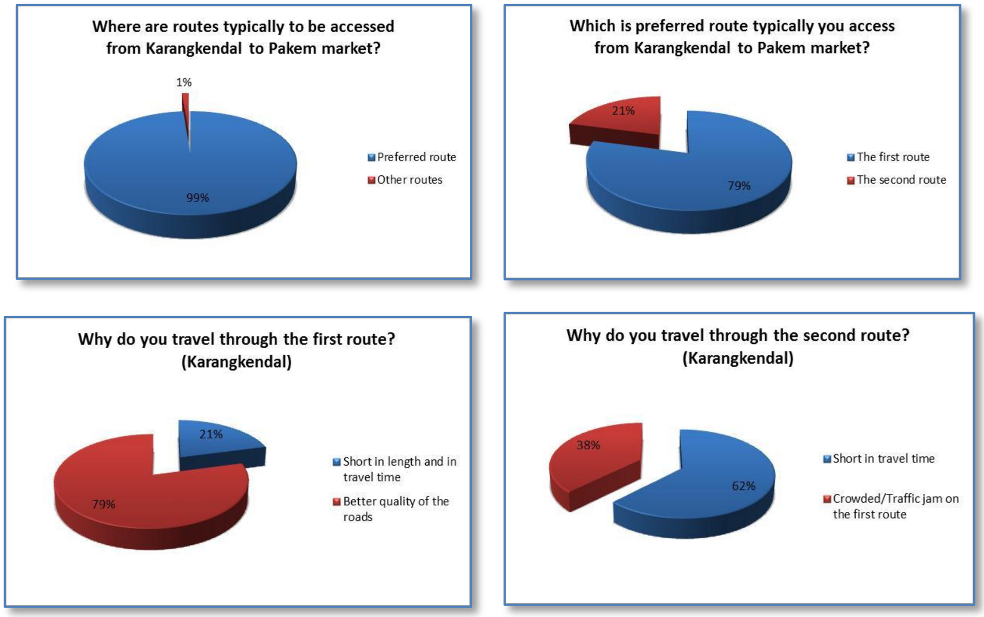


Figure 5-15. Perception of preferred route from Karangkendal to Pakem market by local people

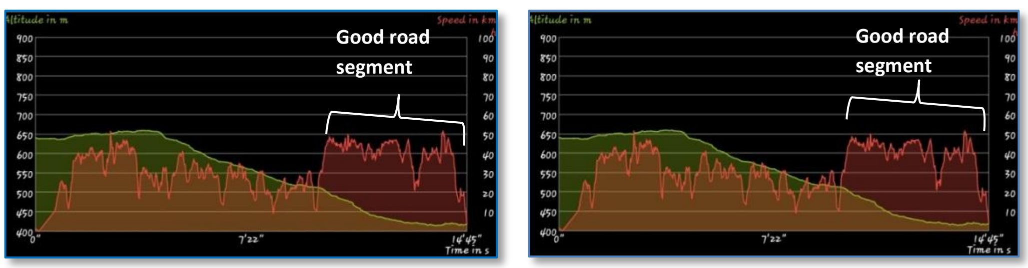


Figure 5-16. Average continuous travel speed from Pagerjurang and Karangkendal to Pakem market (on the first route)

According to the graph above (shown in Figure 5-16), the average continuous speed of motorcycle was likely constant on most road segments. Better road segment condition caused travel speed increased.

In the morning, most local people used the first route to access to the Pakem market, because the traffic was still light, but in the day, most of them accessed through the second route because of heavy traffic on the first route.

5.2. Optimum route by varying cost

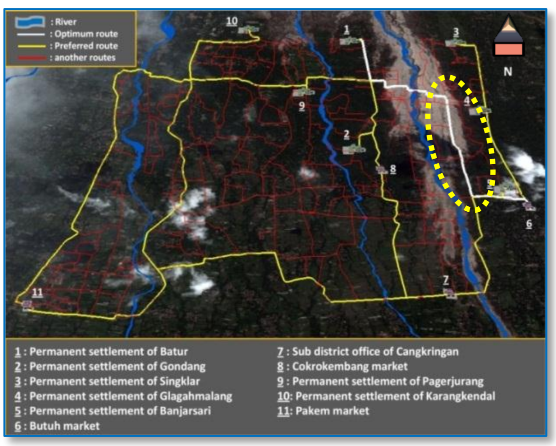
Finding optimum routes was modeled by influence of varying cost variables such as road length, and neutral travel time, route steepness slope, road quality, traffic factor, and travel time influenced by traffic.

5.2.1. Optimum route by cost of road length and neutral travel time

Optimum route influenced by road length and neutral travel time means a route which has the shortest length and time to a given place without an impedance of traffic that comes from vehicles.

5.2.1.1. Optimum route from Batur and Gondang to Butuh market by cost of road length and neutral travel time

The first routes of Batur-Butuh market (see Figure 5-17) and Gondang-Butuh market (see Figure 5-18) become optimum routes since they have shorter road length than the second route (see Table 5-1). It causes shorter travel time through that, except to the route of Gondang-Butuh market. The first route of Gondang-Butuh market has upward road (see Figure 5-19) on the first road segment that decreased travel speed, so that travel time being longer. The second route of Gondang-Butuh market has better quality of road segments. It enables vehicle speed increased, so that travel time will be shorter.



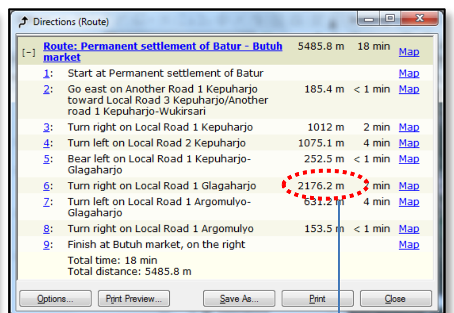
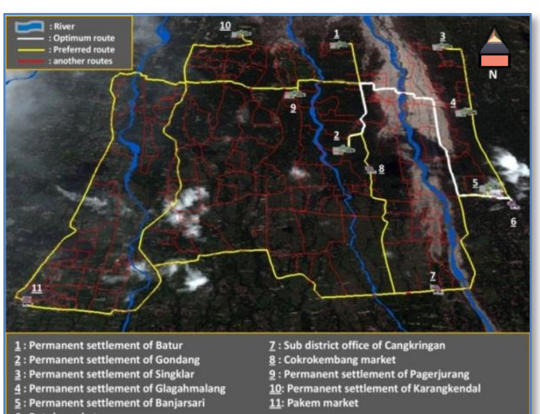


Figure 5-17. Optimum route from Batur to Butuh market based on road length and neutral travel time



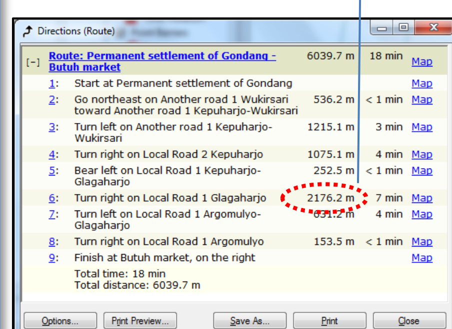
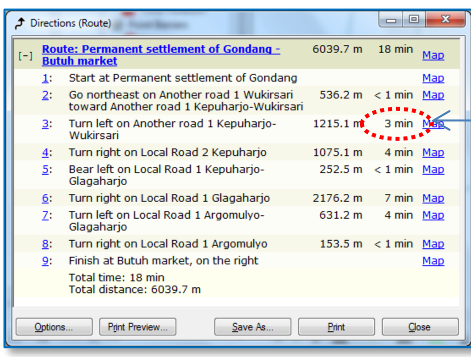


Figure 5-18 Optimum route from Gondang to Butuh market based on road length

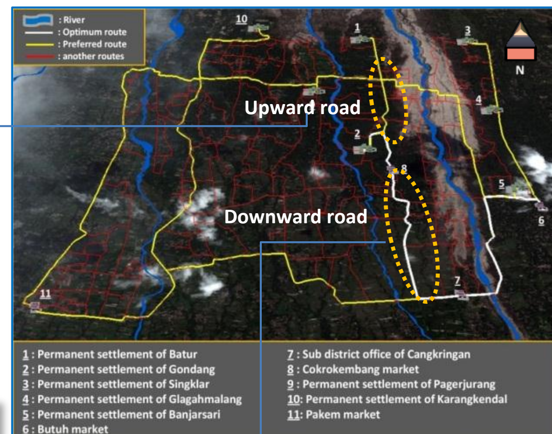
Table 5-1. Road length and neutral travel time from Batur and Gondang to Butuh market

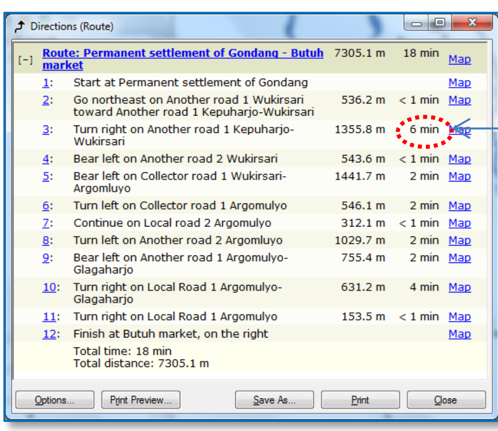
Routes	The first route		The second route	
	Road length (meters)	**Neutral travel time/FT-TF (minutes)**	**Road length (meters)**	**Neutral travel time/FT-TF (minutes)**
Batur-Butuh market	5485.8	18	9181.4	24
Gondang-Butuh market	6036.4	18	7305.1	18

The longest road length is located on Local road 1 Glagaharjo (see Figure 5-17) which is about 2176.2 meters and being the worst damaged road condition caused by lahars flood of Gendol river. Very thin asphalt cover, many cracks and holes, besides it caused road being difficult to be accessed, it also made very long-travel time which was about 7 minutes of 18 minutes as total travel time.



a. Direction of the second route





b. Direction of the optimum route

Figure 5-19. Optimum route from Gondang to Butuh market based on neutral travel time

5.2.1.2. Optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office by cost of road length and neutral travel time

Optimum route modeled by road length in GIS network is similar to the route that local people prefer to (see Figure 5-20). It is the shortest distance from their permanent settlement to sub district office. Fortunately, cracks and holes, thin asphalt covers, could be found on any road sides and causes longer travel time. The longest road length is located on Another road 3 Glagaharjo. Road quality of Another road 2 Argomulyo is also not good enough to be accessed (see Table 5-2).

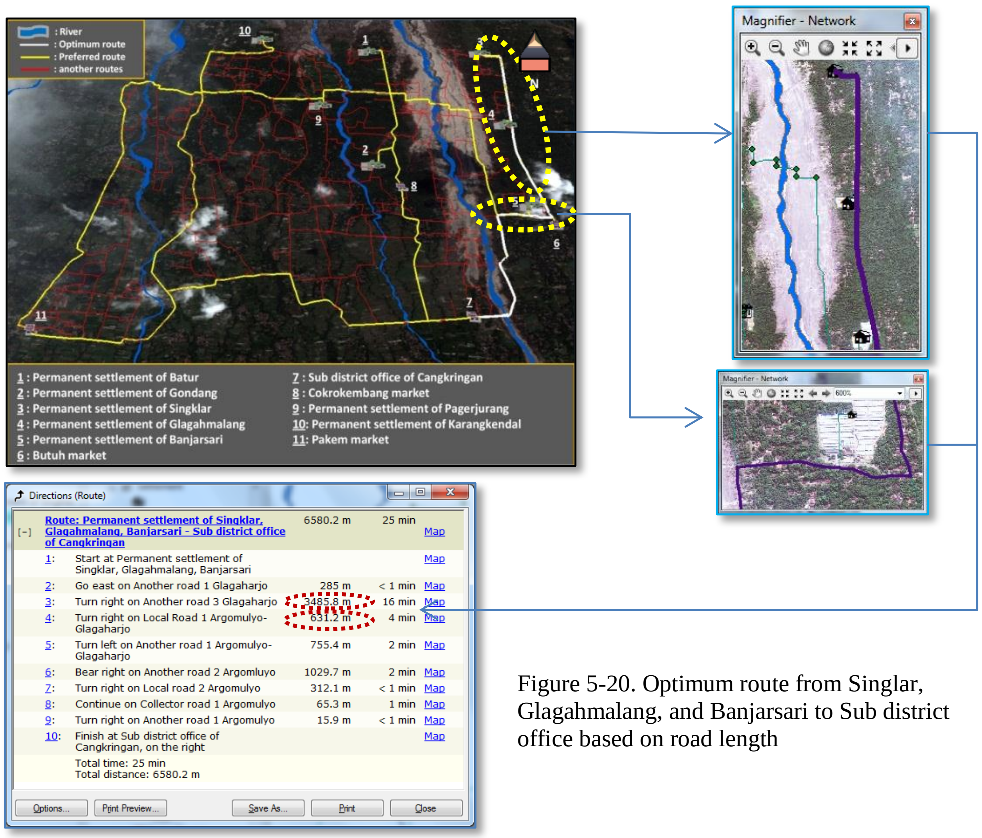


Figure 5-20. Optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office based on road length

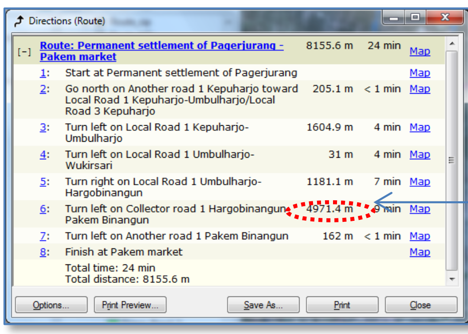
Table 5-2. Route length from Singlar, Glagahmalang, and Banjarsari to Sub district office

Routes	Road length (meters)	Neutral time/FT-TF (minutes)	Longest road segment	Road length (meters)	Neutral time/FT-TF (meters)	General road condition
Singlar-Sub district office	6580.2	25	Another road 3 Glagaharjo	3485.8	16	Some cracks and holes
Glagahmalang- Sub district office	4996.5	17	Another road 3 Glagaharjo	2001.6	8	Some cracks and holes
Banjarsari- Sub district office	2799	7	Another road 2 Argomulyo	1029.7	2	Less asphalt covers; covered by volcanic sand

5.2.1.3. Optimum route of Pagerjurang and Karangkendal to Pakem market by cost of road length and neutral travel time

Optimum routes of from Pagerjurang and Karangkendal to Pakem market are located in the first route (see Figure 5-21 and Figure 5-22). Although they have shorter road length than the second one (see Table 3), congestion often occurred in that route. When traffic gets jam, travel time will be longer, so that the shorter road length does not mean that it has shorter travel time, since it depends also on other influence factors, such as traffic jam. Traffic jam is one of road problems induced by number of vehicles (Chomątek & Poniszewska-Marańda, 2012). Therefore, number of vehicles passing that route will also be analyzed in next sub-chapter of this research.

The longest road length on the first route is on Collector road 1 started from of Hargobinangun sub district to Pakem Binangun sub district. As well as standard of collector road, that road quality is better to be accessed (thick asphalt covers)



Direction of the optimum route

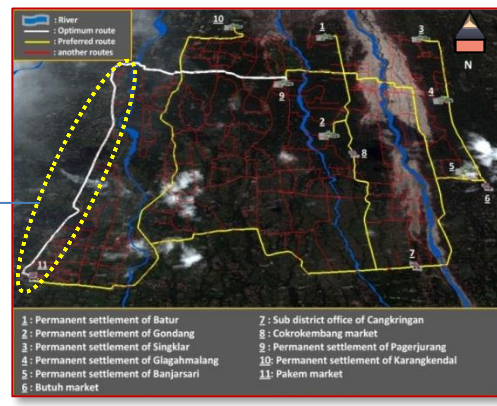
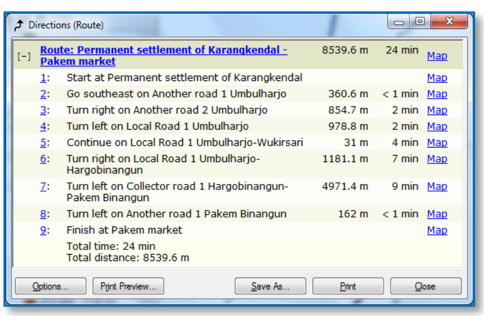


Figure 5-21. Optimum route from Pagerjurang to Pakem market based on road length



Direction of the optimum route

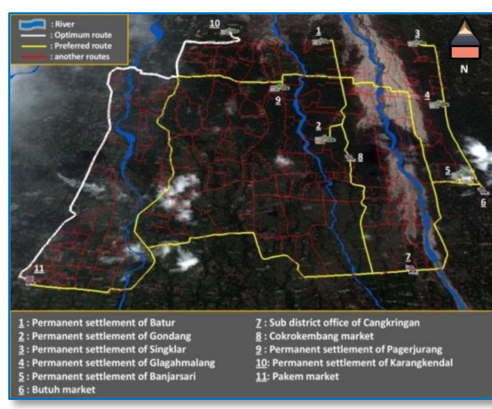


Figure 5-22. Optimum route from Karangkendal to Pakem market based on road length

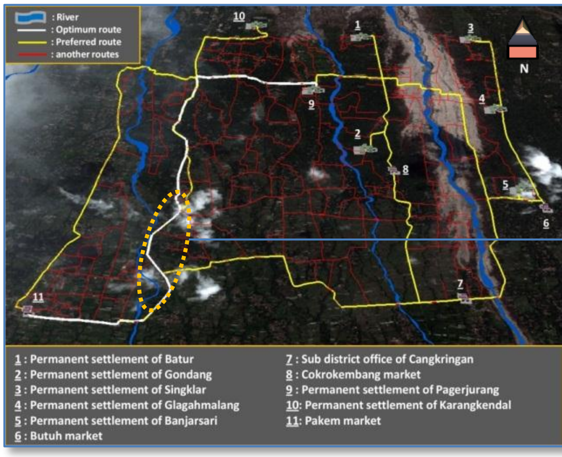
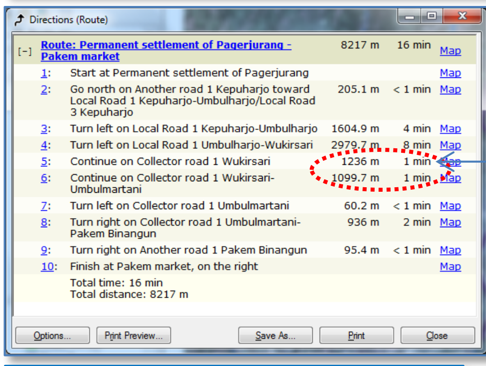


Figure 5-23. Optimum route from Pagerjurang to Pakem market based on neutral travel time. This segment (Collector road 1 Wukirsari) is the steepest road segment in time, so travel time is increased and the travel will be short in time


Directions (Route)

[−]	Route: Permanent settlement of Pagerjurang - Pakem market	8217 m	16 min	Map
1:	Start at Permanent settlement of Pagerjurang			Map
2:	Go north on Another road 1 Kepuharjo toward Local Road 1 Kepuharjo-Umbulharjo/Local Road 3 Kepuharjo	205.1 m	< 1 min	Map
3:	Turn left on Local Road 1 Kepuharjo-Umbulharjo	1604.9 m	4 min	Map
4:	Turn left on Local Road 1 Umbulharjo-Wukirsari	2979.7 m	8 min	Map
5:	Continue on Collector road 1 Wukirsari	1236 m	1 min	Map
6:	Continue on Collector road 1 Wukirsari-Umbulmartani	1099.7 m	1 min	Map
7:	Turn left on Collector road 1 Umbulmartani	60.2 m	< 1 min	Map
8:	Turn right on Collector road 1 Umbulmartani-Pakem Binangun	936 m	2 min	Map
9:	Turn right on Another road 1 Pakem Binangun	95.4 m	< 1 min	Map
10:	Finish at Pakem market, on the right			Map
	Total time: 16 min Total distance: 8217 m			

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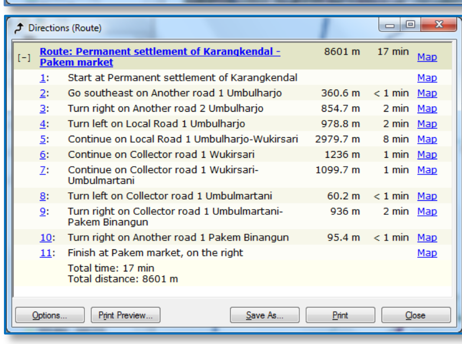
Directions (Route)

[−]	Route: Permanent settlement of Karangkendal - Pakem market	8601 m	17 min	Map
1:	Start at Permanent settlement of Karangkendal			Map
2:	Go southeast on Another road 1 Umbulharjo	360.6 m	< 1 min	Map
3:	Turn right on Another road 2 Umbulharjo	854.7 m	2 min	Map
4:	Turn left on Local Road 1 Umbulharjo	978.8 m	2 min	Map
5:	Continue on Local Road 1 Umbulharjo-Wukirsari	2979.7 m	8 min	Map
6:	Continue on Collector road 1 Wukirsari	1236 m	1 min	Map
7:	Continue on Collector road 1 Wukirsari-Umbulmartani	1099.7 m	1 min	Map
8:	Turn left on Collector road 1 Umbulmartani	60.2 m	< 1 min	Map
9:	Turn right on Collector road 1 Umbulmartani-Pakem Binangun	936 m	2 min	Map
10:	Turn right on Another road 1 Pakem Binangun	95.4 m	< 1 min	Map
11:	Finish at Pakem market, on the right			Map
	Total time: 17 min Total distance: 8601 m			

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a. Direction of the optimum route

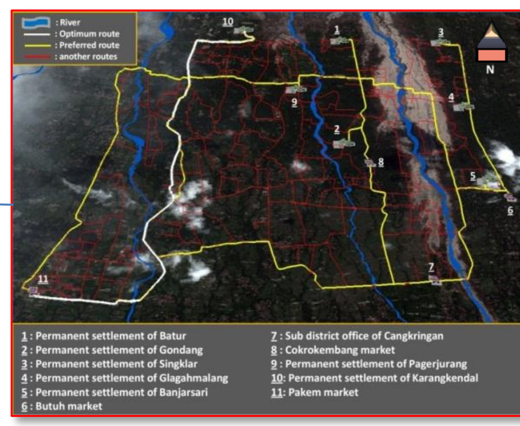


Figure 5-24. Optimum route from Karangkendal to Pakem market based on neutral travel time.

By neutral travel time as a constraint, the second route can be optimum despite of longer road length than the first one (see Figure 5-23 and Figure 5-24). Road segments are mostly steeper, so that the vehicle speed will be more increased due to gravity effect. The road segment of Collector road 1 Wukirsari which has length of 1236 m could be travelled only in 1 minutes (compared with shorter road length of Collector road 1 Wukirsari-Umbulmartani which has length of 1099.7 m, it took 1 minutes also) (see Figure 5-23 and Figure 5-24)). It means that the previous road segment is steeper than the later road segment.

Table 5-3. Route length from Pagerjurang and Karangkendal to Pakem market

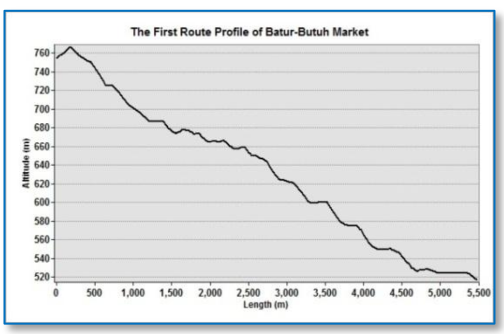
Routes	The first route		The second route	
	Road length (meters)	Neutral travel time (minutes)	Road length (meters)	Neutral travel time (minutes)
Pagerjurang-Pakem market	8155.6	24	8217	16
Karangkendal-Pakem market	8539.6	24	8601	17

5.2.2. Optimum route by cost of route steepness

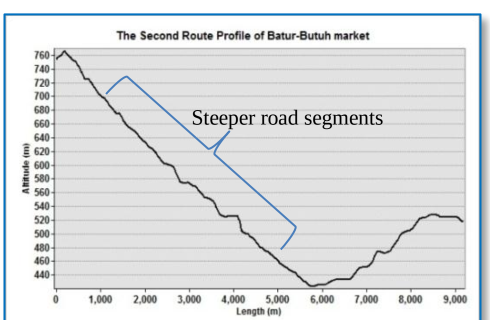
Optimum route by constraint of slope means the route for which road segments mostly has less steepness. The local people typically prefer to choose the less steep roads (flat-like road) since is easier to be accessed.

5.2.2.1. Optimum route from Batur and Gondang to Butuh market by cost of route steepness

Shorter road segments which have steepness of 8-15% are mostly located on the first route from Batur to Butuh market (see Figure 5-25), so it will be easier to be accessed (because of short steeper road, both from-to and to-from). If one travel through the second route, there are many longer road segments which have steepness of 8-15%, besides that, there are more upward roads, so that it will be difficult to be accessed. Route from Gondang to Butuh market has shorter road segments which have steepness of 8-15% on the second route (see Figure 5-26). Long upward road on the first route caused it being difficult to be accessed.



a. Profile of the optimum route



b. Profile of the second route

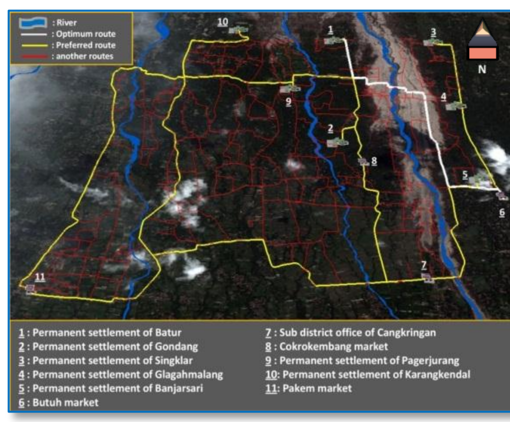
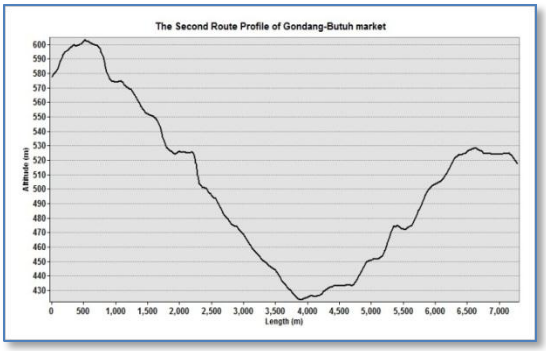
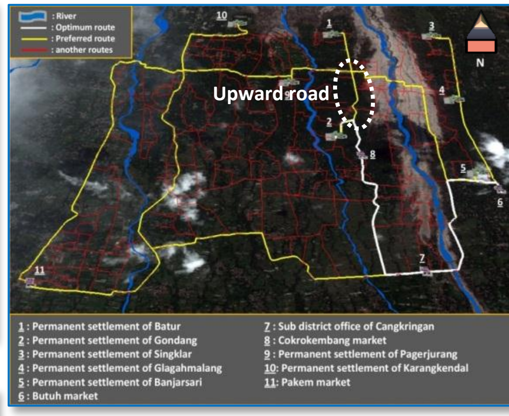


Figure 5-25. Optimum route from Batur to Butuh market based on route steepness.



a. Profile of the optimum route



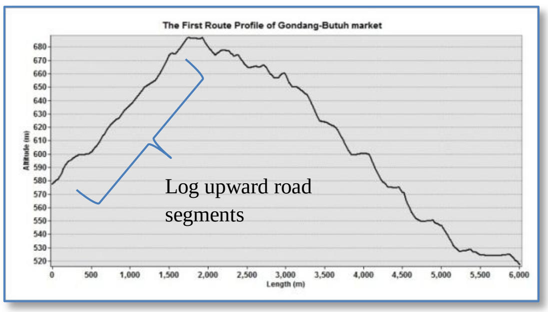
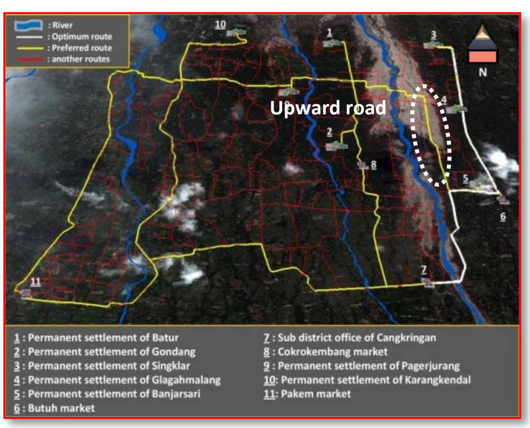


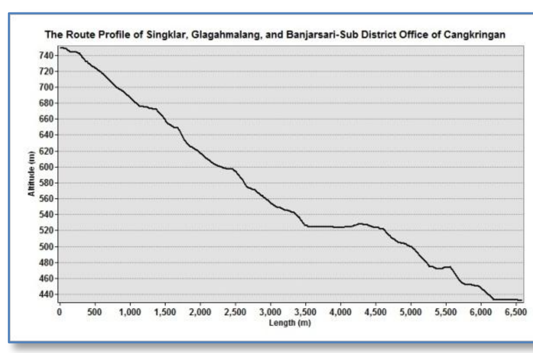
Figure 5-26. Optimum route from Gondang to Butuh market based on route steepness.

b. Profile of the first route

5.2.2.2. Optimum route of Singlar, Glagahmalang, Banjarsari-Sub district office by cost of route steepness

The optimum route is similar to the route which local prefer to (see Figure 5-27). That route has shorter road segments which have steepness of 8-15%. Network model did not direct the optimum route to northward through upward road after stopped on turn point of Local road 1 Argomulyo-Glagaharjo, because upward road segments was more difficult to be accessed than downward road.



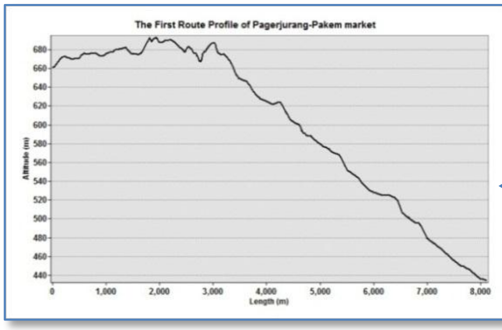


Profile of the optimum route

Figure 5-27. Optimum route from Singlar, Glagahmalang, and Banjarsari-Sub district office based on route steepness.

5.2.2.3. Optimum route from Pagerjurang and Karangkendal to Pakem market by cost of route steepness

Route steepness could be measured by length of downward road. Network model in GIS counted it by combining with slope steepness. The first route can be optimum since it has less steep downward roads than the second route (see Figure 5-28 and Figure 5-29). Most route steepness of the first route is about 8-15%.



a. Profile of the optimum route

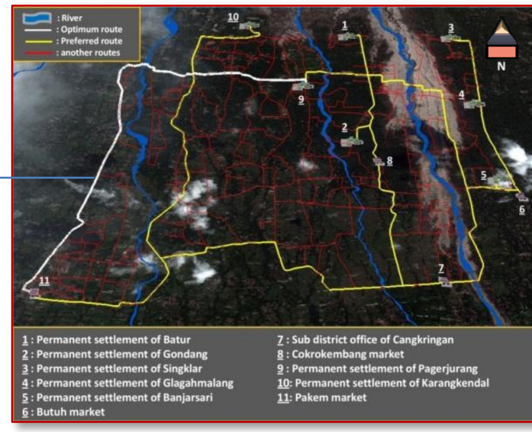
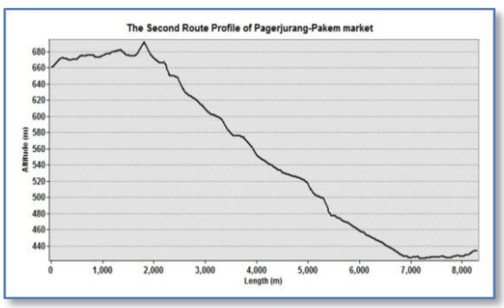
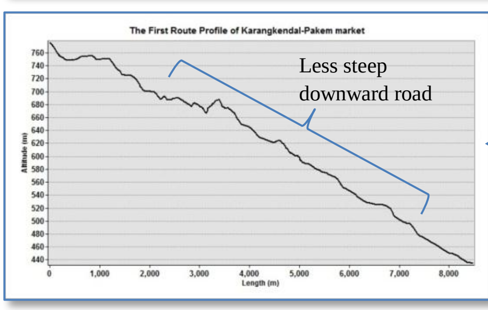


Figure 5-28. Optimum route from Pagerjurang to Pakem market based on route steepness.



b. Profile of the second route



a. Profile of the optimum route

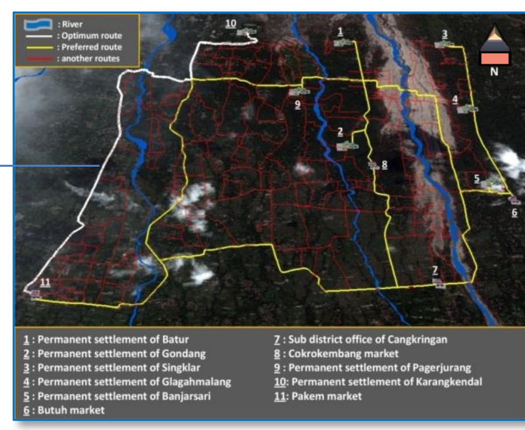
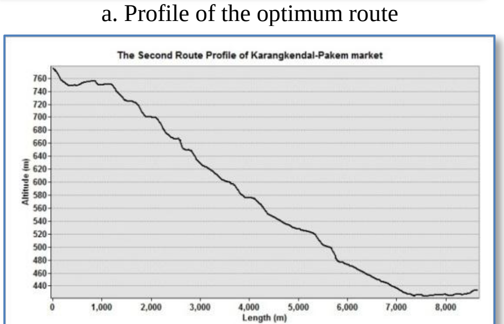


Figure 5-29. Optimum route from Karangkendal to Pakem market based on route steepness.



b. Profile of the second route

5.2.3. Optimum route by influence factor of road quality

Optimum route determined by road quality means route that has better road quality indicated with thick asphalt covers, less cracks or holes on any sides of road. Figure 5-30 shows that surrounding areas of dirt road which are prone to southeast flank colored by red color. Classification of surrounding areas of dirt roads aimed to know if there are road segments located on red color areas; it will be predicted as dirt roads (see Figure 5-30). Those areas were extracted through supervised classification from Geo-Eye image by using parallelepiped method. It used simple rule to classify multispectral data which apply standard deviation threshold from the mean of each selected class (Richards, 1999). Classifying process will be run if a pixel value lies above the low threshold and below the high threshold for all n-bands being classified. ENVI software will put the pixel value into the last class matched, if the classification runs in multiple classes. Unclassified class will be created if there are areas that do not belong to any parallelepiped classes.

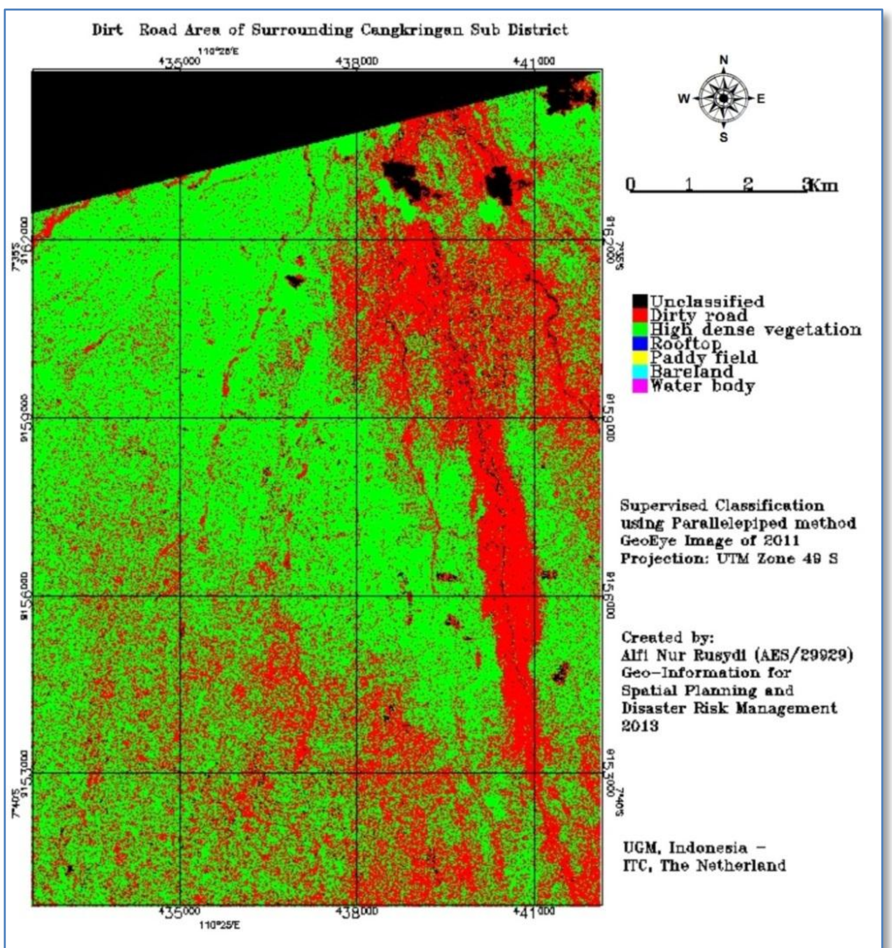
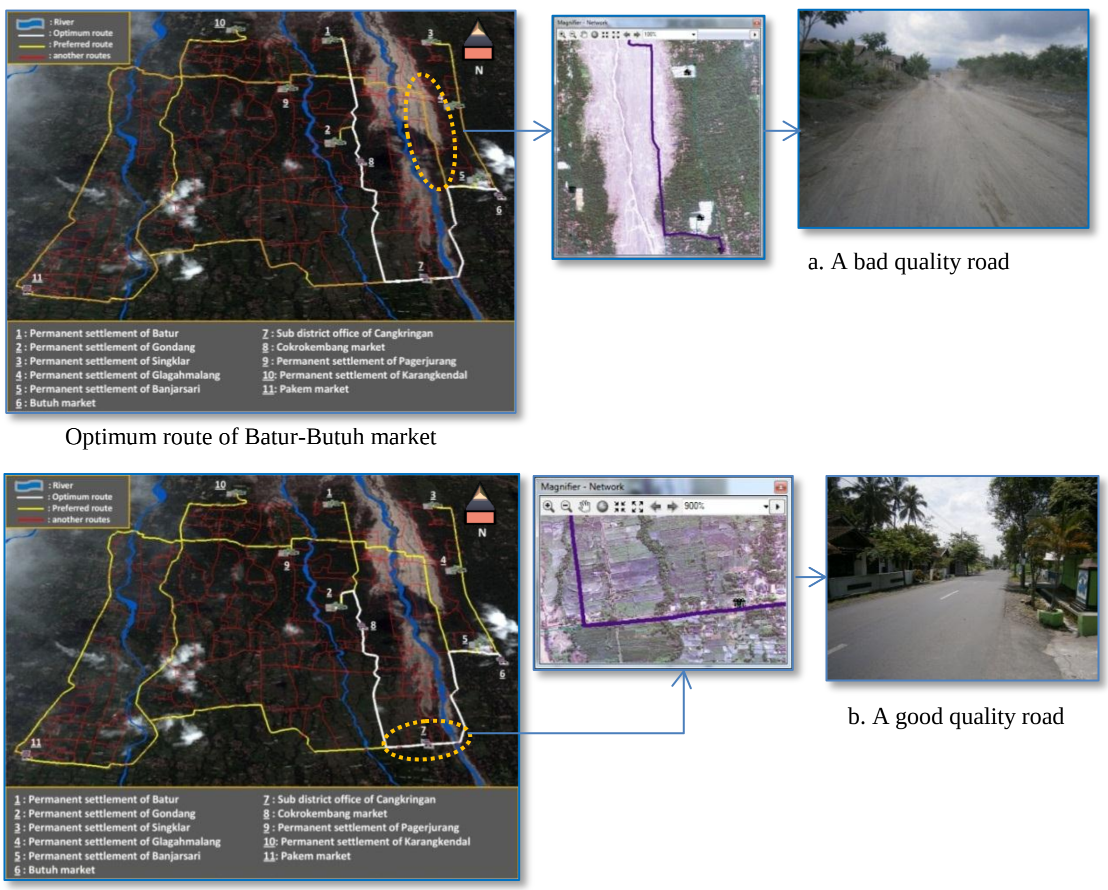


Figure 5-30. Supervised classification of surrounding areas of dirt road using parallelepiped method.

Surrounding areas of dirt road is near to Gendol river that surrounding areas are always flooded by lahars, especially after Merapi eruption of 2010. According to the map, travelling crossing red color area will be more difficult than green color area or other color area.

5.2.3.1. Optimum route from Batur and Gondang to Butuh market by cost of road quality

Quality road on the second route from Batur and Gondang to Butuh market is better than that of the first route which is less cracks and holes (see Figure 5-31). Those damaging roads were caused by overload sand carried by trucks, whereas on the first route, they were caused by pyroclastic flow and lahars flood. Difficult accessibility causing longer travel time came from damaged road surfaces which were dominantly covered by pebble and gravel mixed with volcanic sand and ash.



Optimum route of Batur-Butuh market

a. A bad quality road

Optimum route of Gondang-Butuh market

b. A good quality road

Figure 5-31. Optimum route from Batur and Gondang to Butuh market based on road quality.

5.2.3.2. Optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office by cost of road quality

Better road quality of route crossing through southern Gendol river became main factor causing why it could be optimum (see Figure 5-32). Shorter bad road segment made it being much easily to be accessed. Bad road segments of it were caused by lahar flood and load of trucks. Despite of thin asphalt covers, but it was still much thinner than the route crossing northern Gendol river since damage intensity of this area caused by both pyroclastic flows and lahars flood was not more serious than the northern route.

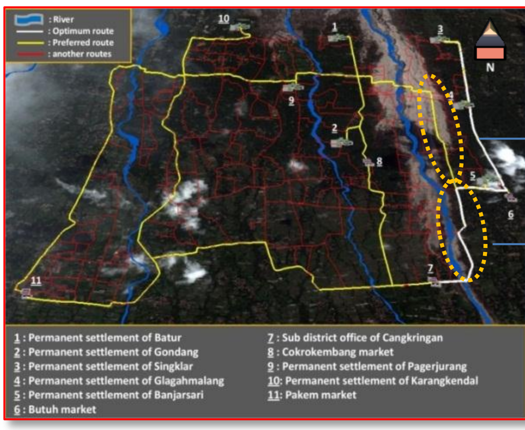
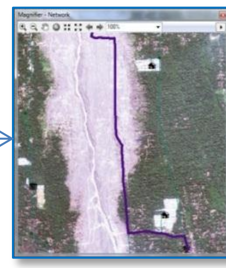
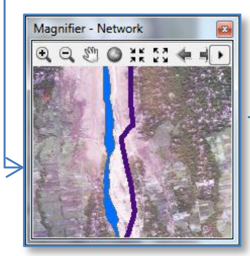


Figure 5-32. Optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office based on road quality consraint.



A worse road condition in the route crossing northern part of Gendol river



A better road condition in the route crossing southern part of Gendol river

5.2.3.3. Optimum route Pagerjurang, Karangkendal-Pakem market by influence factor of road quality

The first route is easier to be accessed due to better road quality than the second one. It has thinner asphalt cover and less cracks and holes (see Figure 5-33). A better road quality could increase vehicle speed. More cracks and small holes of the second route could be found on given sides of its road segments. It was caused by overload of trucks and thicker asphalt cover cannot hold well that load anymore.

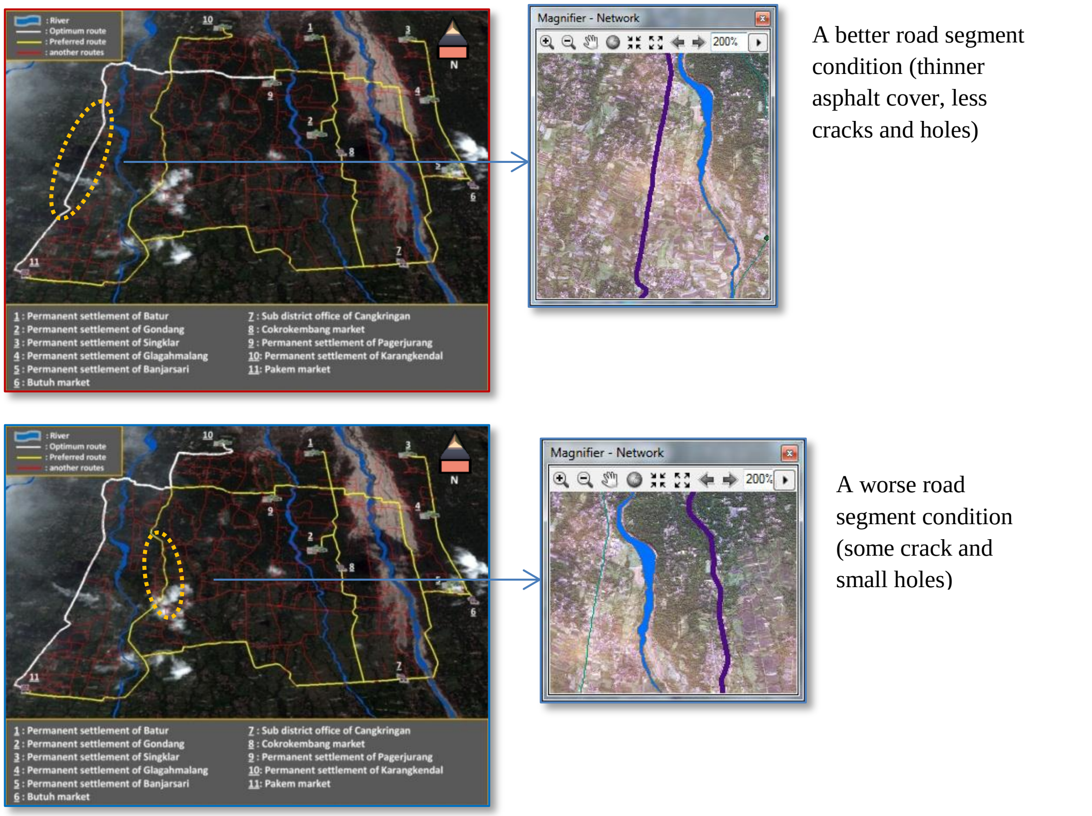


Figure 5-33. Optimum route from Karangkendal to Pakem market based on road quality.

5.2.4. Optimum route by cost of traffic factor

Traffic is an important constraint to be considered in route problems solving. Lu et al. (2003) considered traffic difficulties such as congestion and accessibility to find proper evacuation route. Traffic including traffic flow condition and dynamic control measures was also be strongly considered to find a route out (Dash and Gladwin 2007; Lindell and Prater 2007). Traffic simulation analysis could also be done by travel behavior involving dynamic travel demand modeling, dynamic trip distribution modeling, and dynamic traffic assignment modeling to support better evacuation planning (Pel et al., 2012).

To analyze whether a given route can be accessed properly or not by any vehicles, it needs to involve vehicles type analysis as part of traffic analysis (Mioc, Anton, & Liang, 2008). Their research was about flood evacuation planning for which proper vehicle type passing a route was determined by water depth level on street. The lowest water depth level which was not inundated area could be accessed much easily by any vehicles. Meanwhile the highest level which was extremely inundated area could only be accessed by amphibious craft or boat.

In this research, traffic was analyzed by traffic factor which was meant as a quietness index of route's traffic. A route could be optimum to be accessed if traffic factor was minimum indicating quiet traffic of that route. Traffic factor determined by number of vehicle for each vehicle type was measured by varying hours and days. Types of vehicle measured were motorcycle, car, and truck since they were mostly found in study area. The higher traffic factor, the more difficult a given route to be accessed. The higher traffic factor of a given route, the more possible traffic jam occurred. Which road segment that traffic jam always occurred was also investigated.

5.2.4.1. Optimum route from Batur to Butuh market by cost of traffic factor

Quieter traffic condition on the first route than on the second one occurred on all days; both in the morning and in the day (see Figure 5-34). This was because of worse road quality on the first route, so that vehicles passing through on it were rare since it was difficult to be passed. On the second route, due to better quality road of the second route, most vehicles passed through on it since it was easier for any vehicle to pass.

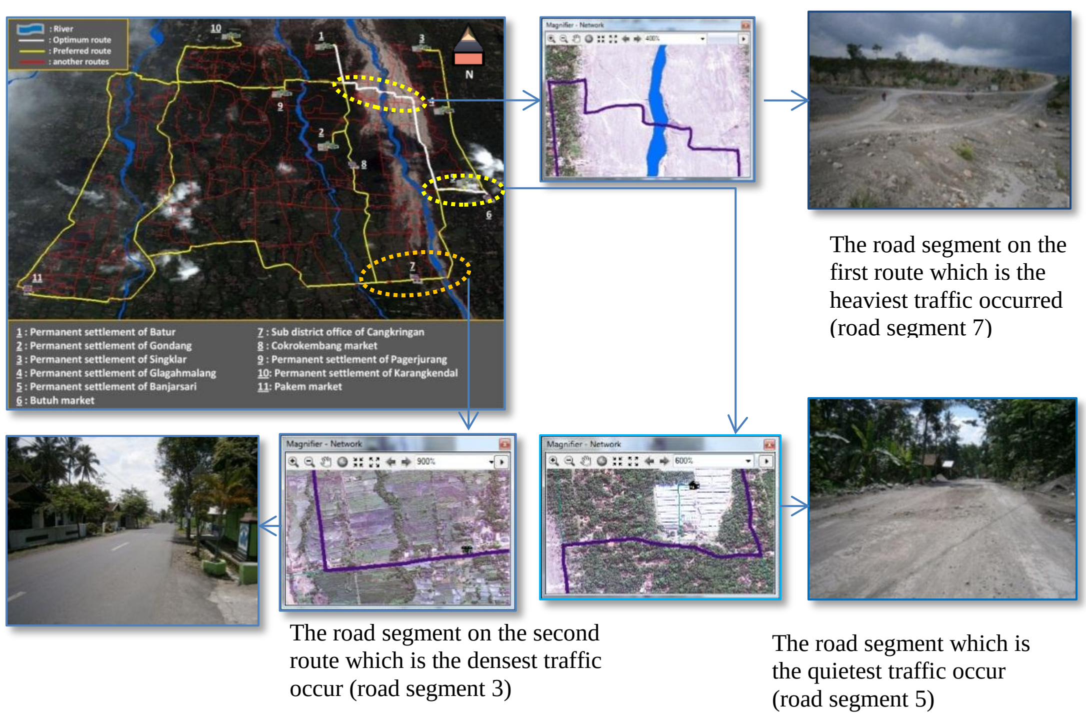


Figure 5-34. Optimum route from Batur to Butuh market market based on traffic factor for all days (Monday –Sunday), both in the morning and in the day.

The quietest traffic occurred on road segment 5 due to bad road quality (see Figure 5-35). Therefore, the first route will be good recommendation for local people who want to travel by considering traffic condition, but it is not recommended if they want to access by considering road quality, since the first route consists of many bad roads segment (on road segment of 7, 8 and 5). They consist of a lot of cracks, holes, less asphalt cover, dominated by volcanic sand and being muddy if raining comes.

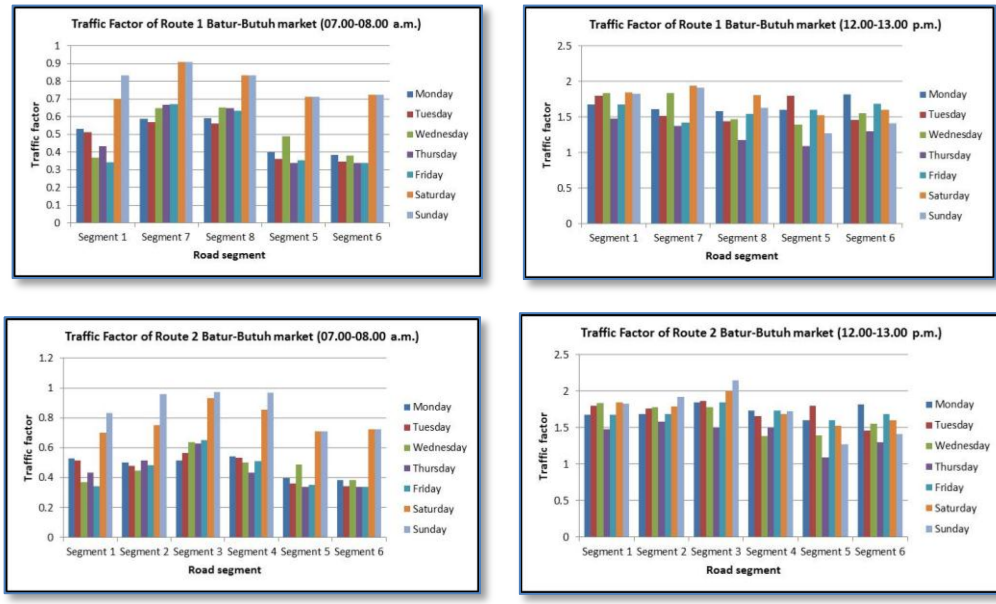


Figure 5-35. Traffic factor of routes from Batur to Butuh market

Road segment 7 is the densest traffic of the first route for all days; both in the morning and in the day (see Figure 5-35). It belonged to truck path, so that there were a lot of trucks carrying volcanic sand typically passing through it which its road width is narrow, so that traffic often came to be heavy.

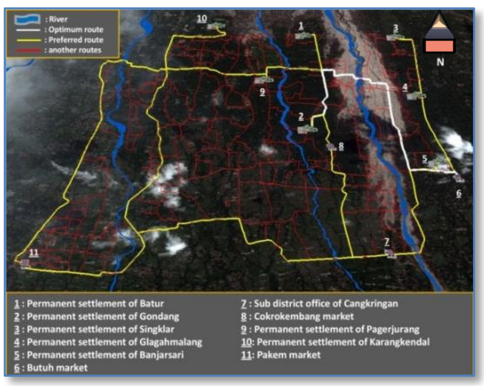
High traffic factor of the second route caused some road segments being jam in a given hours. Traffic jam was mostly caused by blockade of big size trucks, since that road width was narrow to take in those vehicles. Road segment 3 is the heaviest traffic of the second route, for all days both in the morning and in the day. That traffic was dominated by more various vehicles (not only by trucks). Not only as truck path, but that route is also as the main path of Cangkringan sub district where the sub district office is located in. On weekend (both in the morning and in the day), traffic factor on road segment 3 will reach a crest, so that traffic jam mostly occurred on those days (Saturday and Sunday)

According to the Figure 5-35, local people can access the optimum route much easily in the morning than in the day and even on Friday morning since that day has the lowest traffic factor through all road segments. In the day, optimum route can be accessed much easily on Thursday. That route is more difficult to be accessed on weekend (Saturday and Sunday), both in the morning and in the day due to holiday, so that mobility of people's activities will be more increased significantly than on weekday.

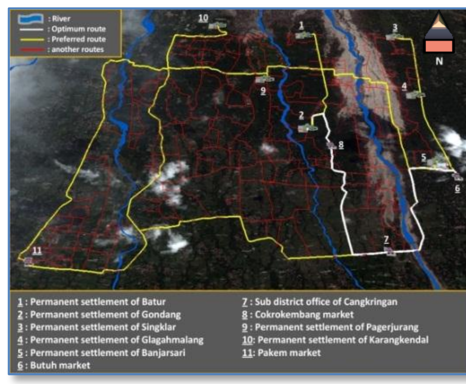
For local people who want to access the second route in the morning, it can be accessed much easily on Friday morning, since the traffic is quieter than other days. In the day, that route can be accessed much easily on Thursday, since mobility of people's activities was not as high as on other days.

5.2.4.2. Optimum route from Gondang to Butuh market by cost of traffic factor

Compared with optimum route of Batur-Butuh market, optimum route of Gondang-Butuh market (see Figure 5-36) in the morning in a week is more various (see Figure 5-37). In the morning (at 07.00-08.00 a.m.), on Monday, Wednesday, Thursday, and Friday, traffic condition on the second route is quieter than on the first route, so that it will be easier to be accessed. Only on Tuesday and weekend (Saturday and Sunday), traffic condition on that route will be heavier, so that on those days, the optimum route shifted to the first route.



The first route



The second route

Figure 5-36. Optimum routes from Gondang to Butuh market

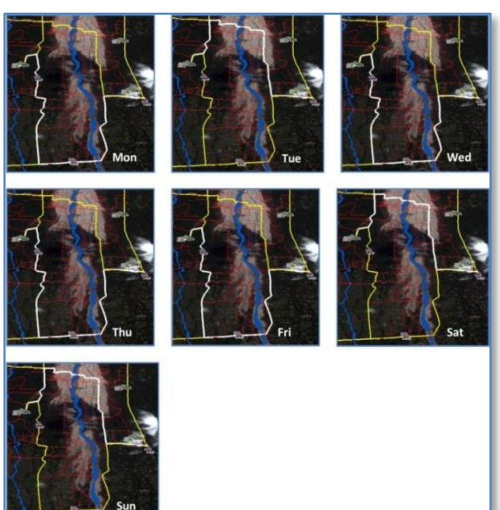


Figure 5-38. Optimum route from Gondang to Butuh market based on traffic factor for all days (Monday – Sunday), at 12.00-13.00 a.m.

Figure 5-37. Optimum route from Gondang to Butuh market based on traffic factor for all days (Monday –Sunday), at 07.00-08.00 a.m.

On Monday, Wednesday, Thursday, and Friday, people activities accessing the first route (including sand mining, going to the market and other places) tended to increase, so that traffic would be heavier than the second route and it became more difficult to be accessed on those days. Therefore, for local people who want to access from Gondang to Butuh market on those days, they are strongly recommended to access through on the second route which has quieter traffic. On Tuesday and weekend as holiday meant decreasing people's activities, traffic condition on the first route become quieter, so that it will be easier to be accessed, even number of trucks passing this route also decreased on those days.

In the day (12.00-13.00 p.m), quieter traffic on the first route caused it being easier to be accessed than the second one for all days (see Figure 5-38). At those hours, number of trucks passing the second route increased because of increasing people's activities which most local people work as sand miner. Due to imbalance between narrow road width and over number of trucks passing on it will cause traffic jam.

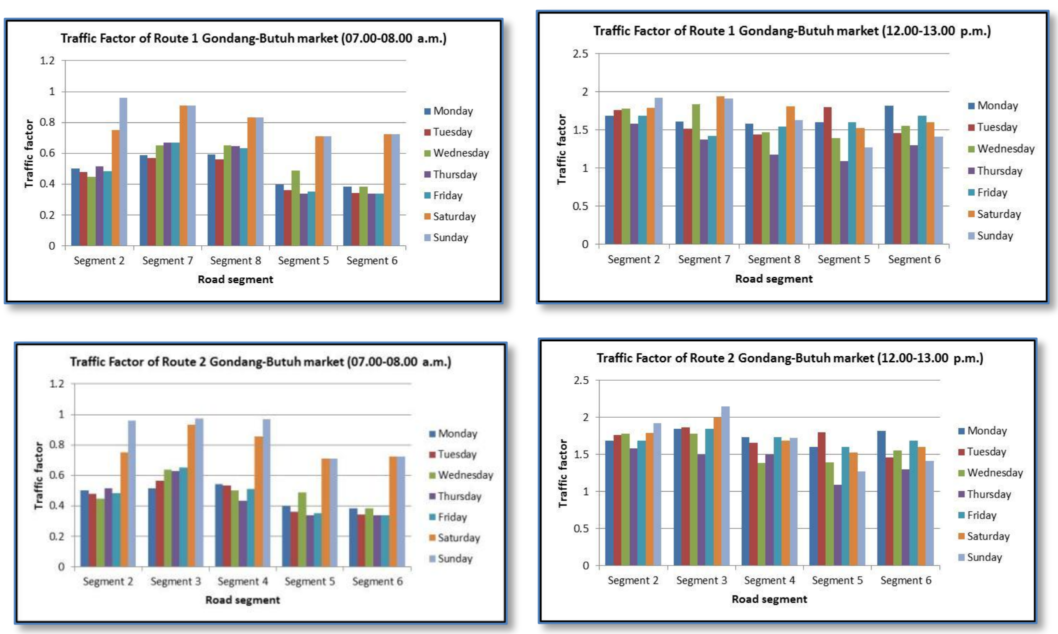


Figure 5-39. Traffic factor of routes from Gondang to Butuh market

Mostly, road segment 7 is the heaviest traffic of the first route (see Figure 5-39), since it was functioned as truck path, so that there were a lot of trucks typically travel through on road segment. Besides that, both narrow road and bad road condition made average vehicle speed being much slower, so that traffic jam would be occurred for a while.

The road segment 5 is the quietest traffic of the first route and the second route (see Figure 5-39), because of least number of vehicles passing through on it. On the second route, the road segment 3 was the road where the heaviest traffic occurred. As main road in this area, it becomes a path for most vehicles travel through on. In the day, traffic jam would be occurred for a while. On weekend (both in the morning and in the day), traffic factor on road segment 3 will culminate (see Figure 5-39), so that traffic jam mostly will be occurred on those days (Saturday and Sunday).

5.2.4.3. Optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office by cost of traffic factor

Optimum route accessing from Singlar, Glagahmalang, and Banjarsari to Sub district office for all days, both in the morning and in the day is located on the first route (see Figure 5-40) because of light traffic condition indicated with less number of vehicles passing it.

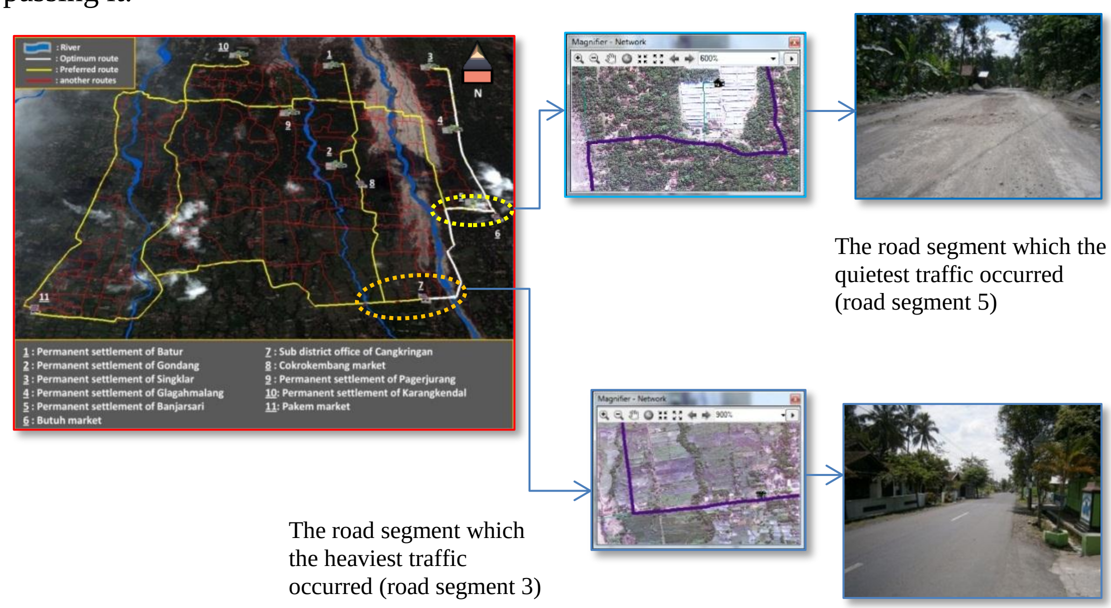
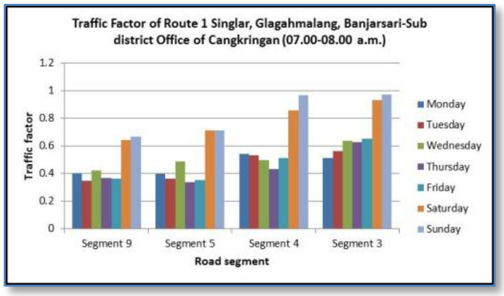


Figure 5-40. Optimum routes from Singlar, Glagahmalang, and Banjarsari to Sub district office based on traffic factor for all days (Monday-Sunday), both in the morning and in the day

The quietest traffic is located on road segment 5 (see Figure 5-41) which trucks and other vehicle types are rare to pass through on it. Most sand trucks passed through on road segment 8 and 9 as well they went to the sand mining places which were located in northern flank. Road segment 8 was mostly to be passed by trucks coming from Surakarta regency after passed through on road segment 4, whereas road segment 9 was mostly passed by trucks coming from Klaten regency.



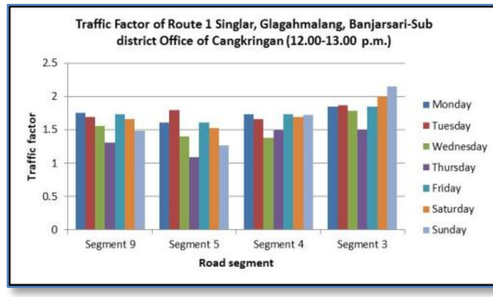


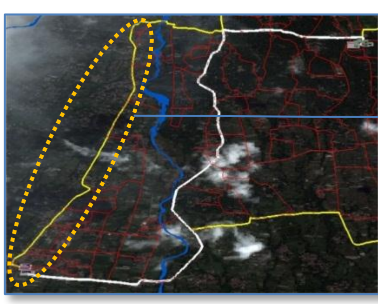
Figure 5-41. Traffic factor of routes from Singlar, Glagahmalang, and Banjarsari to Sub district office

Mostly, the densest traffic is located on road segment 3 for which sub district office of Cangkringan located in, for all days, both in the morning and in the day. Since its road width is narrow, traffic jam often occurred because of blockade of trucks, especially in the day. Those trucks passed through on this road crossing southern part of Gendol river for accessing to sand mining place. On weekend (both in the morning and in the day), the highest traffic factor of road segment 3 occurred, so that traffic jam mostly occurred on those days (Saturday and Sunday)

According to Figure 5-41, the optimum route can be accessed easily on Tuesday morning, because of less people's activities. In the day, local people can access easily the optimum route on Thursday. That route will be more difficult to be accessed on weekend (Saturday and Sunday), since the people's activities increased significantly because of holiday.

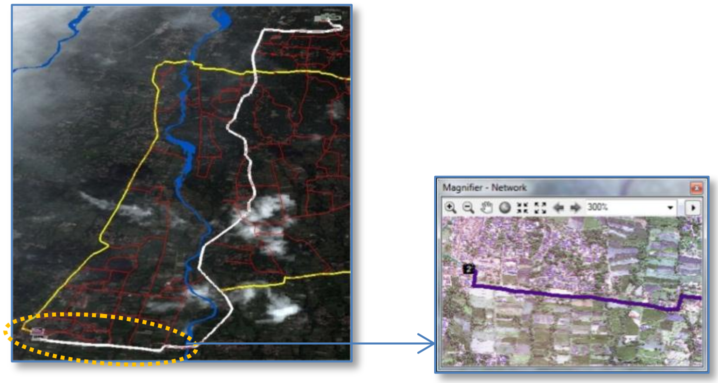
5.2.4.4. Optimum route from Pagerjurang and Karangkendal to Pakem market by cost of traffic factor

Both in the morning and in the day, the optimum route connecting from Pagerjurang and Karangkendal to Pakem market is located on the second route for all days (see Figure 5-42), because of light traffic, however the road quality is worse than the first route.



The road segment which the heaviest traffic occurred on the first route (road segment 14)

Figure 5-42. Optimum route from Pagerjurang and Karangkendal to Pakem market based on traffic factor for all days (Monday – Sunday), both in the morning and in the day.



The road segment which the heaviest traffic occurred on the second route (road segment 12)

Figure 5-42 (continued). Optimum route from Pagerjurang and Karangkendal to Pakem market based on traffic factor for all days (Monday –Sunday), both in the morning and in the day.

According to Figure 5-43, the heaviest traffic of the optimum route is located on road segment 12 because it belongs one of main roads in Cangkringan sub district and an alternative route for traveling to Surakarta regency. That is why that most vehicles passed through on this route to their given destination.

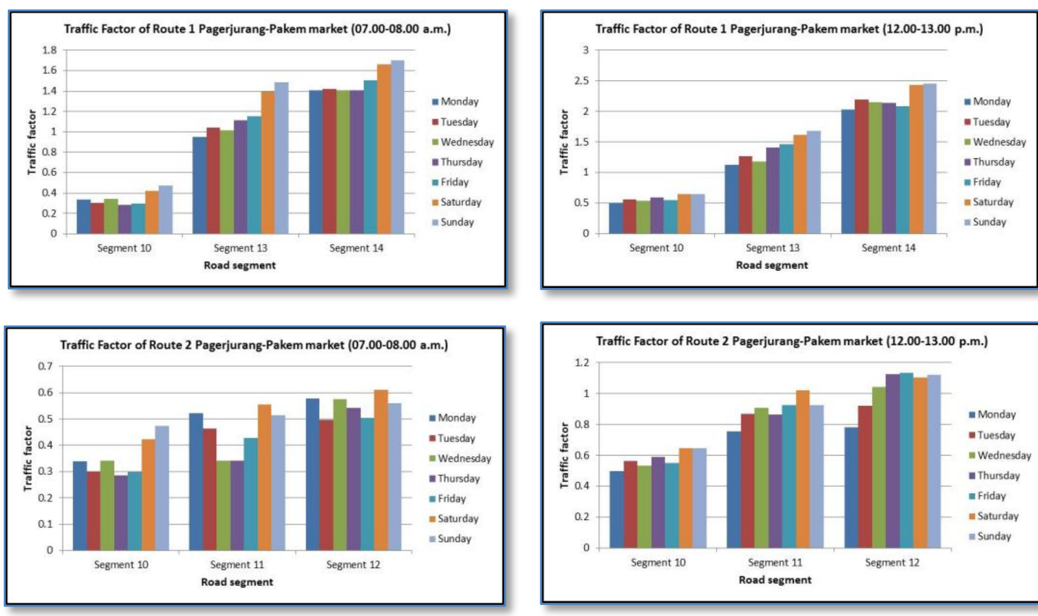


Figure 5-43. Traffic factor of routes from Pagerjurang to Pakem market.

Traffic condition on the road segment 14 (Collector road 1 Hargobinangun-Pakem Binangun and Another road Pakem Binangun) is the heaviest traffic of all road segments on the first route (see Figure 5-44). However, it is the best quality road of all road segments on this route, so that there are many vehicles that pass it, since it is easy to be accessed.

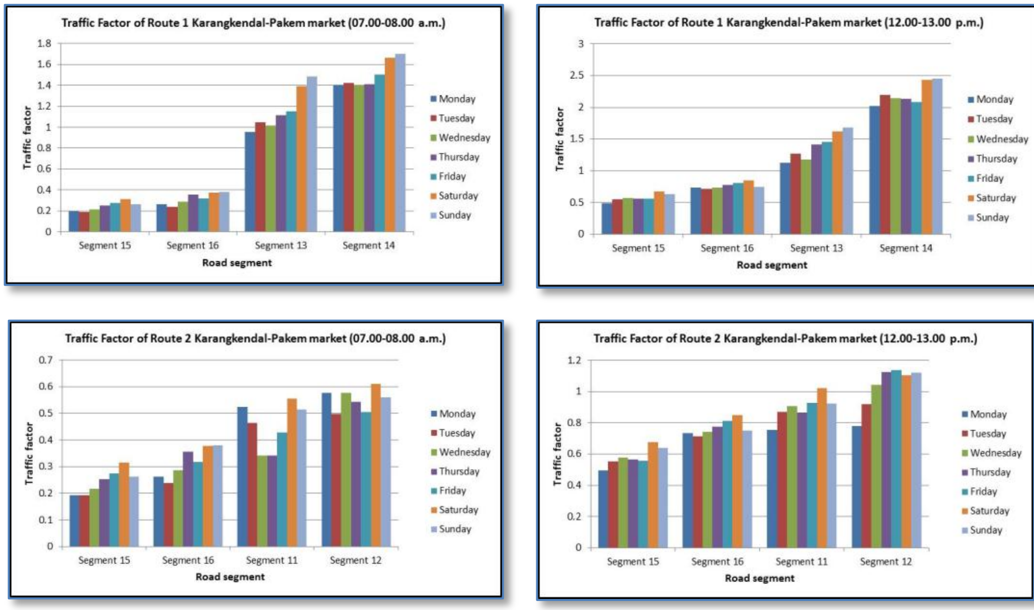


Figure 5-44. Traffic factor of routes from Karangkendal to Pakem market

According to Figure 5-43and Figure 5-44, in the morning, the optimum route can be accessed much easily on Thursday, since mobility of people's activities indicated with accumulation of traffic factor is the lowest of all days. In the day, the optimum route can be accessed much easily on Monday. On weekend, both in the morning and in the day, this route will be more difficult to be accessed since those days are full day. Even, the research area belonged to tourism object area, so that a lot of people having a holiday caused traffic being denser than on weekday. For local people who want to travel to Pakem market through the first route, they can go much easily on Monday. Road segments of the first route are tourism route, so that the traffic will be heavier on weekend or other off-days. Since Monday is not off-day, traffic of the roads will be quieter.

5.2.5. Optimum route by cost of travel time

If neutral travel time was meant as travel time without any impedance of traffic, so travel time here means travel time that was influenced by traffic condition of road segments. It was measured in the morning (at 07.00, 07.15, 07.30, and 07.45 a.m.) and in the day (at 12.00, 12.15, 12.30, and 12.45 p.m). The heavier traffic of road segment, the longer travel time will be taken. This analysis was addressed to know when a route could be easier to be accessed by local people.

5.2.5.1. Optimum route from Batur to Butuh market by cost of travel time

The optimum route of Batur-Butuh market is located on the first route for all days (see Figure 5-45), both in the morning and in the day. Travel time through on this route is shorter indicated by quieter traffic than on the second route.

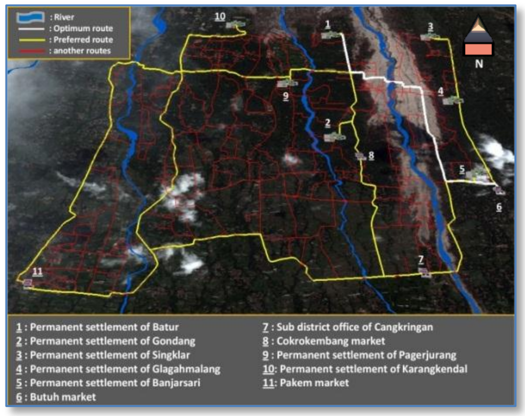


Figure 5-45. The optimum route from Batur to Butuh market by travel time for all days, both in the morning and in the day.

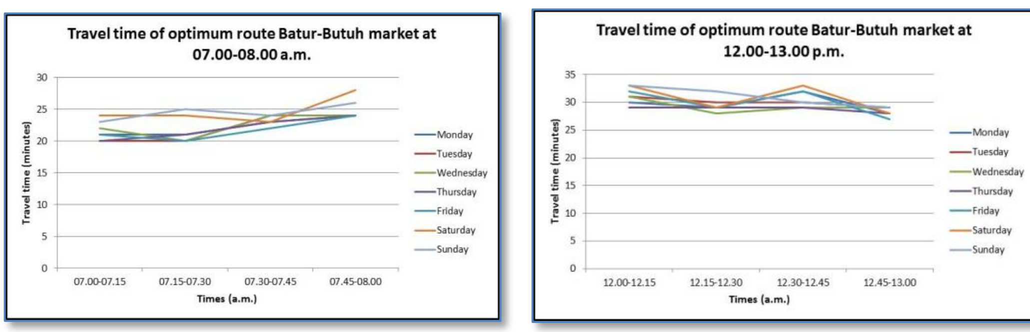


Figure 5-46. Travel time of optimum route from Batur to Butuh market

According to given hours of on weekday, mostly, the optimum route can be accessed much quickly at 07.15-07.30 a.m and at 12.15-12.30 p.m (see Figure 5-46), whereas on weekend, it can be accessed much quickly at 07.30-07.45 a.m on both Saturday and Sunday and at 12.15-12.30 only on Saturday and at 12.30-12.45 on Sunday. Travel time will be longer at 07.45-08.00 a.m on both weekday and weekend and at 12.00-12.15 p.m only on weekday. On weekend, in the day, travel time will be longer at 12.30-12.45 a.m. on Saturday and at 12.00-12.15 p.m. on Sunday. Weekend is holiday, so that mobility of local people’s activity commonly increased, even on the tourism route and truck path. Those accessibility times are reviewed in Table 5-4.

Table 5-4. Hours of the shortest travel time and the longest travel time of optimum route from Batur to Butuh market between on weekday and on weekend

The shortest travel time		The longest travel time	
Weekday	**Weekend**	**Weekday**	**Weekend**
07.15-07.30 a.m.	07.30-07.45 a.m	07.45-08.00 a.m.	07.45-08.00 a.m.
12.15-12.30 p.m.	12.15-12.30 p.m. (on Saturday); 12.30-12.45 p.m (on Sunday)	12.00-12.15 p.m.	12.30-12.45 p.m. (on Saturday); 12.00-12.15 p.m (on Sunday)

According to given days, on Friday morning and Thursday at noon, that travel time of optimum route will be shorter, because of less number of vehicles passing this route on both days than on other days (see Figure 5-47 and Figure 5-49). Travel time will be longer on weekend, both in the morning and in the day (Saturday and Sunday) because of more numbers of vehicles (truck, car, motorcycle) passing that route on weekend morning than that on weekday (see Figure 5-47 and Figure 5-49). Those accessibility times are reviewed in Table 5-5.

Table 5-5. Days of the shortest travel time and the longest travel time of optimum route from Batur to Butuh market

The shortest travel time	The longest travel time
Friday (in the morning/07.00-08.00 a.m.)	Weekend (Saturday and Sunday) (in the morning/07.00-08.00 a.m. and in the day/12.00-13.00 p.m.)
Thursday (in the day/12.00-13.00 p.m.)	

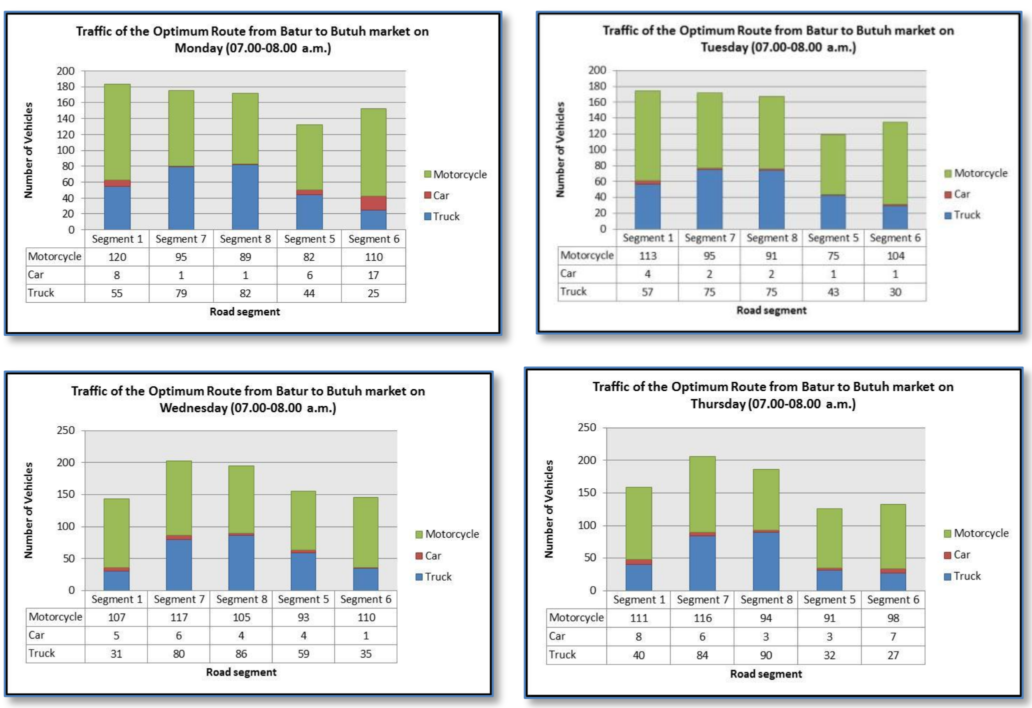


Figure 5-47. Traffic condition of the optimum route from Batur to Butuh market in the morning.

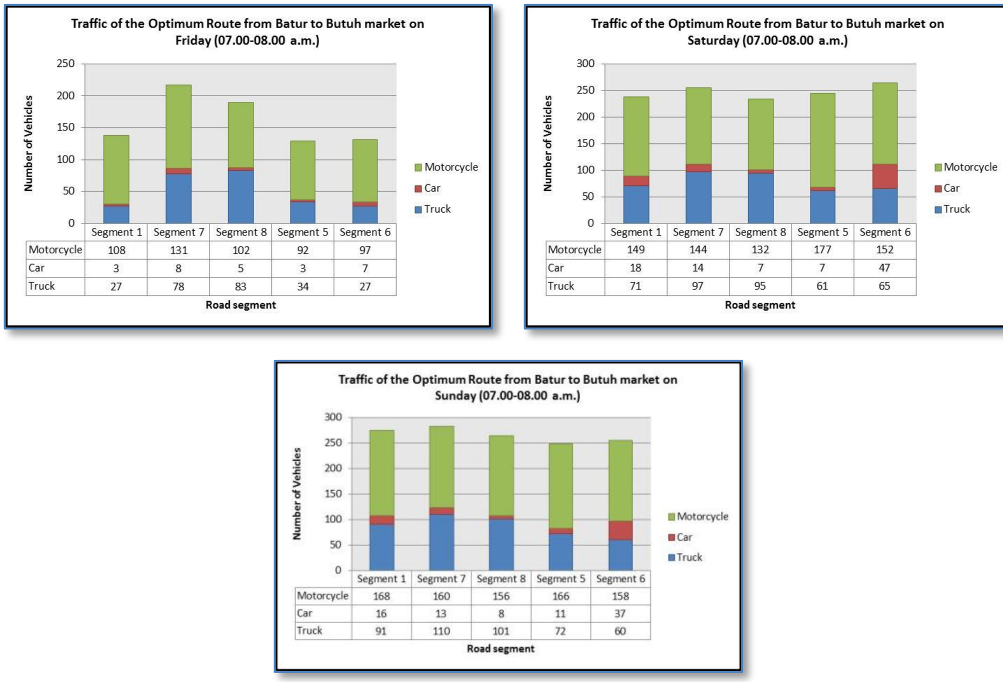
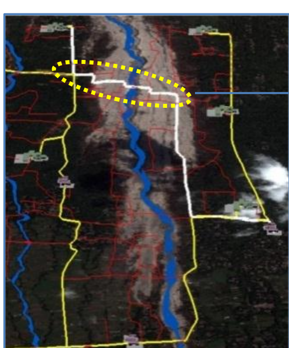


Figure 5-47 (continued). Traffic condition of the optimum route from Baturto Butuh market in the morning.

In the morning, on Monday and Tuesday, heavy traffic occurred on the road segment 1, whereas on Wednesday until Friday and Sunday, it occurred on the road segment 7 (see Figure 5-48). On Saturday, it occurred on road segment 6. All traffics for all days were dominated by motorcycle, since most local people used motorcycle as daily kind of transportation. For truck, it dominated traffic that occurred on the road segment 8, since it belongs to truck path. Of course, travel time will be longer on that road segment (sometimes, traffic jam occurred), since truck is more difficult to overtake than other vehicle types. For cars, they were more various on road segments in a week.



Road segment of 7: the heaviest traffic occurred on Wednesday-Friday and Sunday in the morning. In the day, it occurred on weekday

Fig 5-48. The heaviset traffic on the optimum route from Batur to Butuh market in the morning

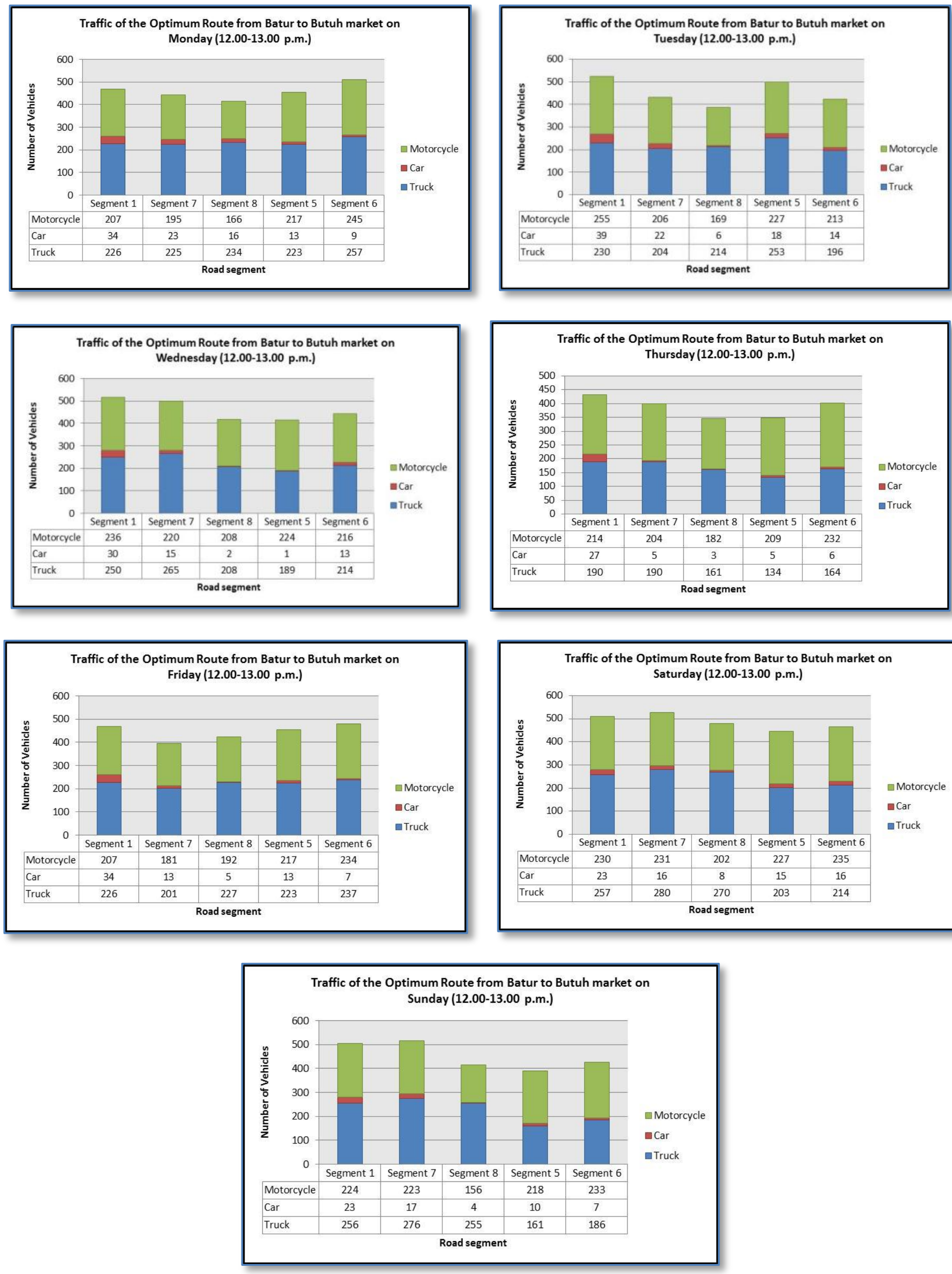


Figure 5-49. Traffic condition of the optimum route from Batur to Butuh market in the day.

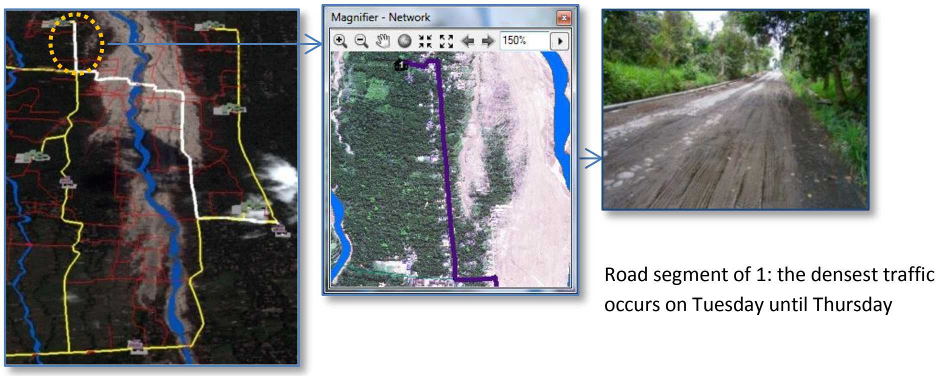


Figure 5-50. The heaviest traffic on the optimum route from Batur to Butuh market in the day

According to Figure 5.50, in the day, heavy traffic dominated by motorcycle occurred on road segment 1 which as truck path on Tuesday until Thursday. On Wednesday, there were more trucks passing this road segment than motorcycle. On Monday and Friday, heavy traffic dominated by truck and motorcycle occurred on road segment 6 for which Butuh market located in. On weekend (Saturday and Sunday), the traffic dominated by truck on road segment 7 will be heavy. Since those days were rush days of sand mining activity, so there were more trucks carrying volcanic sand on it. It indicates that on weekend in the day, travel time from Batur to Butuh market mostly will be longer than on weekday. Road segments which heaviest traffic occurred are represented in Table 5-6.

Table 5-6. Road segments of optimum route from Batur to Butuh market that the heaviest traffic occurred in the morning and in the day

In the morning (07.00-08.00 a.m.)		**In the day (12.00-13.00 p.m.)**	
Day	**The heaviest traffic**	**Day**	**The heaviest traffic**
Monday	Road segment 1	Monday	Road segment 6
Tuesday		Tuesday	Road segment 1
Wednesday	Road segment 7	Wednesday	
Thursday		Thursday	
Friday		Friday	Road segment 6
Saturday	Road segment 6	Saturday	Road segment 7
Sunday	Road segment 7	Sunday	

5.2.5.2. Optimum route from Gondang to Butuh market by cost of travel time

For all days, travel time from Gondang to Butuh market through on the first route (see Figure 5-51) is shorter than the second route, both in the morning and in the day. According to Figure 5.52, the shortest travel time mostly occurred at 07.15-07.30 a.m (on weekday); 07.30-07.45 a.m. (on weekend) and 12.15-12.30 p.m. (on weekday); 12.30-12.45 p.m. (on Sunday) and 12.45-13.00 p.m. (on Saturday). The longest travel time occurred at 07.45-08.00 a.m (on weekday and weekend); 12.00-12.15 p.m (both on weekday and on weekend); and 12.30-12.45 (only on Saturday). Table 5-7 shown also those times.

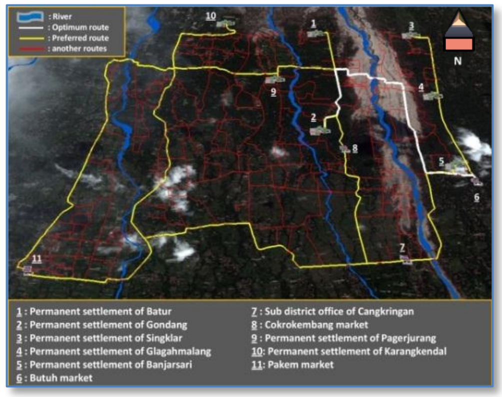


Figure 5-51. The optimum route from Gondang to Butuh market by travel time for all days, both in the morning and in the day.

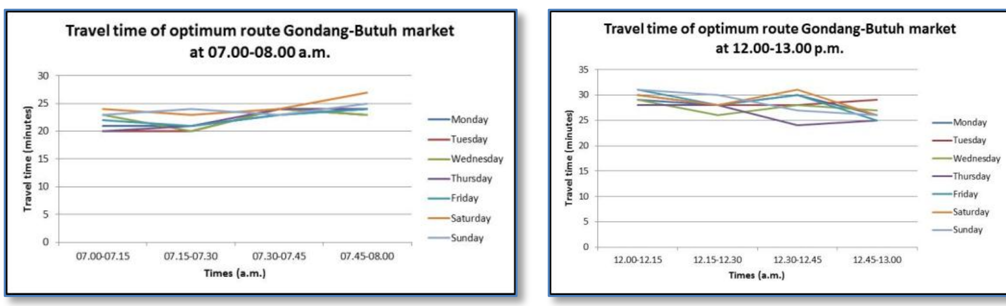


Figure 5-52. Travel time of optimum route from Gondang to Butuh market.

Table 5-7. Hours of the shortest travel time and the longest travel time of optimum route from Gondang to Butuh market between on weekday and on weekend

The shortest travel time		The longest travel time	
Weekday	**Weekend**	**Weekday**	**Weekend**
07.15-07.30 a.m.	07.30-07.45 a.m	07.45-08.00 a.m.	07.45-08.00 a.m.
12.15-12.30 p.m. 12.45-13.00 p.m.	12.30-12.45 p.m. (on Sunday); 12.45-13.00 p.m. (on Saturday)	12.00-12.15 p.m;	12.00-12.15 p.m; 12.30-12.45 p.m. (only on Saturday)

According to given days, travel time of optimum route will be shorter on Friday morning and Thursday at noon, because of less numbers of vehicles on both days than that on other days (see Figure 5-53 and Figure 5-55). On weekend, both in the morning and in the day, travel time will be longer (Saturday and Sunday) (see Figure 5.52) since there were more numbers of vehicles (5-53 and Figure 5-55).

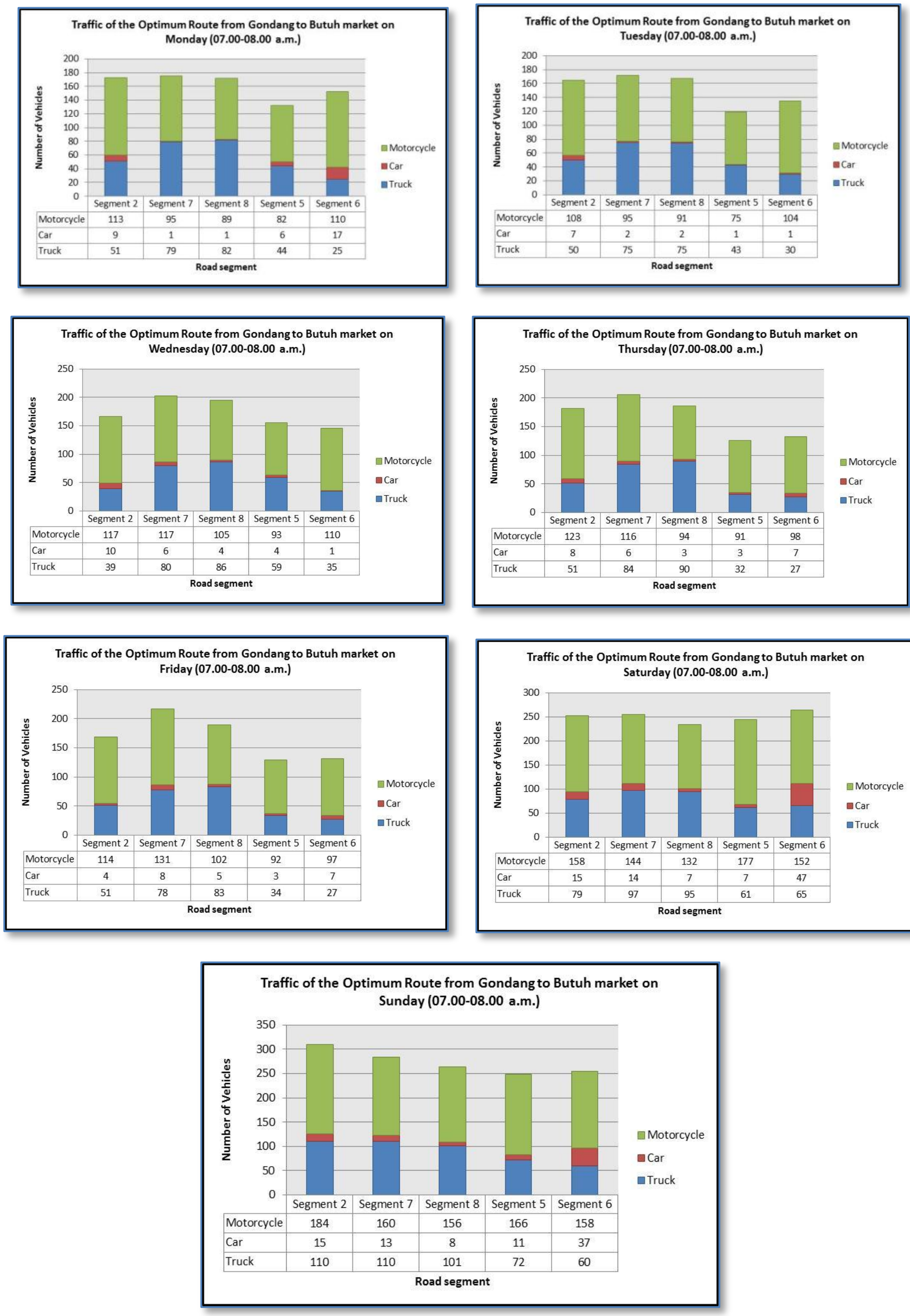


Figure 5-53. Traffic condition of the optimum route from Gondang to Butuh market in the morning.

Table 5-8. Days of the shortest travel time and the longest travel time of optimum route from Gondang to Butuh market

The shortest travel time	The longest travel time
Friday (in the morning/07.00-08.00 a.m.)	Weekend (Saturday and Sunday) (in the morning/07.00-08.00 a.m. and in the day/12.00-13.00 p.m.)
Thursday (in the day/12.00-13.00 p.m.)	

In the morning, on Monday until Friday, heavy traffic occurred on the road segment 7 which is functioned as truck path (see Figure 5-54). On Saturday and Sunday, heavy traffic shift to the road segment 6 and road segment 2. Since travel time was influenced by traffic condition, suspected road segments could be investigated as main cause of longer travel time of that route on a given day.

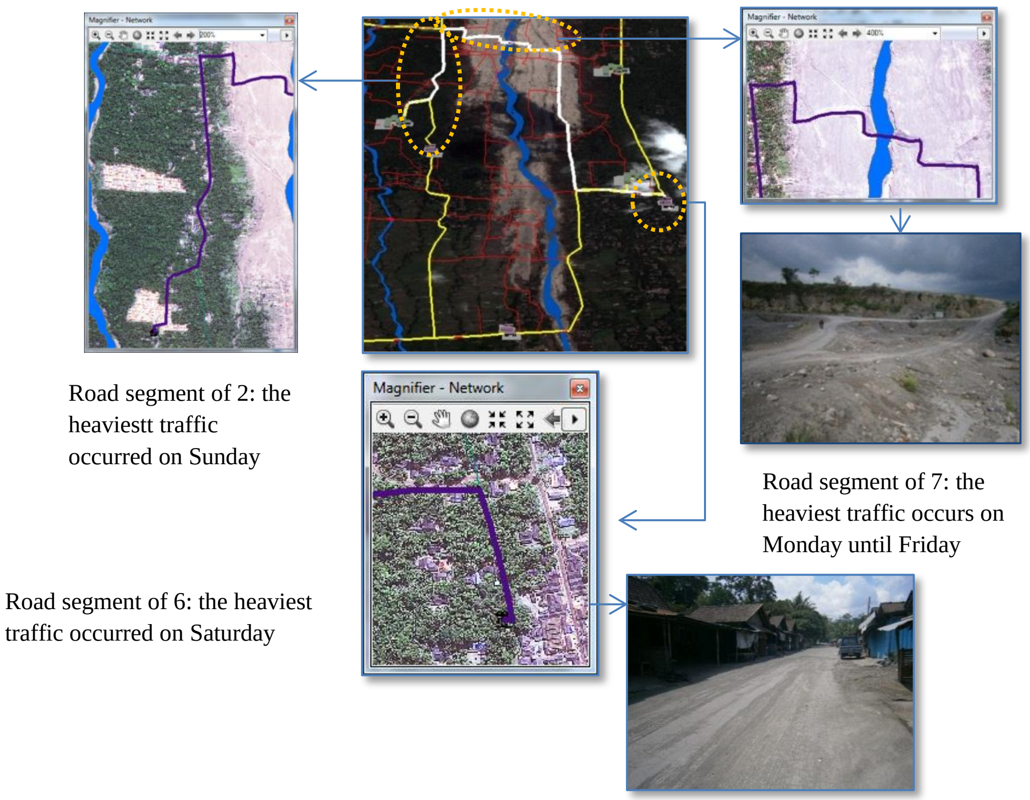


Figure 5-54. The heaviest traffic on the optimum route from Gondang to Butuh market in the morning

The traffic condition was also influenced by kind of transportation. For example, a lot of trucks passing a given road segment would more cause longer travel time than a lot of motorcycles and cars. In a week, road segments of that optimum route were mostly dominated by motorcycle. Trucks mostly dominated on the road segment 8 (see Figure 5-53 and Figure 5-55). The number of car tended to be various on road segments of that route, but car was rare on road segment 8 since this segment is dirty road, so that the car was difficult to pass.

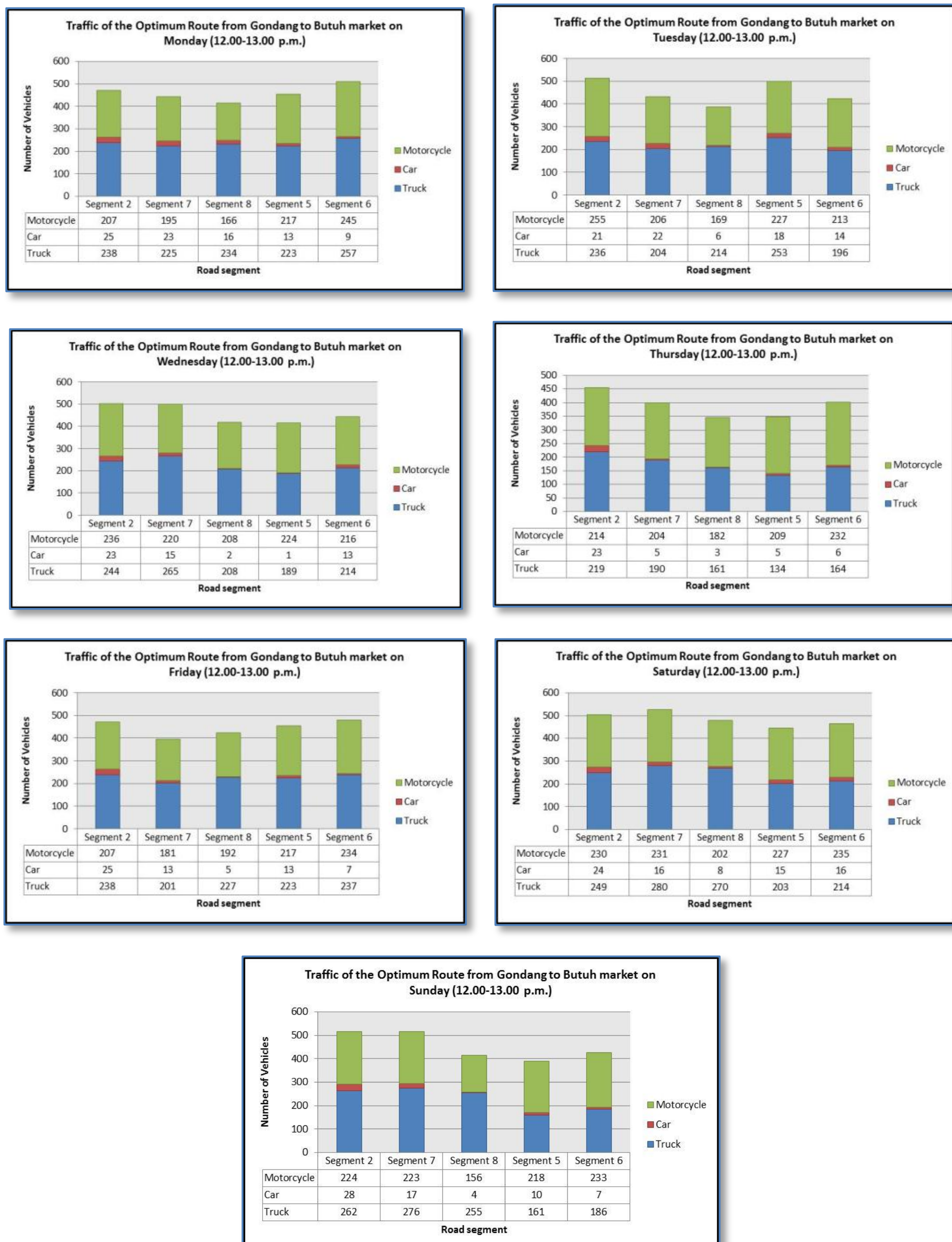


Figure 5-55. Traffic condition of the optimum route from Gondang to Butuh market in the day.

Table 5-9 represents that in the day, Tuesday until Friday and Sunday, heavy traffic occurred on road segment 2 (see Figure 5-56). As main route for trucks to access to sand mining place, so that there were many trucks along this road segment. Both

Road segment 6 and road segment 7 are the segments which heavy traffic occurred on Monday and Saturday, respectively (see Figure 5-56).

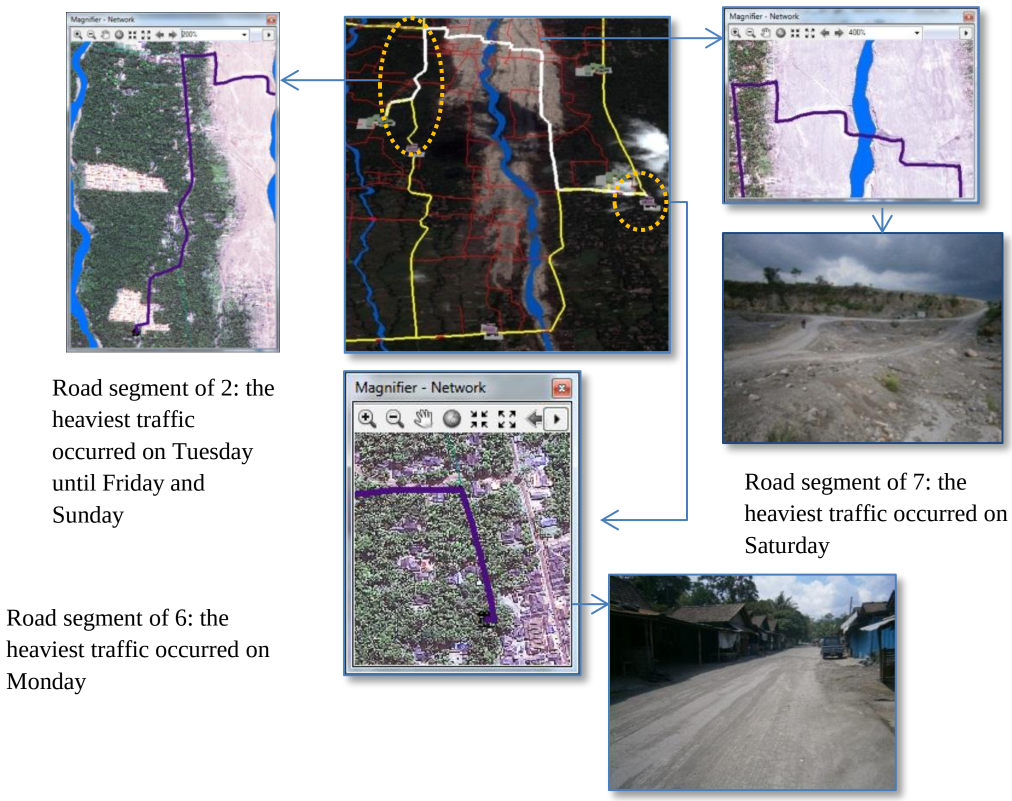


Figure 5-56. The heaviest traffic on the optimum route from Gondag to Butuh market in the day

Table 5-9.Road segments of optimum route from Gondang to Butuh market that the heaviest traffic occurred in the morning and in the day

<table>
<tr><th colspan="2">In the morning (07.00-08.00 a.m.)</th><th colspan="2">In the day (12.00-13.00 p.m.)</th></tr>
<tr><th>Day</th><th>The heaviest traffic</th><th>Day</th><th>The heaviest traffic</th></tr>
<tr><td>Monday</td><td rowspan="5">Road segment 7</td><td>Monday</td><td>Road segment 6</td></tr>
<tr><td>Tuesday</td><td>Tuesday</td><td rowspan="4">Road segment 2</td></tr>
<tr><td>Wednesday</td><td>Wednesday</td></tr>
<tr><td>Thursday</td><td>Thursday</td></tr>
<tr><td>Friday</td><td>Friday</td></tr>
<tr><td>Saturday</td><td>Road segment 6</td><td>Saturday</td><td>Road segment 7</td></tr>
<tr><td>Sunday</td><td>Road segment 2</td><td>Sunday</td><td>Road segment 2</td></tr>
</table>

5.2.5.3. Optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office of Cangkringan by cost of travel time

Travel time from Singlar, Glagahmalang, and Banjarsari to Sub district office is shorter through on the first route (see Figure 5-57) in a week, both in the morning and in the day. Figure 5-58 inform that the shortest travel time occurred at 07.15-07.30 a.m, and 12.15-12.30 p.m on both weekday and weekend, whereas the longest travel time occurred at 07.45-08.00 a.m (only for on weekday and Saturday); 07.00-07.15 (for Sunday) and 12.00-12.15 p.m both on weekday and weekend . These times are represented also in Table 5.10.

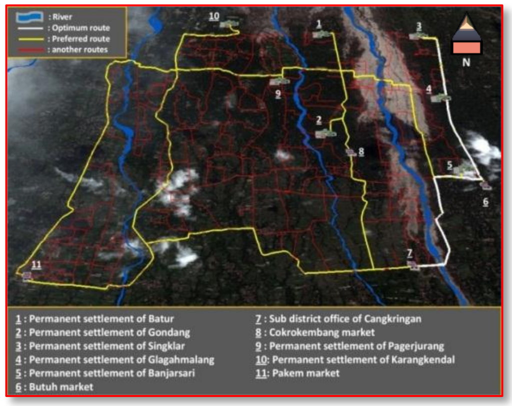


Figure 5-57. The optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office of Cangkringan by travel time for all days, both in the morning and in the day.

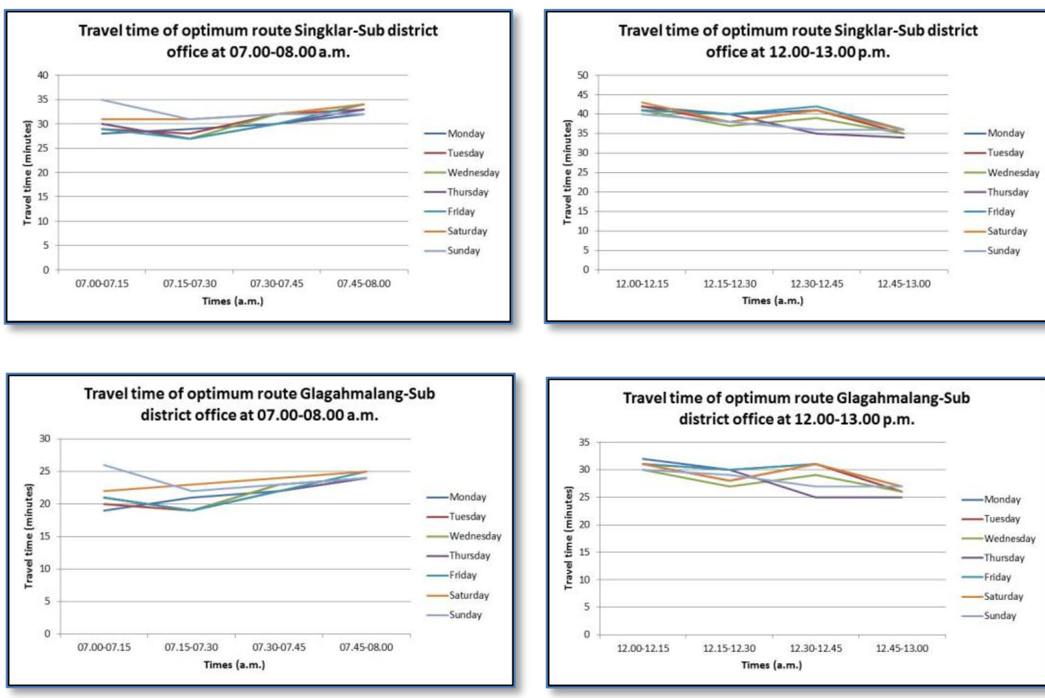
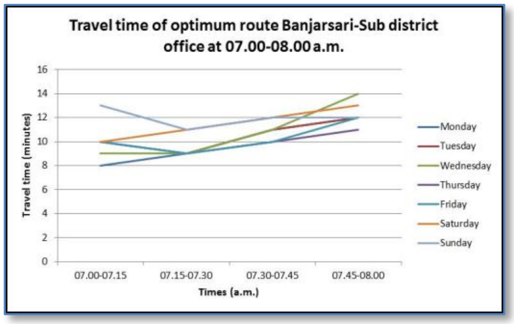


Figure 5-58. Travel time of optimum routes from Singlar, Glagahmalang, Banjarsari to Sub district office



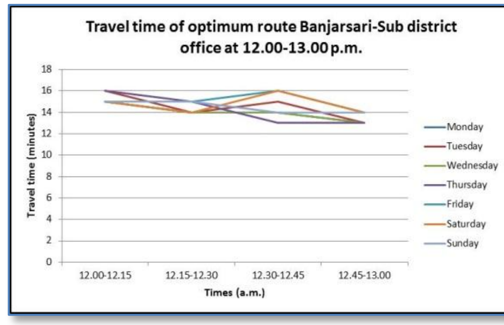


Figure 5-58 (continued). Travel time of optimum routes from Singlar, Glagahmalang, Banjarsari to Sub district office

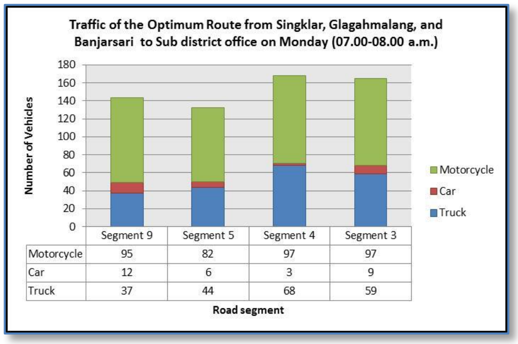
Table 5-10. Hours of the shortest travel time and the longest travel time of optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office between on weekday and on weekend

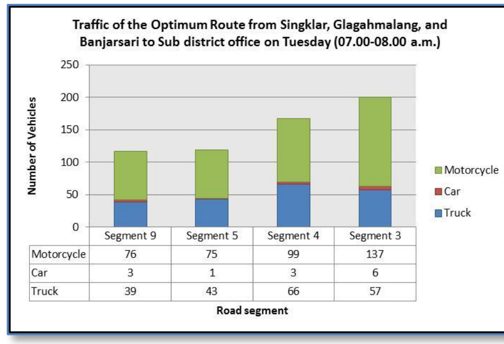
The shortest travel time		**The longest travel time**	
Weekday	**Weekend**	**Weekday**	**Weekend**
07.15-07.30 a.m.	07.15-07.30 a.m.	07.45-08.00 a.m.	07.45-08.00 a.m. (on Saturday); 07.00-07.15 a.m. (on Sunday)
12.15-12.30 p.m.	12.30-12.45 p.m.	12.00-12.15 p.m;	12.00-12.15 p.m

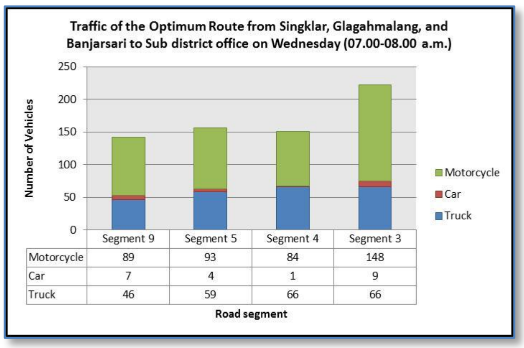
According to given days, the shortest travel time will be reached on Monday morning and on Thursday at noon, whereas the longest travel time often occurred on weekend (see Table 5-11). On Monday morning and Thursday at noon, number of vehicles passing this route will be at least, whereas on weekend (Saturday and Sunday), they will be at most (see Figure 5-59 and Figure 5-60). On weekend, traffic will be heavy because of holiday. On those days, sometimes traffic jam occurred that it came from a lot of trucks.

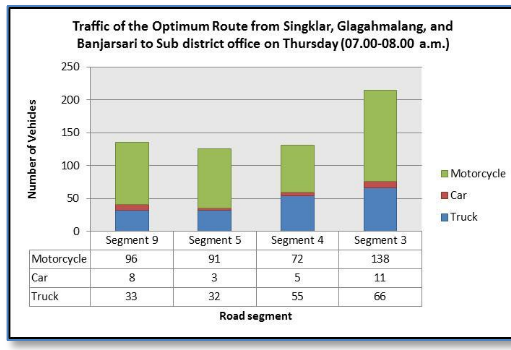
Table 5-11. Days of the shortest travel time and the longest travel time of optimum route from from Singlar, Glagahmalang, and Banjarsari to Sub district office

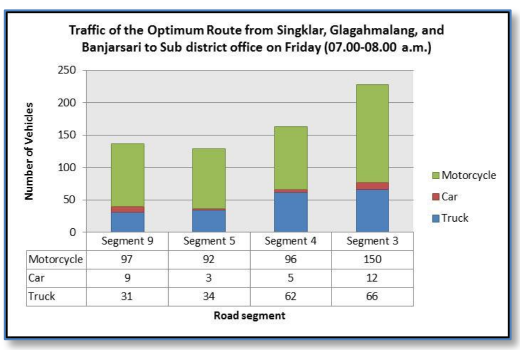
The shortest travel time	**The longest travel time**
Monday (in the morning/07.00-08.00 a.m.)	Weekend (Saturday and Sunday) (in the morning/07.00-08.00 a.m. and in the day/12.00-13.00 p.m.)
Thursday (in the day/12.00-13.00 p.m.)	

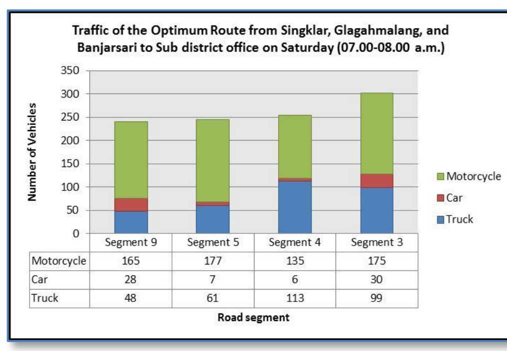












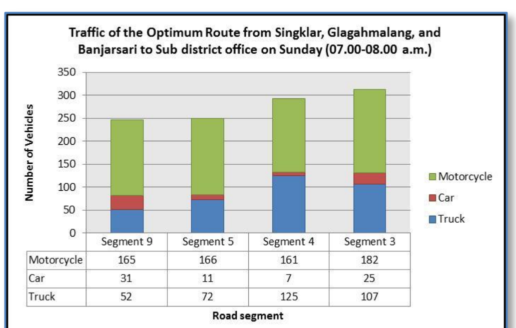
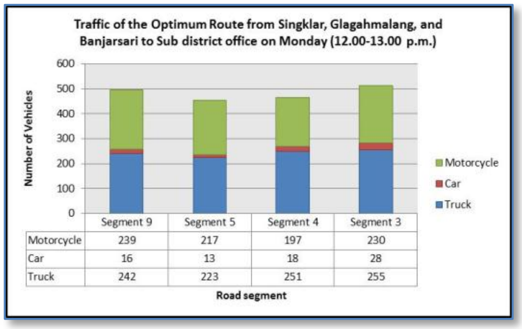
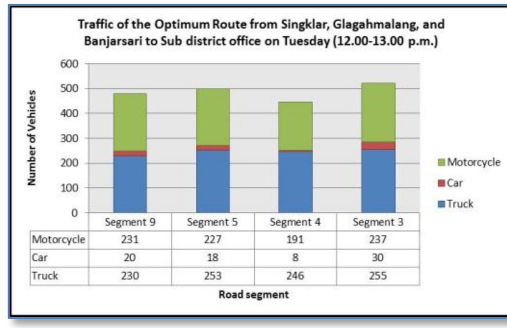
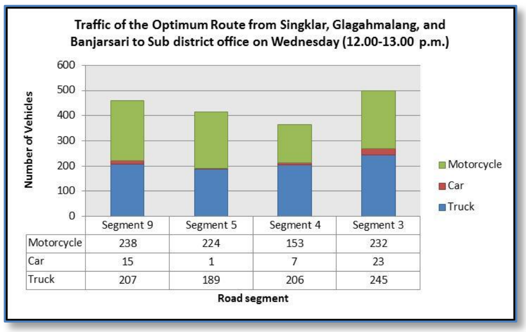
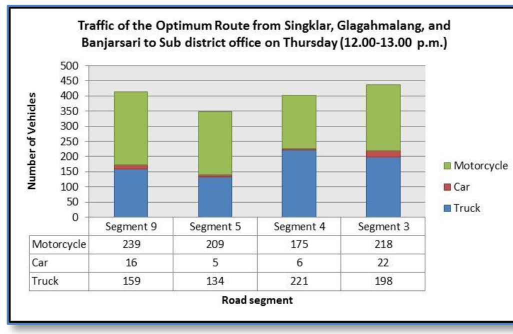


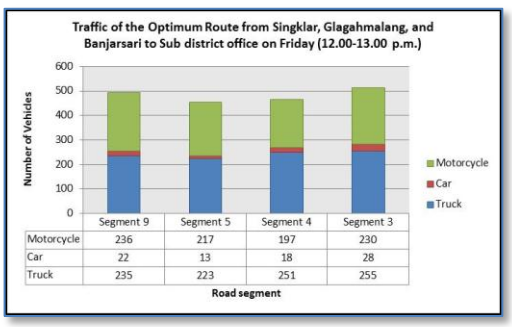
Figure 5-59. Traffic of the optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office in the morning

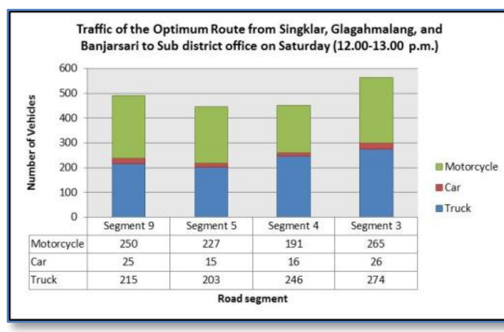












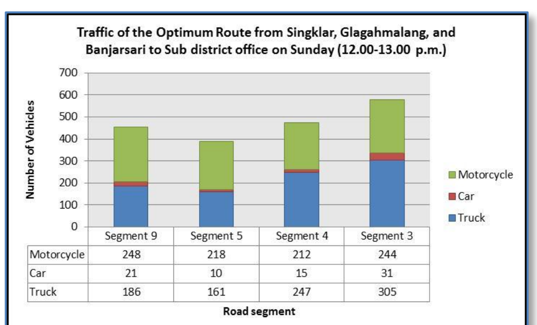


Figure 5-60. Traffic condition of the optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office in the day

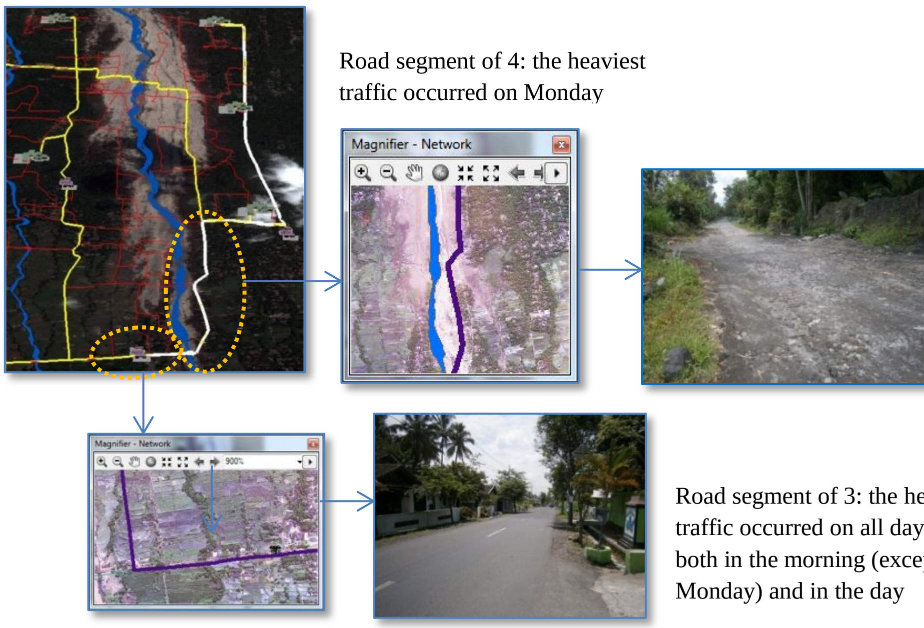


Figure 5-61. The heaviest traffic on the optimum route from Singklar, Glagahmalang, and Banjarsari to Sub district office

Table 5-12 inform that heavy traffic for all days (except Monday morning) in the morning and in the day mostly occurred on the road segment 3 as shown in Figure 5-61 which is main road segment of Cangkringan. In a week, traffic on this segment is always heavy which was dominated by trucks and motorcycle coming from other regencies, such as Klaten and Surakarta. Meanwhile, the highest traffic on Monday morning occurred on road segment 4. On this, besides a lot of vehicles passed this segment, road quality was worse also, so that vehicles speed always decreased. As consequence, traffic jam occurred at a given times, especially in the day, due to more number of vehicles than in the morning.

Table 5-12. Road segments of optimum route from Singlar, Glagahmalang, and Banjarsari to Sub district office that the heaviest traffic occurred in the morning and in the day

In the morning (07.00-08.00 a.m.)		**In the day (12.00-13.00 p.m.)**	
Day	**The heaviest traffic**	**Day**	**The heaviest traffic**
Monday	Road segment 4	Monday	
Tuesday		Tuesday	
Wednesday		Wednesday	
Thursday	Road segment 3	Thursday	Road segment 3
Friday		Friday	
Saturday		Saturday	
Sunday		Sunday	

5.2.5.4. Optimum route from Pagerjurang to Pakem market by cost of travel time

The optimum route from Pagerjurang to Pakem market is located on the second route for all days; both in the morning and in the day because of quieter traffic than that on the first route (see Figure 5-62). Table 5-13 and Figure 5-63 show that the optimum route can be accessed much quickly at 07.00-07.15 a.m (on weekday); 07.30-07.45 (on weekend) and 12.30-12.45 p.m (on weekday and weekend). Travel times on those days are the quickest time from Pagerjurang to Pakem maret through on the optimum route. Meanwhile the longest travel time occurs at 07.15-07.00 a.m (on weekday and weekend); at 12.00-12.15 p.m (on weekday and Sunday); and at 12.15-12.30 p.m and 12.45-13.00 p.m (only on Saturday).

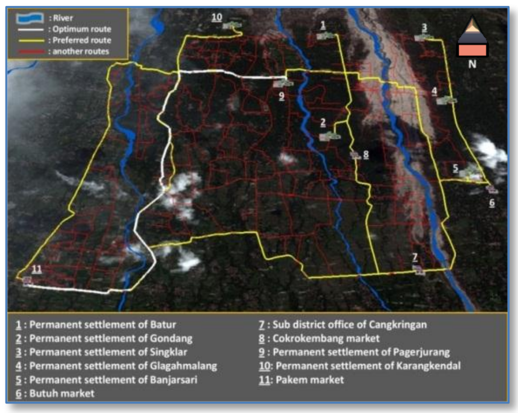


Figure 5-62. The optimum route from Pagerjurang to Pakem market by travel time for all days, both in the morning and in the day.

Table 5-13. Hours of the shortest travel time and the longest travel time of optimum route from Pagerjurang to Pakem market between on weekday and on weekend

The shortest travel time		**The longest travel time**	
Weekday	**Weekend**	**Weekday**	**Weekend**
07.00-07.15 a.m.	07.30-07.45 a.m.	07.15-07.30 a.m.	07.45-08.00 a.m. (on Saturday); 07.00-07.15 a.m. (on Sunday)
12.30-12.40 p.m.	12.30-12.45 p.m.	12.00-12.15 p.m;	12.00-12.15 p.m (on Sunday); 12.15-12.30 p.m and 12.45-13.00 p.m (on Saturday)

In the same Figure, in the morning, mostly the quickest travel time will be reached on Wednesday, whereas in the day, it will be occurred on Thursday. Both in the morning and in the day, travel time will be longer on weekend. Table 5-14 represents that on Wednesday and Thursday, mostly traffic indicated with number of vehicles tended to be quieter than that on other days, so that travel time will be shorter (see Figure 5-64 and Figure 5.65). On weekend, there were more numbers of vehicles than that on weekday. Compared with the route of Batur, Gondang, and Singlar, vehicles types passing the route of Pagerjurang-Pakem market was absolutely dominated by motorcycle, both in the morning and in the day, and it was very rare for trucks to pass this route since that route was not as truck path, but was functioned as tourism route.

Table 5-14. Days of the shortest travel time and the longest travel time of optimum route from Pagerjurang to Pakem market

The shortest travel time	**The longest travel time**
Wednesday (in the morning/07.00-08.00 a.m.)	Weekend (Saturday and Sunday) (in the morning/07.00-08.00 a.m. and in the day/12.00-13.00 p.m.)
Thursday (in the day/12.00-13.00 p.m.)	

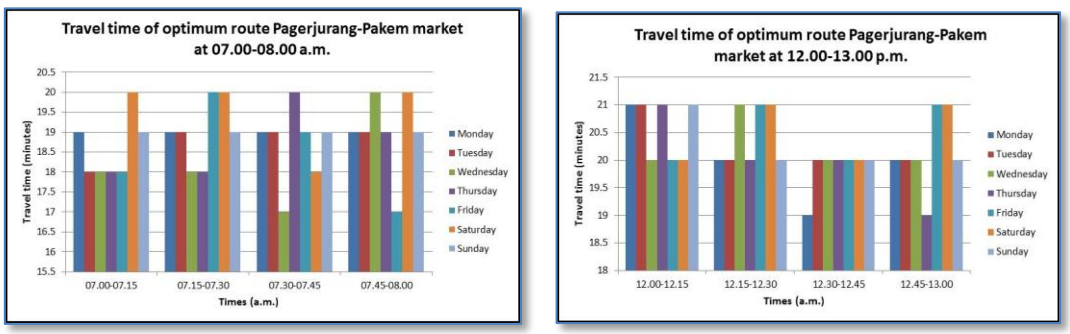
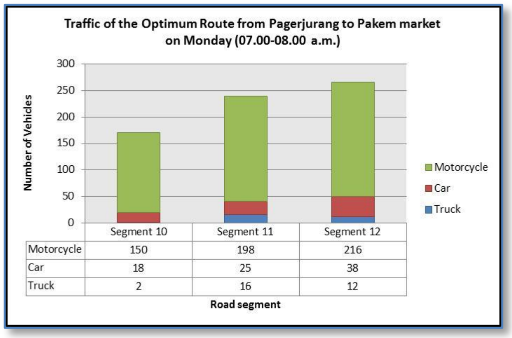
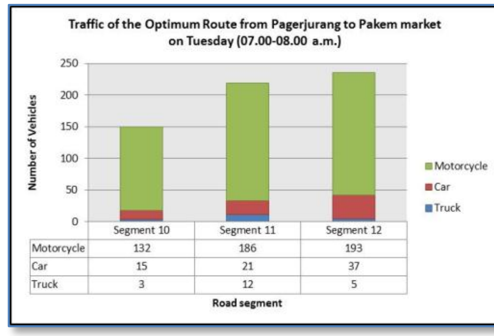
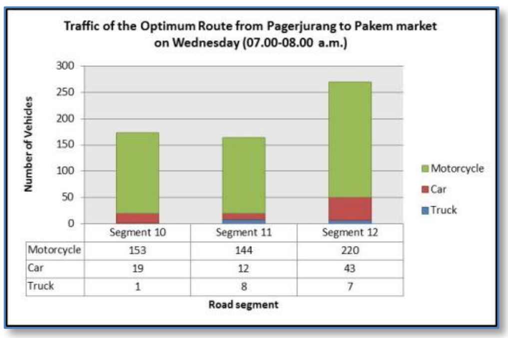
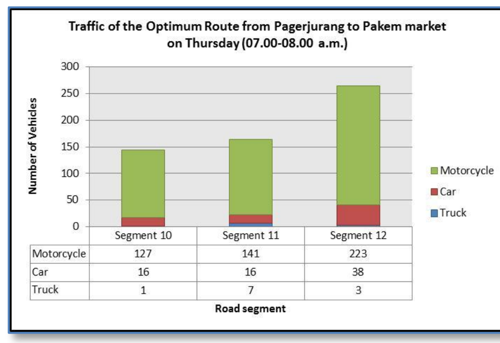


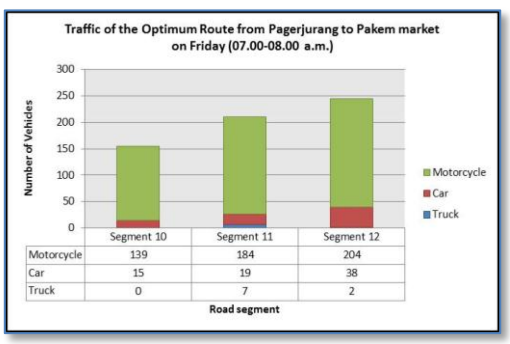
Figure 5-63 Travel time of optimum route from Pagerjurang to Pakem market

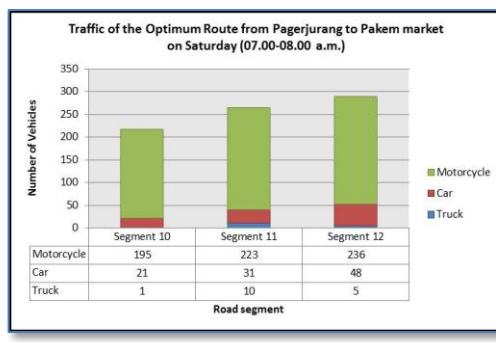












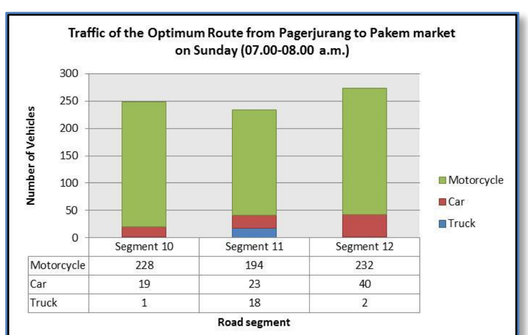
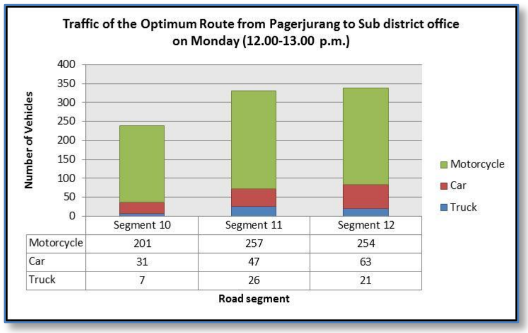
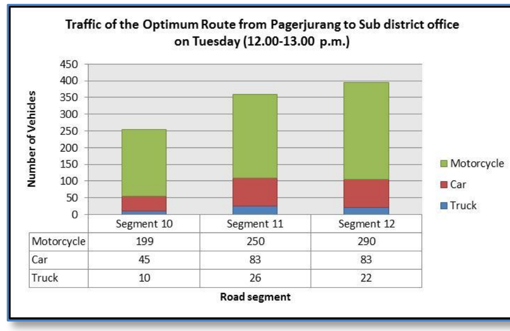
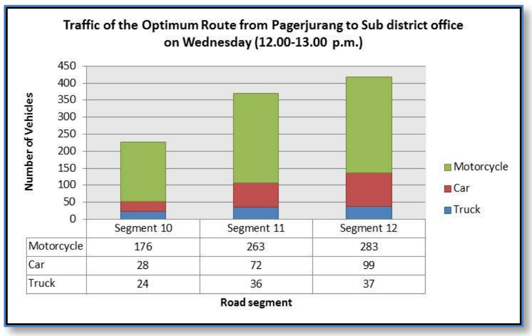
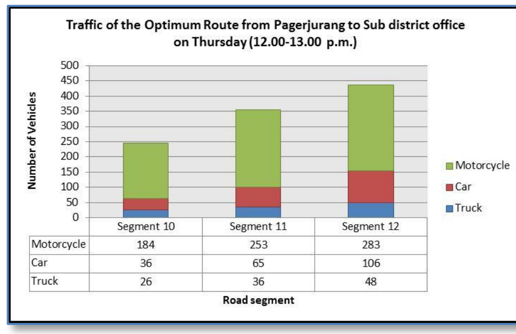


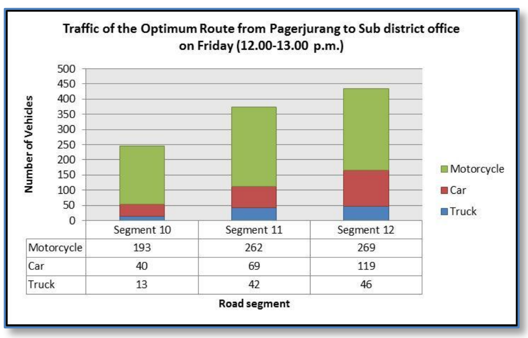
Figure 5-64. Traffic condition of the optimum route from Pagerjurang to Pakem market in the morning

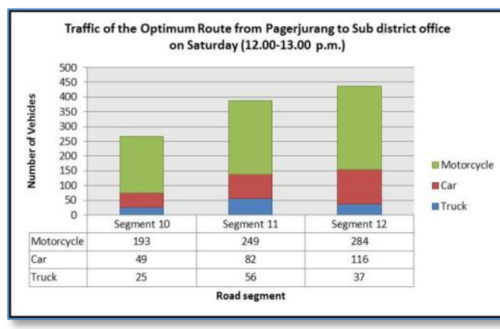












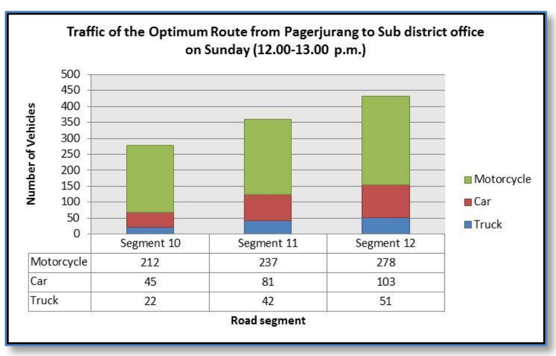


Figure 5-65. Traffic condition of the optimum route from Pagerjurang to Pakem market in the day

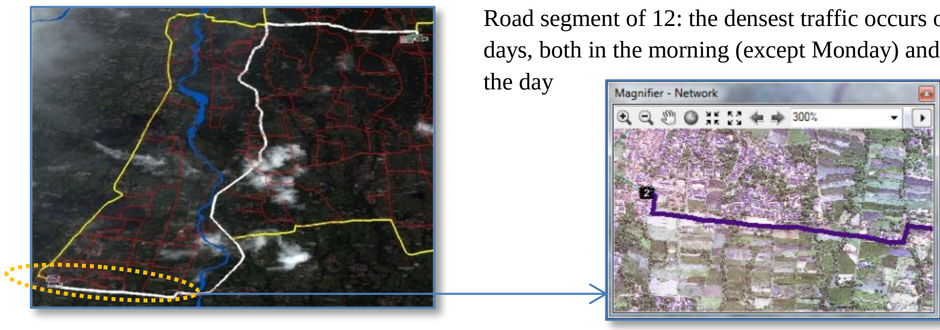


Figure 5-66. The heaviest traffic on the optimum route from Pagerjurang to Pakem market

Both in the morning and in the day, as shown in Figure 5-66, the heaviest traffic occurred on road segment 12 (see Table 5-15) since it is the one of main roads connecting between Pakem sub district to Cangkringan sub district. There were a lot of vehicles that travelled through on this route. Even, this route was used by some vehicles to access to Surakarta regency since it was an alternative route. Road segment that most sand trucks coming from Surakarta regency passed is located on road segment of 11 since the alternative routes for accessing to Surakarta regency is continuation from that road segment. They used it to come and go from Surakarta regency to Cangkringan sub district to carry volcanic sand.

Table 5-15. Road segments of optimum route from Pagerjurang to Pakem market that the heaviest traffic occurred in the morning and in the day

In the morning (07.00-08.00 a.m.)		**In the day (12.00-13.00 p.m.)**	
Day	**The heaviest traffic**	**Day**	**The heaviest traffic**
Monday	Road segment 12	Monday	Road segment 12
Tuesday		Tuesday	
Wednesday		Wednesday	
Thursday		Thursday	
Friday		Friday	
Saturday		Saturday	
Sunday		Sunday	

5.2.5.4. Optimum route from Karangkendal to Pakem market by cost of travel time

The optimum route from Karangkendal to Pakem market caused by light traffic as shown in Figure 5-67 is similar with that from Pagerjurang to Pakem market. According to Figure 5-68, the shortest travel time can be reached at 07.00-07.15 (on weekday); at 07.30-07.45 a.m. (on weekend) and 12.30-12.45 p.m. (both on weekday and weekend). Meanwhile, the longest travel time will be occur at 07.45-08.00 a.m. (both on weekday and weekend) and 12.00-12.15 (on weekday); 12.15-12.30 (on weekend) (see Table 5-16 also).

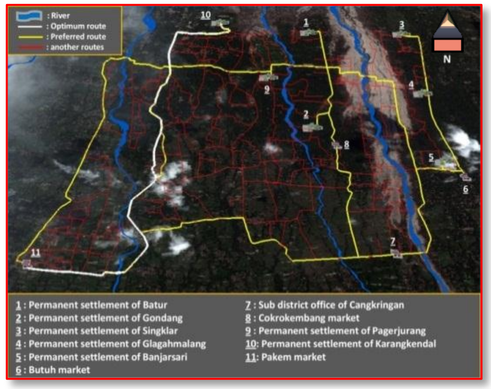


Figure 5-67. The optimum route from Karangkendal to Pakem market by travel time for all days, both in the morning and in the day.

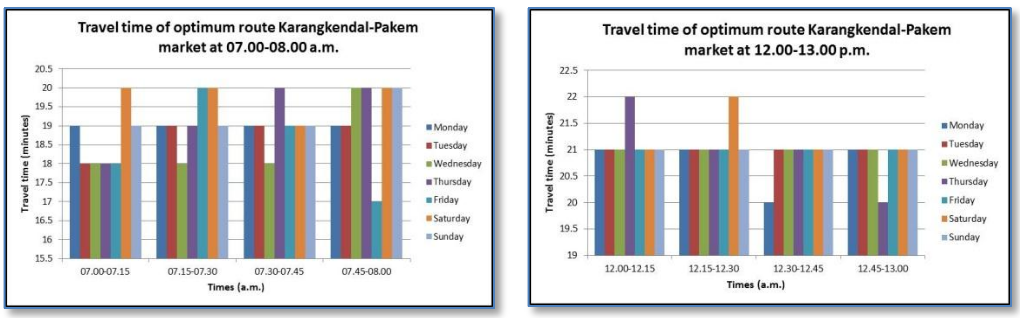


Figure 5-68. Travel time of optimum route from Karangkendal to Pakem market

Table 5-16. Hours of the shortest travel time and the longest travel time of optimum route from Karangkendal to Pakem market between on weekday and on weekend

The shortest travel time		The longest travel time	
Weekday	**Weekend**	**Weekday**	**Weekend**
07.00-07.15 a.m.	07.30-07.45 a.m.	07.45-08.00 a.m.	07.45-08.00 a.m.
12.30-12.40 p.m.	12.30-12.45 p.m.	12.00-12.15 p.m;	12.15-12.30 p.m

On weekday, the shortest travel time occurred mostly on Thursday as represented in Table 5-17, both in the morning and in the day because of less number of vehicles (see Figure 5-69 and Figure 5-70). Less trucks passing through on this route caused shorter travel time, since each vehicles could overtake others easily. According both figures also, there are more number of vehicles passing this route on weekend because of holiday that causes longer travel time, even the traffic became jam at given moment.

Table 5-17. Days of the shortest travel time and the longest travel time of optimum route from Karangkendal to Pakem market

The shortest travel time	The longest travel time
Thursday (in the morning/07.00-08.00 a.m.)	Weekend (Saturday and Sunday) (in the morning/07.00-08.00 a.m. and in the day/12.00-13.00 p.m.)
Thursday (in the day/12.00-13.00 p.m.)	

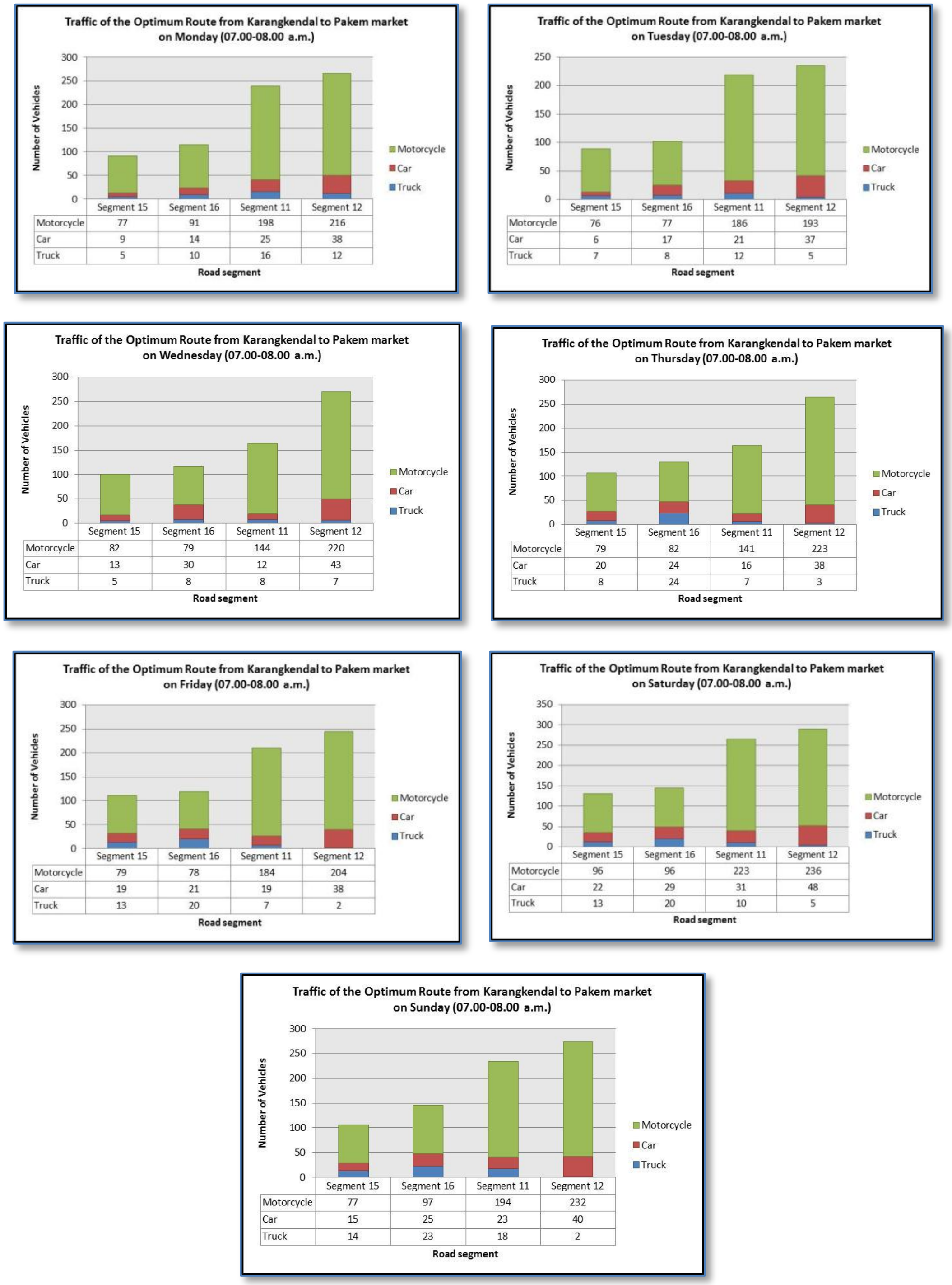
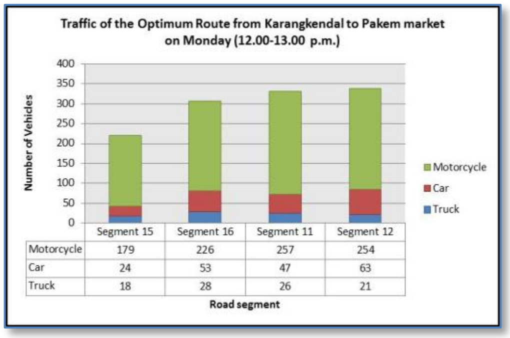
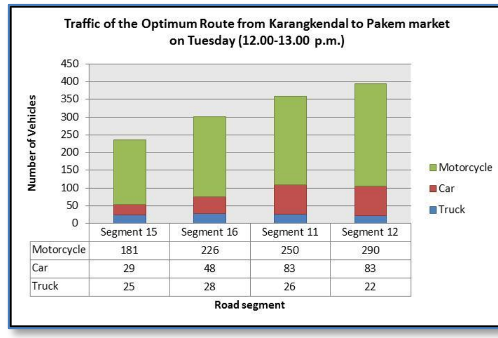
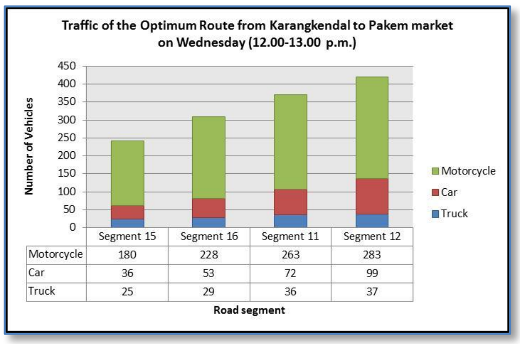
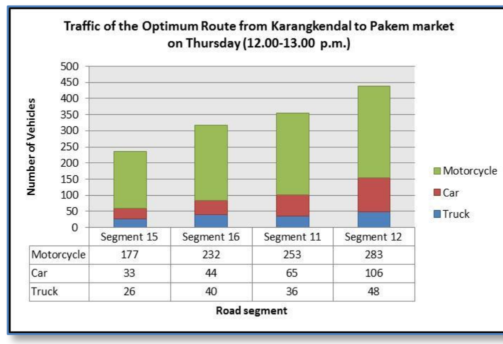


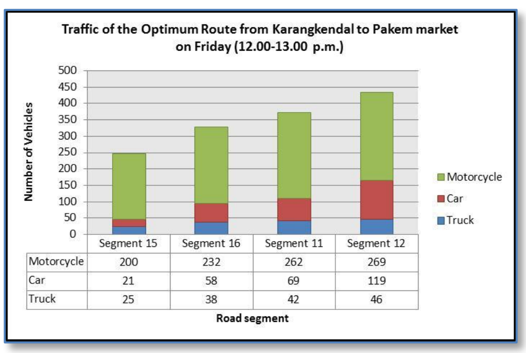
Figure 5-69. Traffic condition of the optimum route from Karangkendal to Pakem market in the morning

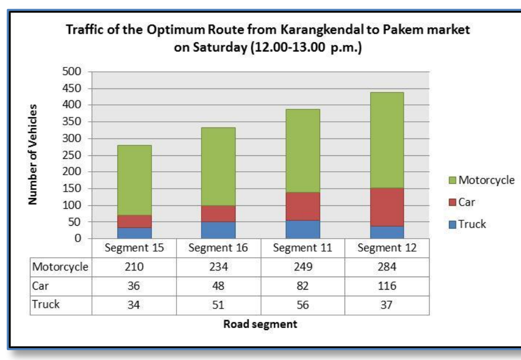












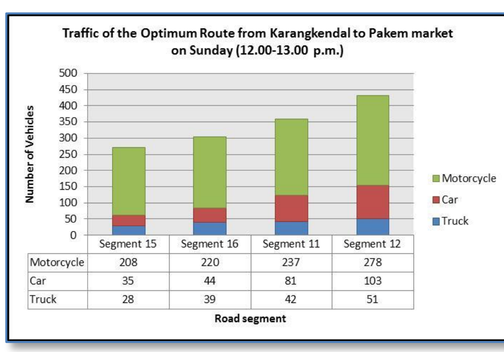


Figure 5-70. Traffic condition of the optimum route from Karangkendal to Pakem market in the day

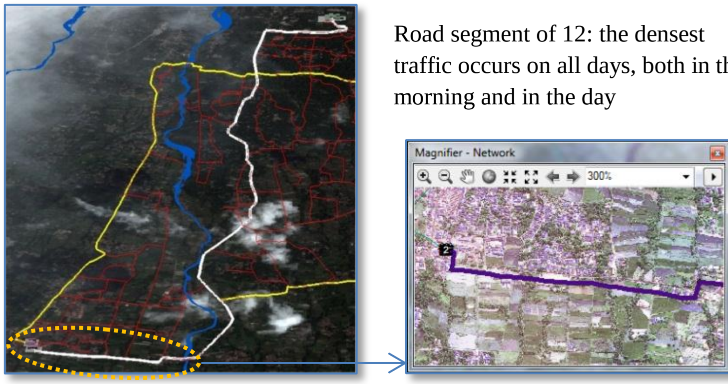


Figure 5-71. The heaviest traffic on the optimum route from Karangkendal to Pakem market

Similar with the optimum route of Pagerjurang-Pakem market, the heaviest traffic occurred on road segment 12 as shown in Figure 5-71, for all days, both in the morning and in the day (see Table 5-18). Compared with road segment 14 on the second route, its traffic is much quieter because of less public facilities that are located along on that segment. On the road segment 14, there are a lot of public facilities, so that traffic on it is much crowded. Vehicles on road segment 12 were mostly dominated by motorcycle as typical vehicle used by local people. Besides that, the road segment is not functioned as bus/truck path, so that travel will be easier.

Table 5-18. Road segments of optimum route from Karangkendal to Pakem market that the heaviest traffic occurred in the morning and in the day

<table>
<tr><th colspan="2">In the morning (07.00-08.00 a.m.)</th><th colspan="2">In the day (12.00-13.00 p.m.)</th></tr>
<tr><th>Day</th><th>The heaviest traffic</th><th>Day</th><th>The heaviest traffic</th></tr>
<tr><td>Monday</td><td rowspan="7">Road segment 12</td><td>Monday</td><td rowspan="7">Road segment 12</td></tr>
<tr><td>Tuesday</td><td>Tuesday</td></tr>
<tr><td>Wednesday</td><td>Wednesday</td></tr>
<tr><td>Thursday</td><td>Thursday</td></tr>
<tr><td>Friday</td><td>Friday</td></tr>
<tr><td>Saturday</td><td>Saturday</td></tr>
<tr><td>Sunday</td><td>Sunday</td></tr>
</table>

Chapter 6. Evaluation of optimum route by means hazard zone of Merapi volcano

This chapter discussed about evaluation of optimum route related to the type of volcanic hazard and its hazard level which segment of route located in. This part also analyzed whether optimum route is located in safety area or in hazardous area.

6.1. Hazard zones of Merapi volcano

Detailed hazard map of Merapi volcano as shown in Figure 6-3 has four levels of hazard zone which zone 4 is the most hazardous zone. According to the map, high hazard zone tends to southward because of collapsed southern Merapi's dome. The collapsed Merapi's dome causes the eruption prone to southward. Map created by BPPTK (2010) depicts that Merapi eruption activity over 1911-2006 is mostly prone to South West flank (see Figure 6-1). It had shifted for first time since 1942 from South West flank to South flank (on June 2006) (J.-C. Thouret et al., 2010). That change is shown in Figure 6-2.

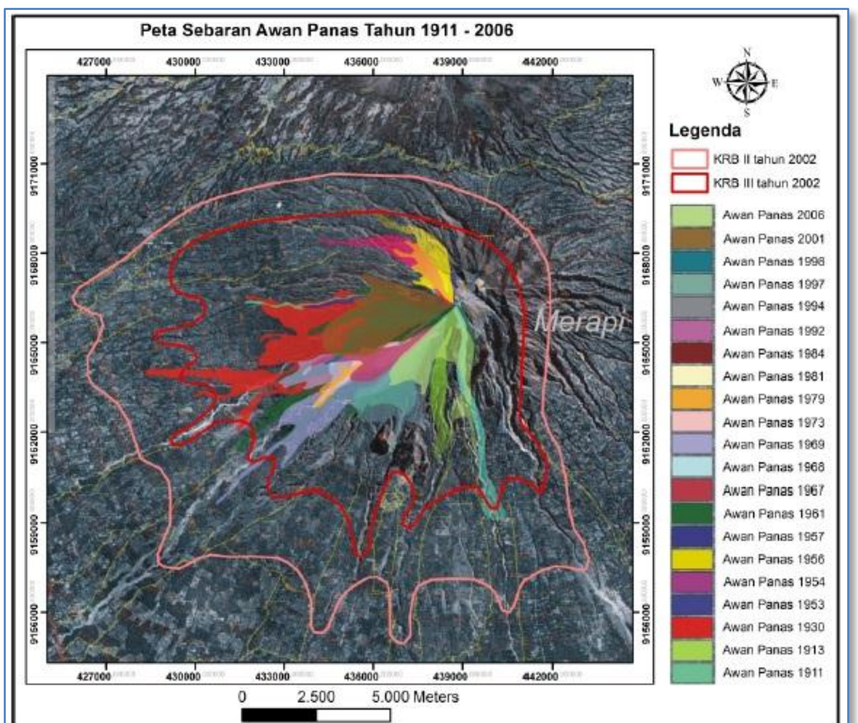


Figure 6-1. Merapi eruption activity over 1911-2006 (BPPTK after Darmawan, 2010)

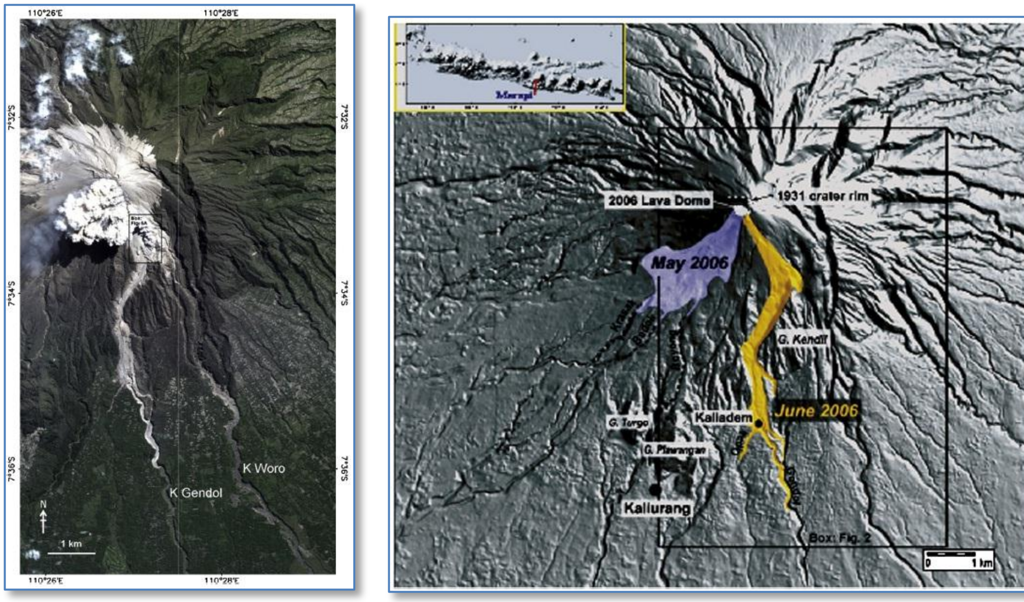


Figure 6-2. Change of merapi eruption activity from South West flank to South flank identified from IKONOS image and DEM extraction (J.-C. Thouret et al., 2010)

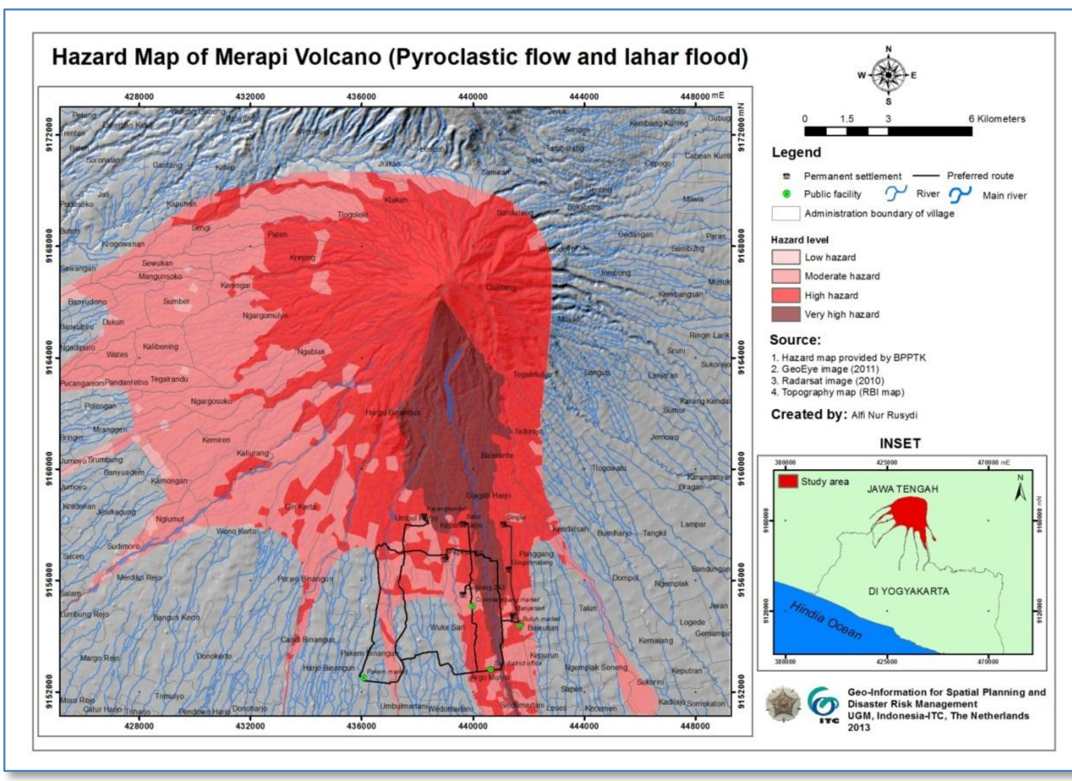


Figure 6-3. Volcanic hazard of post-2010 Merapi eruption generated from DEM of 2010 Radarsat image

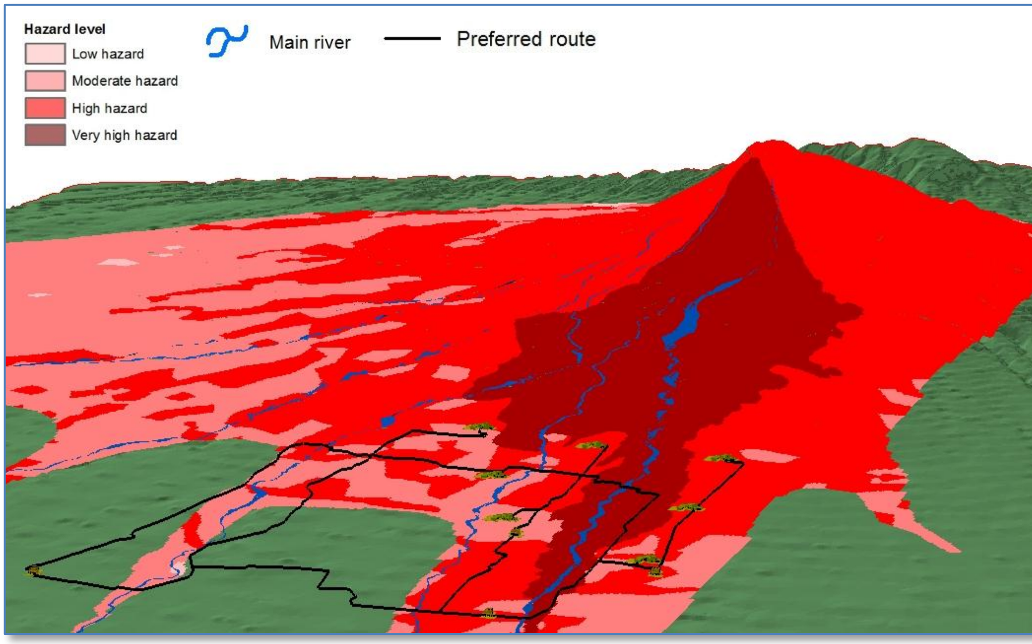


Figure 6-4. Hazardous route of volcanic hazard of Merapi in 3-dimensions

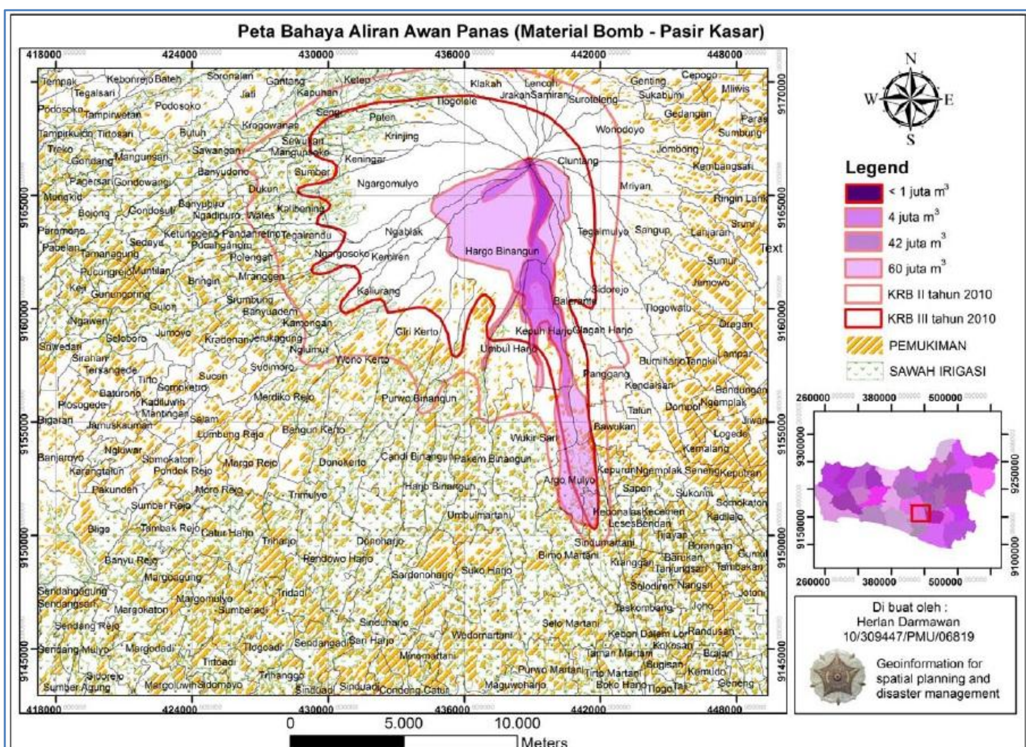
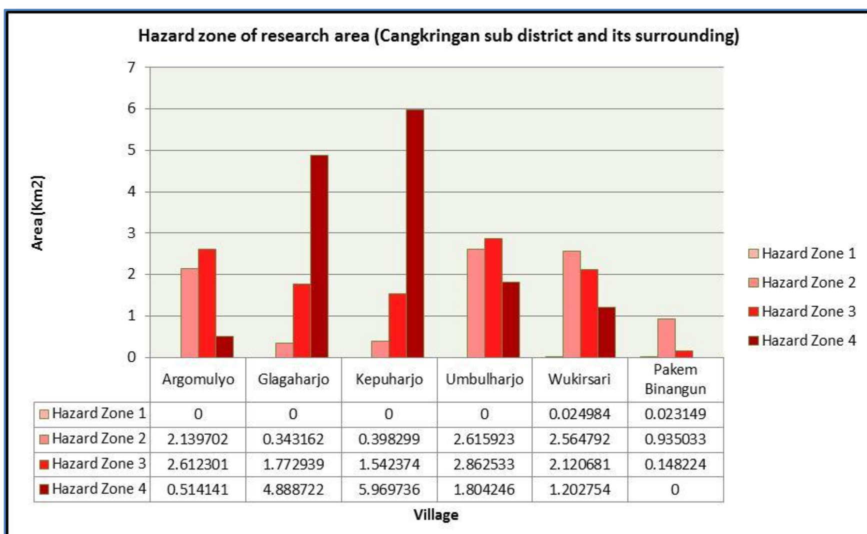


Figure 6-5. Pyroclastic flow (bomb-grain sand) hazard of post-2010 Merapi eruption which gradation of violet color indicates total of pyroclastic flow materials (Darmawan, 2012)

According to the detailed hazard map of Merapi volcano as shown in Figure 6-3 and Figure 6.4, most area of Glagaharjo village belongs to the highest hazard zone since most of pyroclastic flow and lahar flood washed this area out (see Figure 6-6). By visual image interpretation, the affected area can be seen by white color areas in surrounding area of Gendol river. They had been swept off by pyroclastic flow and lahars flood coming from that river. Darmawan (2012) has also identified that most direction of pyroclastic flow tended to southward through Gendol river than Woro river (see Figure 6-5) since there was Kendil hill that could bend that flow to Gendol river. As consequence, southern flanks located surrounding that river including Glagaharjo became most serious damaged area.

All infrastructures including roads and buildings were destructed and being collapsed. Damaged road which asphalt cover was swept off could not be passed easily by any vehicle types. Only trucks and trail motorcycles were able to pass through on this road. Most areas of Kepuharjo and Glagaharjo village belong to zone IV. In the next period of eruption, both villages may be most damaged areas.

Zone III and zone II as shown in Figure 6-3 are zones that dominantly affected by pyroclastic flow and lahars flood; however, destruction level is lower than zone IV. The areas of zone III mostly are located in the southern flanks. The spreading out of pyroclastic flow seemingly followed the presence of river valley. If there is a narrow river valley, whereas pyroclastic flow comes massively, that flow will probably spreads out to the right side and left side of that river. Most infrastructures such as road, bridge, buildings will be also more damaged. In Cangkringan sub district, most areas of Wukirsari village is located in Zone II, and being most secure village of research area from volcanic eruption (see Figure 6-6).



	Argomulyo	Glagaharjo	Kepuharjo	Umbulharjo	Wukirsari	Pakem Binangun
Hazard Zone 1	0	0	0	0	0.024984	0.023149
Hazard Zone 2	2.139702	0.343162	0.398299	2.615923	2.564792	0.935033
Hazard Zone 3	2.612301	1.772939	1.542374	2.862533	2.120681	0.148224
Hazard Zone 4	0.514141	4.888722	5.969736	1.804246	1.202754	0

Figure 6-6. Total of hazard zones area for each village of research area

Zone I is the zone which is located in the volcanic foot plain. Since most areas are near to the main river, so that the most hazard type is lahars flood that will be more tremendous if heavy rain occur in the upper flanks. Abundant pyroclastic materials consisting of stones and gravel will be washed away by rain and they will flow through rivers. Since the river capacity is limited to retain those materials, lahars will be overflowed and will inundate surrounding areas of that river. Many buildings and infrastructures were damaged since they were collided by lahars.

6.2. Evaluation of Optimum Route by Considering Volcanic Hazard Zone

There are seven road segments of zone IV for which Local road 1 Glagaharjo is the longest road length marked with yellow color column (see Table 5-18). As shown in Figure 6-7, it is located near to Gendol river which its road surface is mostly covered by sand, dust, gravel and pebbles (called as dirty road). It is the most difficult road segment to be accessed by car and motorcycle. Only trucks and trail motor cycle that can pass easily through this segment. As main truck path, it may be damaged by pyroclastic flow and lahars in the next period of Merapi eruption.

Table 6-1. Road segments prone to hazard zones of Merapi volcano

Name of Road	Road length (meter)		
	Zone II	Zone III	Zone IV
Another road 1 Argomulyo-Glagaharjo	246.224	-	509.1234
Another road 1 Kepuharjo-Wukirsari	240.1059	1508.041	-
Another road 1 Umbulharjo	353.9072	6.690456	-
Another road 1 Wukirsari	515.2912	20.87322	-
Another road 1 Kepuharjo	-	390.4867	-
Another road 1 Argomulyo	-	15.87188	-
Another road 1 Glagaharjo	-	284.9592	-
Another road 2 Argomulyo	-	132.661	1029.668
Another road 2 Umbulharjo	576.8865	277.7595	-
Another road 2 Wukirsari	-	543.5476	-
Another road 3 Glagaharjo	125.3018	3545.944	-
Another road 4 Glagaharjo	-	252.7435	-
Another road Cokrokembang market	11.44606	-	-
Collector road 1 Argomulyo	-	546.087	-
Collector road 1 Hargobinangun-Pakem Binangun	1657.135	439.3732	-
Collector road 1 Umbulmartani	4.669502	-	-
Collector road 1 Wukirsari-Umbulmartani	545.4796	-	-
Collector road 1 Wukirsari-Argomulyo	-	1441.695	-

Table 6-1 (continued). Road segments prone to hazard zones of Merapi

Local road 1 Argomulyo	-	153.466	-
Local road 1 Argomulyo-Glagaharjo	344.7972	286.4088	1.260167
Local road 1 Glagaharjo	138.4556	319.7598	1717.935
Local road 1 Kepuharjo	-	1012.026	-
Local road 1 Kepuharjo-Glagaharjo	-	-	252.5115
Local road 1 Kepuharjo-Umbulharjo	468.2726	1136.619	-
Local road 1 Umbulharjo	323.5501	655.2139	-
Local road 1 Umbulharjo-Hargobinangun	354.3536	826.7554	-
Local road 1 Umbulharjo-Wukirsari	1071.728	906.1145	-
Local road 2 Kepuharjo	-	151.4409	923.6302
Local road 2 Argomulyo	-	312.0516	23.52154
Local road 3 Argomulyo	170.4907	218.3803	-
Local road 3 Kepuharjo	297.6909	738.8074	-

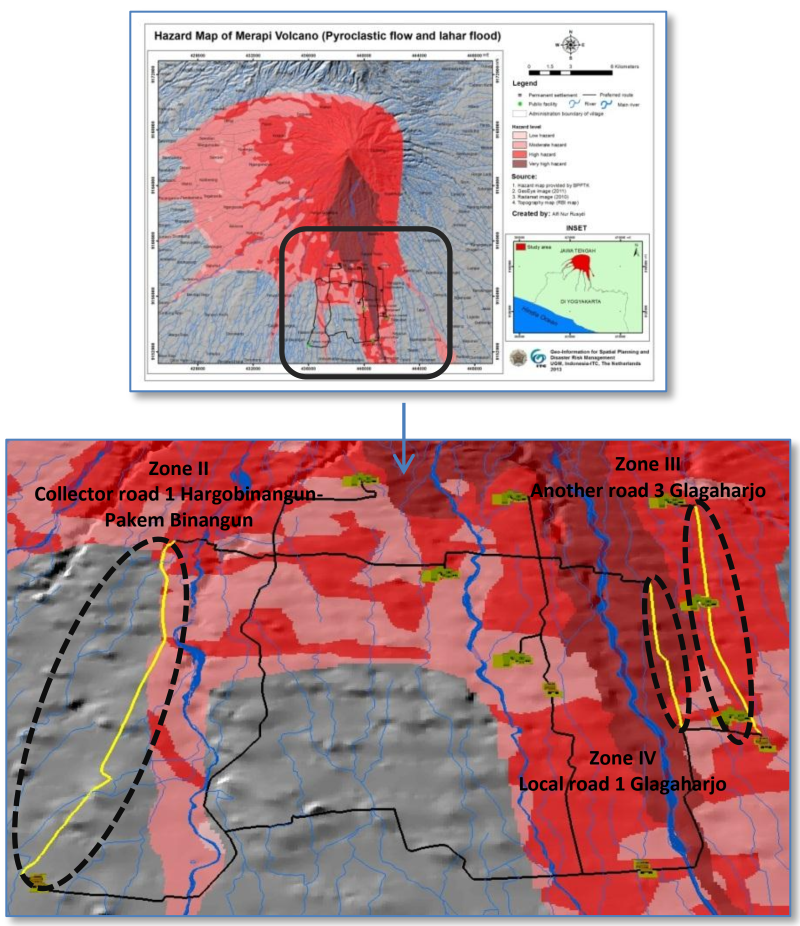


Figure 6-7. Zoom in of road segments prone to hazard zones of Merapi volcano

There are two different perceptions in assessing this road segment. Based on economic view, it should be repaired to increase economic life of local people who work as sand miner. If it is repaired, more trucks will pass through it. If there are many trucks passing through this road, much volcanic sand will be carried by them. If much volcanic sand is carried by those trucks, household income of local people who work as sand miner can be increased. Increasing household income will increase their economic life.

Compared with disaster management view, that road segment was forbidden as main accessible route, since it belonged to the most hazard zone. Therefore, local government would not repair hazardous roads segment and other infrastructures anymore. It could force local people who still live in the high hazardous area to migrate to more secure living area. It has to be done to reduce victims and damaging infrastructures if Merapi erupts again in next period. More serious unrepaired road segments located in hazard area will more reduce also sand mining activity since it become more difficult for cars or even sand trucks carrying volcanic sand to pass. That activity has to be reduced, even be stopped for reducing total loss of volcanic eruption, since most sand mining places are located in high hazardous area.

According to the map, it can be known that the second route from Batur and Gondang to Butuh market is more secure from hazard than the first route despite of longer road length and travel time. Therefore, this route is recommended for local people who want to access safely to the Butuh market. For they who live in Singlar, Glagahmalang, and Banjarsari, sub district office can be accessed through the southward route crossing southern part of Gendol river, since the road segments which belong to hazard zone 3 are is more secure than those of the northward route crossing northern part of Gendol river.

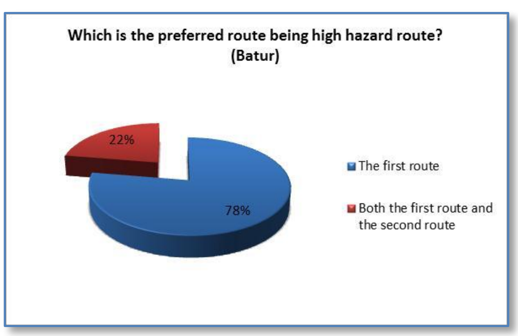
The longest road segment of hazard zone 3 is located on Another road 3 Glagaharjo (see Figure 6-7) which connects from Singlar and Glagahmalang to sub district office of Cangkringan and as main route of sand trucks coming from Klaten regency to access sand mining places located in upper flanks. Lahar is the main hazard that should be taken into account by local people who live in surrounding area of that route. Next overflowing lahars from Gendol river may destruct infrastructures more intensively including roads and even it can cut accessing to sub district office off.

Overflowing lahars is also be more noticed by local people who want to access to Pakem market from Pagerjurang and Karangkendal. Road segments of that route belong to hazard zone 3 and hazard zone 2. The longest road segment is located on the first route which is Collector road 1 Hargobinagun-Pakem Binangun as shown in Figure 6-7. Although hazard level is less than zone 3 and zone 4, this road segment should be taken into account, since more infrastructures and human settlements located along that route. If lahars strike these areas, there will be more total loss than that of zone 3 or zone 4. The road segment that should be more kept on guard is Local road 1 Umbulharjo-Hargobinagun for which it belongs to Zone 3. It crosses Kuning river as lahars channel, besides Gendol river, and the lahars can overflow out to any sides of river. Bridge may able to be destructed by lahars and if it occurred, the main accessing from both permanent settlement; Pagerjurang and Karangkendal will be cut. Therefore, the second route can be alternative path to access to Pakem market if the bridge is collapsed. The most secure road segment is located on Collector road 1 Umbulmartani-Pakem Binangun since it is does not belong to any volcanic hazard zones.

6.3. Evaluation of Optimum Route by Considering Local People's Perception of Volcanic Hazard

6.3.1. Hazardous route based on local people's perception of Batur and Gondang

According to local people of Batur and Gondang, the first route is more hazardous path than the second one (see Figure 6-8), since there are road segments that are located near to main river especially Gendol river. They knew that the river is main channel for which lahars flow and can be overflow out of the channel and then inundates surrounding area of it. Fortunately, they still used it as main route for them who would access to Butuh market since another preferred route which is the second route took longer travel time. They were forced to access through the first route to their destination since it took shorter time. If they access through the second one, although it is safer from hazard, but travel time will be much longer and sometimes traffic jam can be occurred since blockade of trucks often occur.



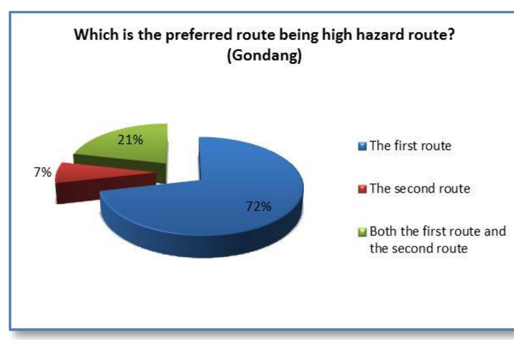


Figure 6-8. Perception of local people about high hazardous route from Batur and Gondang to Butuh market

Local people said that on the first route, most hazardous route segment was located on Local road 1 Kepuharjo-Glagaharjo and Local road 2 Kepuharjo (see Figure 6-9). Those segments were functioned as connection road from east side area to west side area of Gendol river for which Gendol river is main channel of lahars. If lahars flood occurred, damaged intensity of those roads will be highest and roads can be destructed more tremendously. Before Merapi eruption of 2010, there was a bridge that connected between those two side areas, but because of high damaging intensity by lahars, that bridge was washed out by it. Nowadays, there is no bridge anymore, and only a road crossing that river as it is. If the lahars come again in next eruption period, that segment may not able to be functioned as a well-transportation route.

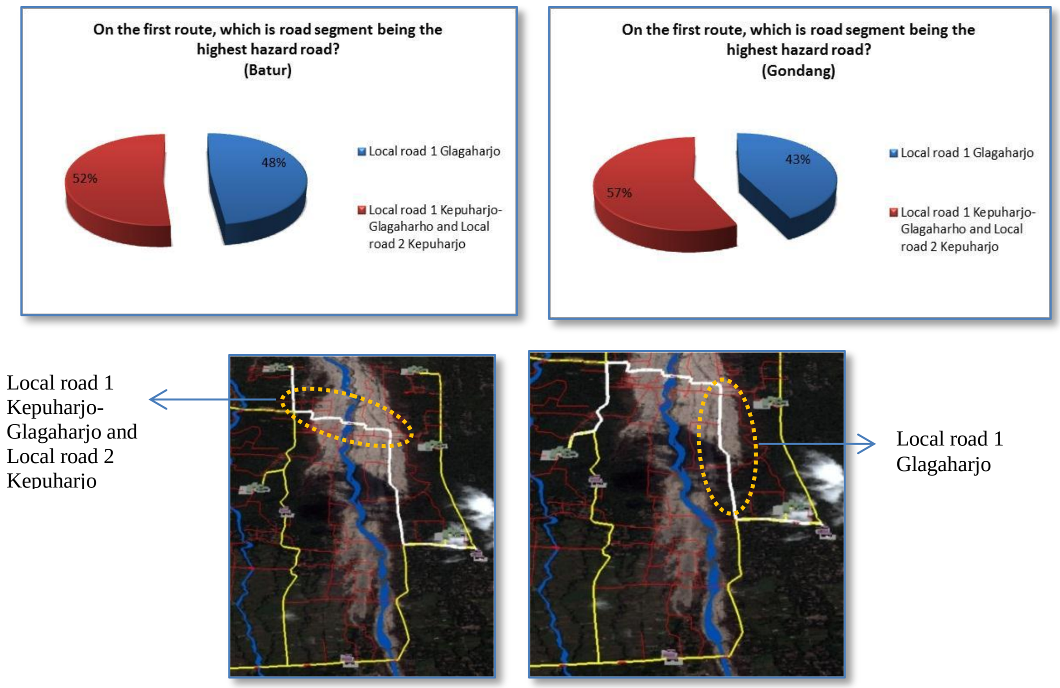


Figure 6-9. Local people's perception about the highest hazardous road segment of the first route from Batur and Gondang to Butuh market

On the second route, the highest vulnerable road segment to be destructed by lahars and pyroclastic flow were Another road 1 Argomulyo-Glagaharjo and Another road 2 Glagaharjo (see Figure 6-10). High vulnerability of Another road 1 Argomulyo-Glagaharjo was caused by its roles as connection road between west side area (Argomulyo) and east side area (Glagaharjo). This condition was similar with Local road 1 Kepuharjo-Glagaharjo and Local road 2 Kepuharjo located on the first route. Meanwhile, Another road 2 Glagaharjo being high vulnerable route from hazard since the location was near to Gendol river and there was no barrier (something like dike) between Gendol river and surrounding area of that road. Lahars could be overflow from that river and inundated that area called as lahars flood. It could polish road surface (asphalt cover) and made more cracks and holes on that road so that road would be more and more difficult to be accessed.

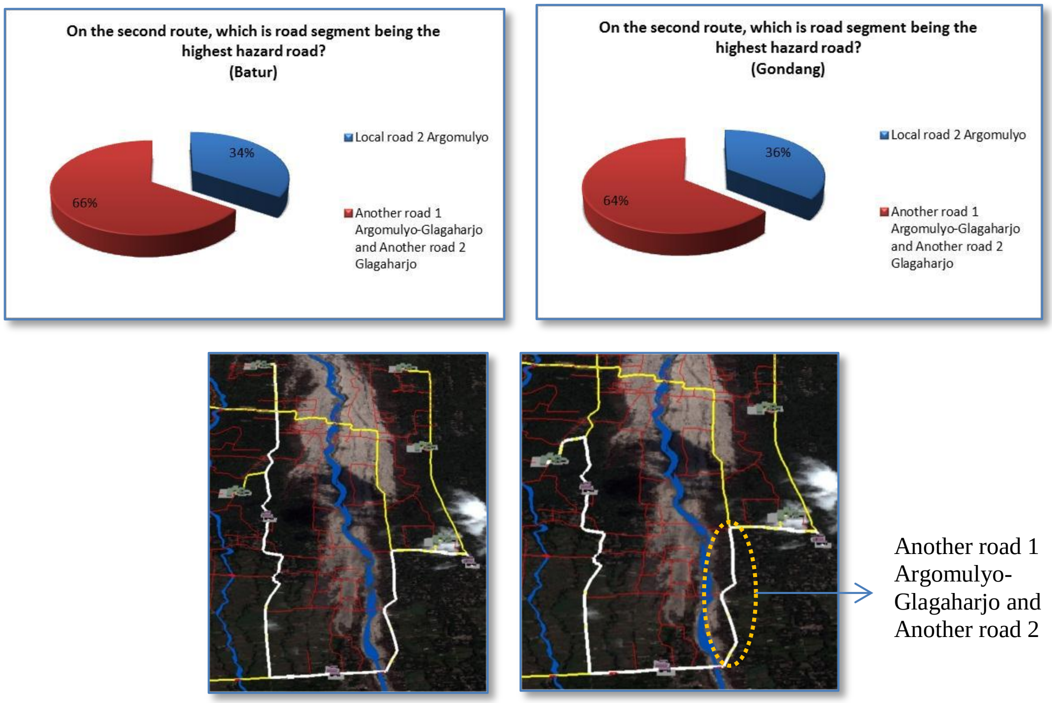


Figure 6-10 Local people perception about the highest hazardous road segment of the second route from Batur and Gondang to Butuh market

6.3.2. Hazardous route based on local people's perception of Singlar, Glagahmalang, and Banjarsari

Most hazardous route based on local people's perspective was on the first route since it crossed Gendol river in southern part area which was as main channel of lahars flow. There is no another route being more hazardous than the first route, since only one route that become main preferred path for local people to access to the sub district office.

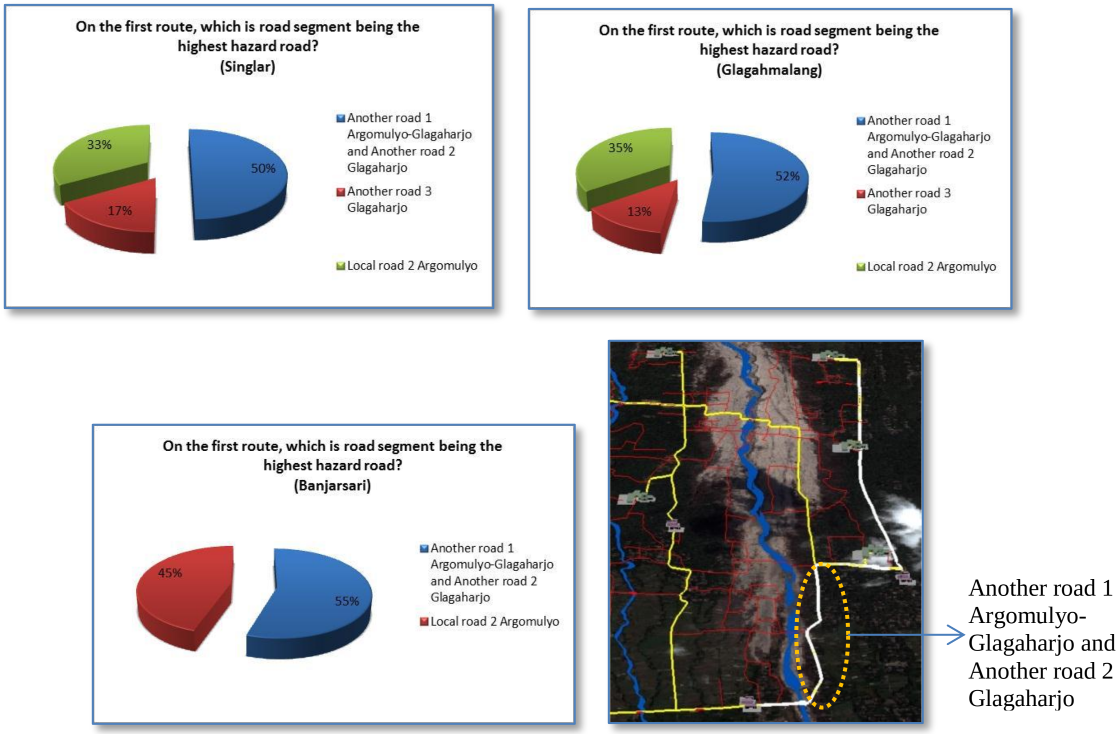


Figure 6-11 Local people perception about the highest hazardous road segment of the first route from Singlar, Glagahmalang, and Banjarsari to Sub district office of Cangkringan

On the first route, most hazardous road segments were located on Another road 1 Argomulyo-Glagaharjo and Another road 2 Glagaharjo (see Figure 6-11). As connection road, Another road 1 Argomulyo-Glagaharjo was the most important road segment since it connected the west side area to the east side area of Gendol river. If that segment is damaged and cannot be accessed anymore, accessing to sub district office will be more difficult, and they are forced to travel through on further route. Meanwhile, Another road 2 Glagaharjo being the most hazardous road segment since it was location that lahars flood occurred, besides there was no barrier to restrain lahars inundating surrounding area of that road segment.

6.3.3. Hazardous route based on local people's perception of Pagerjurang and Karangkendal

The second routes from Pagerjurang and Karangkendal to Pakem market were the most hazardous routes (see Figure 6-12). They were prone to be nearer to main river, so that route could be destructed more seriously than the first one. Besides that, asphalt cover on the second route was thinner than on the first route, so that if lahars come and inundates that route, there will be much more cracks, holes, and dirty roads.

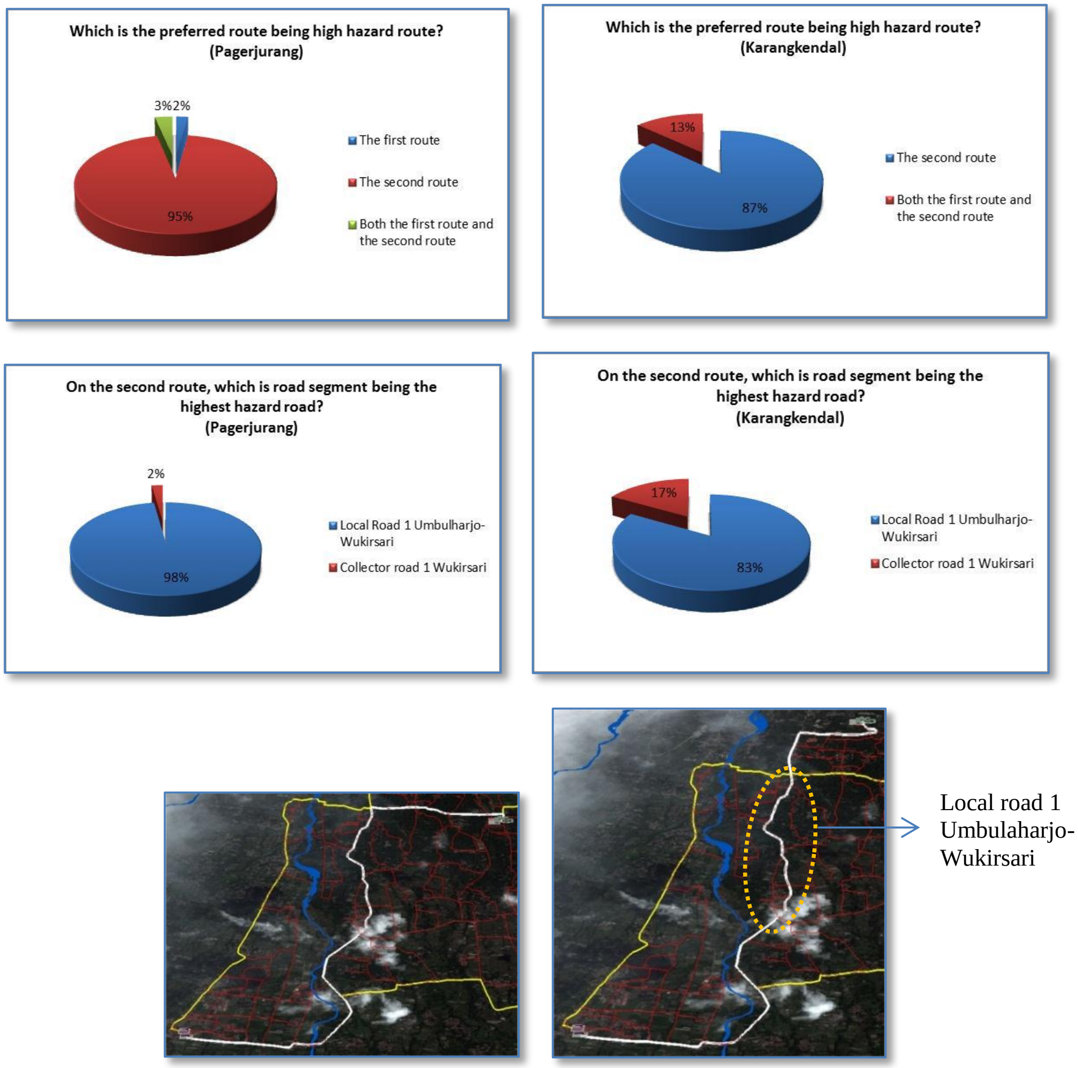


Figure 6-12 Local people perception about the highest hazardous road segment of the second route from Pagerjurang and Karangkendal to Pakem market

On the second route, the most hazardous road segmentwas located on Local road 1 Umbulharjo-Wukirsari since there were more seasonal river channels surrounding it. Those rivers could be additional channels for lahar overflowed to surrounding areas, so that road segments located in these areas might be inundated by it.

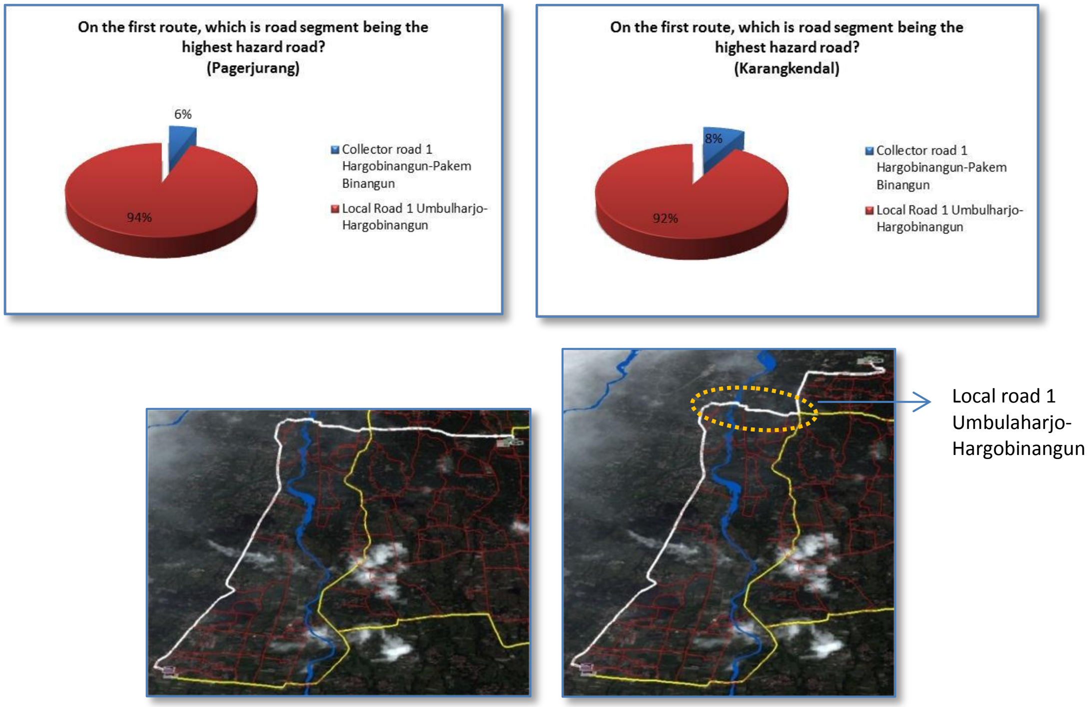
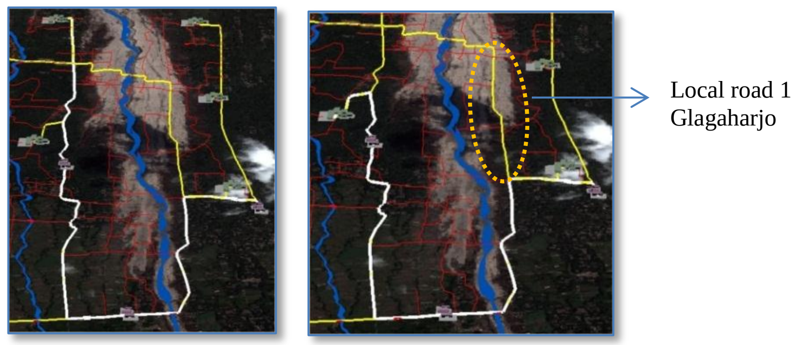


Figure 6-13 Local people perception about the highest hazardous road segment of the first route from Pagerjurang and Karangkendal to Pakem market

Meanwhile, on the first route, connection road of Local road 1 Umbulharjo-Hargobinangun crossing Kuning river was the most hazardous road segment. Besides Gendol river, Kuning river was one of lahars channels. More tremendous lahars and pyroclastic flow hazard coming from high explosive eruption of Merapi might destruct it including the bridge located over there. Nowadays, the bridge is still functioned well to connect two side area of that river. If there are a lot of vehicles passing through road segment which in fact, the bridge was built in bad construction, vulnerability of lahars and pyroclastic flow in its surrounding areas will be higher.

6.4. Evaluation of optimum route by considering recommended route by Local Government

Routes accessing from permanent settlements to public facilities in Cangkringan sub district mostly belonged to high hazard zones. According to interviewing to local government, recommended routes to be accessed to public facilities should mostly be secure from high volcanic hazard (Zone IV) (see Figure 6-14, Figure 6-15, Figure 6-16, Figure 6-17, and Figure 6-18). Merapi 2010 eruption caused more damaged roads, especially road segment of Local road 1 Glagaharjo. Before Merapi eruption in 2010, it could still be accessed easily by local people, but now, it is very difficult to be accessed because of worse road condition. There are a lot of cracks, holes, and thin asphalt cover. Therefore, local government suggested that routes which road segment of Local road 1 Glagaharjo (see Figure 6.14) included in are not recommended route to go to their public facilities.

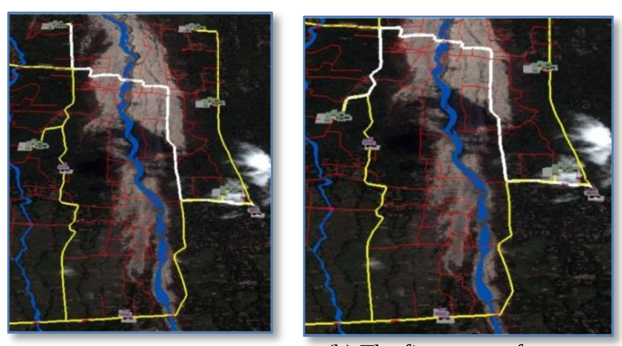


(a) The second route of Batur to Butuh market

(b) The second route of Gondang to Butuh market

Fig 6-14. Recommended routes from Butuh and Gondang to Butuh market by local government (in existing condition)

If next Merapi eruption occurred while many local people pass that route, there may be more victims and loss. Therefore, for short term, local government has a plan that route will be not repaired, although it has the shortest road length and travel time. The plan was decided to avoid increasing loss caused by Merapi eruption by reducing number of local people who want to access through on this route.



(a) The first route of Batur to Butuh market

(b) The first route of Gondang to Butuh market

Fig 6-15. Recommended routes from Butuh and Gondang to Butuh market by local government (in future condition/dormant period of Merapi's activities)

The second routes from Batur and Gondang were better recommendation for transportation route to Butuh market, since it was more secure than the first one. As previous explanation above, most road segments of the first route belonged to high hazard zone, since it was near to Gendol river which played role as lahars channel.

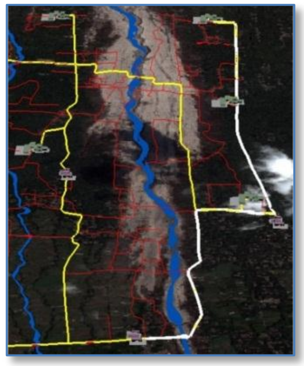


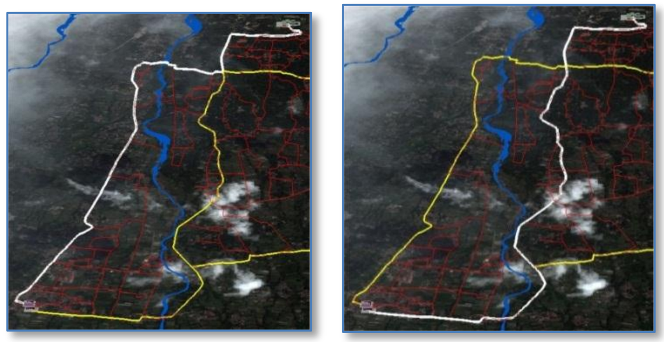
Fig 6-16. Recommended routes from Singlar, Glagahmalang, and Banjarsari to Sub district office by local government (in both existing condition and future condition)

If Merapi volcano gets in dormant period and the eruption become rare occurred, and condition of area of road segment Local 1 Glagaharjo will be more secure to be accessed, and it will be allowed to be repaired by government. It can be the main route for local people to accesses because of shorter road length and travel time. If it is already repaired, it will increase local area development indicated with many human settlements completed with infrastructures and public facilities that are built there. This condition will give easier accessibility for local people who live in surrounding Batur, Gondang, Singlar, Glagahmalang, and Banjarsari to access those public facilities, especially to Butuh market and to sub district office of Cangkringan. For local people who live in Pagerjurang (Kepuharjo) and Karangkendal, they were recommended to access through on either the first route or the second route since those routes are secure since road segments mostly are not located in high hazard area (see Figure 6-17 and Figure 6-18).

(a) The first route of Pagerjurang to Pakem

(b) The second route of Pagerjurang to Pakem

Figure 6-17. Recommended routes from Pagerjurang to Pakem market by local government (in both existing condition and future condition)



(a) The first route of Karangkendal to Pakem

(b) The second route of Karangkendal to Pakem

Figure 6-18. Recommended routes from Karangkendal to Pakem market by local government (in both existing condition and future condition)

Road segments that should be repaired if Merapi does not erupt anymore are those that are located in hazard zone IV. First priority of roadwork will be addressed to the road segment that has the longest road length in hazard zone IV which is Local road 1 Glagaharjo, since it has long damaged road side consisting of cracks and holes. Long damaged road is more difficult to be accessed than short damaged road.

6.5. Determining the best route

The best routes could be determined by considering all constraints that influenced a given route being optimum route (see Table 6-2). They were road length and neutral travel time, route steepness, road quality, traffic factor, travel time influenced by traffic, and hazard zones. A given optimum route was chosen as the best route if that route mostly became optimum route in varying costs. The best route means that a best way that can be accessed by local people in existing condition. In the future, that route may be changed depending on future situation.

As shown in Figure 6-19, the best route connecting from Batur to Butuh market is located on the first route because of shorter road length and neutral travel time, despite of dirty road. If there is no eruption activity of Merapi volcano anymore, that route will be the best way since it is not disturbed by volcanic hazard’s activities anymore, such as pyroclastic flow and lahars. If there is increasing volcanic activity, the second route will be the best one to be accessed. It is relatively more secure from volcanic hazard and better road quality than the first route despite of longer road length and neutral travel time.

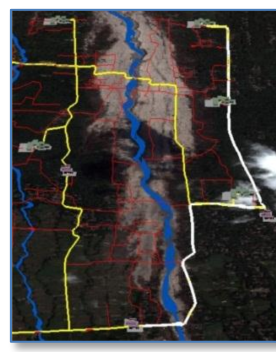
Table 6-2. The best route based on minimum constraints by varying cost

Cost	Batur-Butuh market	Gondang-Butuh market	Singklar-Sub district office	Glagahmalang-Sub district office	Banjarsari-Sub district office	Pagerjurang-Pakem market	Karangkendal-Pakem market
Length	The first route	The first route	The first route	The first route	The first route	The first route	The first route
Neutral travel time	The first route	The second route	The first route	The first route	The first route	The second route	The second route
Route steepness	The first route	The second route	The first route	The first route	The first route	The first route	The first route
Road Quality	The second route	The second route	The first route	The first route	The first route	The first route	The first route
Traffic factor (morning)	The first route	The second route	The first route	The first route	The first route	The second route	The second route
Traffic factor (day)	The first route	The first route	The first route	The first route	The first route	The second route	The second route
Travel time (morning)	The first route	The first route	The first route	The first route	The first route	The second route	The second route
Travel time (day)	The first route	The first route	The first route	The first route	The first route	The second route	The second route
Detailed hazard map	The second route	The second route	The first route	The first route	The first route	The first route	The first route
Perception of hazard	The second route	The second route	The first route	The first route	The first route	The first route	The first route
Recommended route	The second route	The second route	The first route	The first route	The first route	The first route or the second route	The first route or the second route
Best route	**The first route**	**The second route**	**The first route**	**The first route**	**The first route**	**The second route**	**The second route**

Local people who live in Gondang can access through the second route as the best route. However it is longer road length, but it is shorter neutral travel time because of better road quality than the first route. Fortunately, there were many vehicles passing through this route, so that traffic jam occurred at given times. It would cause longer travel time. If the first route could be repaired (means that road quality becomes better), besides shorter road length, travel time would be shorter, so that it would be the best route to be accessed. If the volcanic eruption activities increased, the second route will still be the best one.

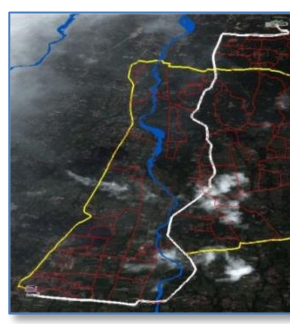
Batur

Gondang



Singlar, Glagahmalang, Banjarsari

Pagerjurang



Karangkendal

Figure 6-19 The best routes indicated with minimum cost/constraints

Meanwhile, for local people who live in Singklar, Glagahmalang, and Banjarsari, the first route can be main route to be accessed since it is more effective route in varying costs. However, there are road segments that need to be repaired since there are a lot of cracks and holes because of lahars and pyroclastic flow. They are Local Road 1 Argomulyo-Glagaharjo, Another road 4 Glagaharjo, Another road 2 Argomulyo, and Another road 1 Argomulyo-Glagaharjo. According to interviewing to local people there, there was another alternative route that road condition was better than the first route (good asphalt cover), but it had longer road length and travel time since it crossed Klaten regency first, then Cangkingan sub district later.

For accessing from Pagerjurang and Karangkendal to Pakem market, the second route can be the best route because of shorter neutral travel time, although road length is longer than the first route. Less number of vehicles passing the second route was caused by worse road quality of road segments than the first one. Therefore, local people who want to travel to Pakem market still preferred to access through the first route, although traffic jam could be occurred at given time. If road condition of the second route could be repaired, accessing to Pakem market would be easier than the first one. According to hazard analysis, although the second route is relatively higher hazardous route, but the location of that route is relatively far from main rivers for which lahars and pyroclastic flow follows through those rivers.

6.6. Post-analysis discussion with government

According to discussion with government about the results of this research, at least, governments known that the routes closing to main river (Gendol river, Opak river, and Kuning river) was hazardous and they agreed about that. Therefore, to reduce loss caused by next Merapi eruption, those routes will never be repaired to avoid more people that want to go through on this route, since it has shorter travel time to Butuh market or another places that they want to go. Government (Both Public Work Department of Yogyakarta province and Public Work Department of Sleman Regency) clearly stated that routes will let it as it is for existing condition and they will plan to make it as evacuation route, if the budget is sufficient. If there is no sufficient budget, the route will be let as it is.

Local government of Cangkringan sub district (sub district head and village head) also known and agreed with the hazardous routes that are represented in Hazardous route map (see Figure 6-3 and Figure 6-4). They admitted that they had suggested local people to avoid going through on the routes which are close to main rivers, but the local people likely ignore that recommendation, even some of them asked local government to repair those route by cooperating with regional and provincial government.

Most hamlet heads accepted that the routes is properly to be evacuation route, but they hoped that it can also be commercial routes since there are many common local people works as sand miner. If the route is repaired, the social well-being of local people living in permanent settlements can be increased and it will help them to live properly there.

Chapter 7. Conclusion and Recommendation

The recommendation was provided to give reference in doing future research focusing on Merapi volcano to local government, local community, other stakeholders and researchers.

7.1. Conclusion

1. The main consideration of local people in choosing their preferred route is shorter road length and shorter travel time, although it belongs to hazardous route. They will more take factor of volcanic hazard into account if Merapi volcano's activities increased significantly. The preferred route may able to change in that condition.
2. Route traffic located in high hazard zone is dominated by trucks since there is abundant volcanic sand over there. Imbalance between road width and number of trucks can cause congestion and the route can be more difficult to be accessed, especially in the day. Meanwhile, route traffic located in more secure area is dominated by motorcycle since it is a typical vehicle used by local people.
3. In both high hazard area and low hazard area, traffic will be heavier in the day than in the morning since that time is rush hours for local people working. Therefore, in that time, the route will be more difficult to be accessed. It causes longer travel time from their settlement to the destination.
4. Optimum route is not constant. It can be dynamically changed depending on traffic. A route will able to be optimum if the traffic becomes quiet indicated with less number of vehicles on that route.
5. Optimum route can be accessed much easily in the morning for all days and it will be more difficult to be accessed on weekend because of holiday and there are a lot of vehicles pass through that route such as car and tourism bus.
6. For existing condition, the best route that can be accessed by local people living in Batur, Singklar, Glagahmalang, and Banjarsari is the first route since it has minimum obstacles. Meanwhile, the second route is the best way that can be accessed by them living in Gondang, Pagerjurang, and Karangkendal. If activities of Merapi increased, the second route will be the best path to be accessed by local people, especially for they who live in Batur and Gondang.
7. Road segments located in nearest area of Gendol river or other main rivers (Opak river and Kuning river) of hazard zone are the highest risk road segment facing lahars and pyroclastic flow. Lahars flood and spreading out of pyroclastic flow can destruct them being more difficult route to be accessed.
8. Recommended routes by local government that should be accessed by local people are those that are located in secure area. In this case, the second route from Batur and Gondang to Butuh market is more secure from volcanic hazard than the first route.

7.2. Recommendation

1. For existing condition, since the second route from Batur and Gondang to Butuh market is more secure route than the first route, it needs to be repaired, so that local people can access much easily through on that route. Cracks and holes on that route were caused by trucks carrying volcanic sand since their load exceeds weight of roads. They should be limited and are recommended to travel through the first route since they can still pass much eminently through on that route than cars or motorcycles. Road segments that belong to the highest hazardous road are recommended to be functioned as evacuation route from volcanism event of Merapi volcano.
2. If Merapi eruption does not occur anymore for long period (or get in dormant period), the first route of Batur and Gondang to Butuh market should be given first priority to be repaired, especially on road segment of Local 1 Glagaharjo. Since the first route has shorter road length than the second one, after it repaired (asphalt covering), the travel time will be much shorter.
3. For accessing Pakem market from Pagerjurang and Karangkendal, the second route should also be repaired. It can reduce over number of vehicles passing through the first route by shifting partial traffic flow of it to the second route since traffic congestion on the first route is caused by limited road capacity.
4. For short term, public facilities such as market and public services should be built near to the place that local people live in. They have to be completed with proper infrastructures, especially good roads. For example, Cokrokembang market as a new market which the location is nearer to Butuh market should be revitalized as soon as possible. Farming lands rehabilitation and revitalization should be done, especially for farm lands located in upper flanks. Thereby, harvest produced by them can supply marketable goods in Cokrokembang market. Hopefully, the market can serve daily needs of local people who living surrounding area of it.
5. During land rehabilitation and revitalization, to activate commercial activities in Cokrokembang market, marketable goods can be supplied temporarily from Pakem market since it is nearest market from Cokrokembang market. It can avoid for local people to go further to Butuh market to fulfill their daily needs.
6. Since this research is lack of model verification, particularly the schedule of the shortest and the longest travel time, it is recommended for further research. Model of road network can be tested by applying it in the field and be evaluated how effective the model represents the circumstances in the field. Thus, the model can be improved by analysis of fuel consumption, particularly for finding out optimum route based on route steepness and road quality. It is focused on whether travelling through on the flatter roads, although it has worse road quality than the steeper road, consume fuel much more or not.

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APPENDIX A.

QUESTIONNAIRE

"Optimum Route Evaluation of Permanent Settlements for Accessing to Public Facilities after Merapi 2010 Eruption in Sleman Regency"

*Each answer given by respondent has to be filled by **enumerator**. The answers filled by respondents they self are not allowed.*

Date :...../……/…………
Location :
Sub Village :………………………………………………
Village :………………………………………………
Coordinate X :………………………
Coordinate Y :……………………….
Enumerator :……………………………………………………………….

Identity of Respondent

Name :………………………………………………..
Previous address
:…………………………………………………………………………
Address
:………………………………………………………………………….
Gender : M/F
Age :…………….
Education :

a. Elementary
b. Junior High School
c. Senior High School
d. Bachelor
e. Other

Current occupation :

a. Farmer
b. Civil servant
c. Employee
d. Entrepreneur
e. Other :……………………

1. Is there problem of accessibility that you feel in this settlement?
   Answer:…………………………………………………………………………
   ………………………………………………….
2. If yes, what is the place that you need to access?
   Answer:…………………………………………………………………………
   ………………………………………………….

3. What is the importance of that facility to your life?
   Answer:………………………………………………………………………………
   ……………………………………………………………
4. Where are routes typically to be accessed? (by sketch on the map)
   Answer:………………………………………………………………………………
   ………………………………………………………….……..
5. How do you go to that place from your house? What is kind of transportation that you use to go?
   Answer:………………………………………………………………………………
   ……………………………………………………………
6. Why do you use that kind of transportation?
   Answer:………………………………………………………………………………
   ……………………………………………………………
7. Which is preferred route typically you access?
   Answer:………………………………………………………………………………
   ……………………………………………………………
8. Why do you travel through the first route?
   Answer:………………………………………………………………………………
   ……………………………………………………………
9. Why do you travel through the second route?
   Answer:………………………………………………………………………………
   ……………………………………………………………
10. Which is the preferred route being high hazardous route?
    Answer:………………………………………………………………………………
    ……………………………………………………………

APPENDIX B.

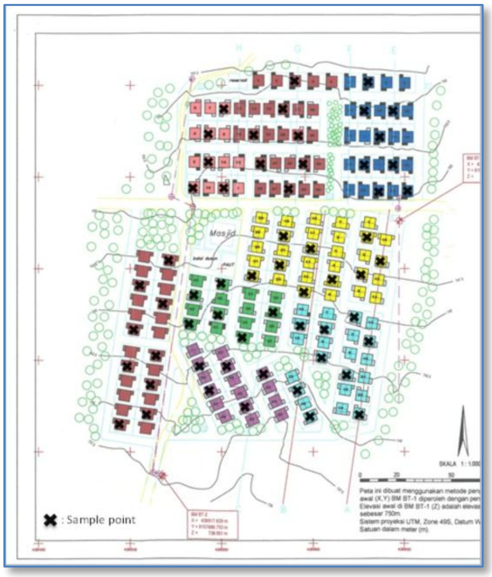
Sketched map of preferred route by local people

From : ……………..………………… (Coordinate X=……..., Y=………)
Destination : ……………..………………… (Coordinate X=……..., Y=………)

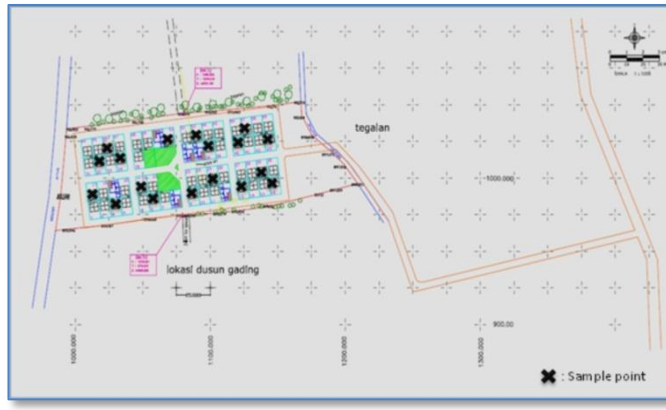
1. On the first route, which is road segment being the highest hazardous road?
   Answer:……
2. On the second route, which is road segment being the highest hazardous road?
   Answer:………

APPENDIX C.

Sample points of permanent settlement

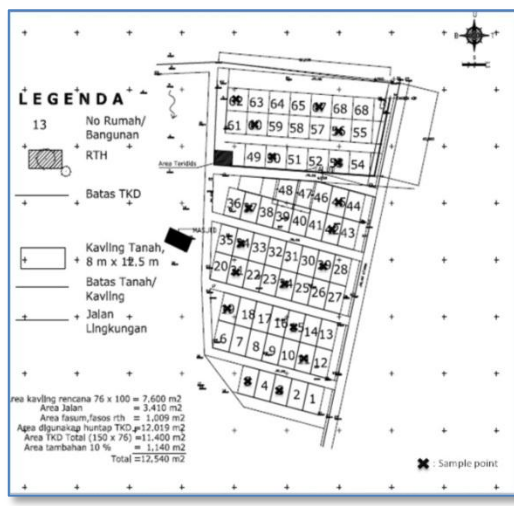


Permanent settlement of Batur



Permanent settlement of Gondang

Permanent settlement of Singlar



Permanent settlement of Glagahmalang

Permanent settlement of Banjarsari

Permanent settlement of Pagerjurang

Permanent settlement of Karangkendal

APPENDIX D. ROUTES OVERVIEW