Analysing changes in landslide vulnerability using GIS and local spatial knowledge

Geraldine Paula Babirye

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by

Geraldine Paula Babirye

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Thesis Assessment Board

Prof. Dr. V. G. Jetten (Chair)
Dr. M. K. Mc Call (External examiner)
Dr. C. J. van Westen (1st Supervisor)
Drs. N. Kingma (2nd Supervisor)

Observer
Drs. T. M. Loran (Programme Director)

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Abstract

The aim of the research was to investigate people's vulnerability and perceptions to landslides. Information from respondents was gathered by use of questionnaires from two villages in Banjarmangu district, Central Java province, Indonesia. These two villages were randomly sampled to get a feel of the different views from different people.

Some elements related to the physical and socio-economic aspects of the respondents in the two villages were identified and analyzed using some indicators. These indicators were used in relation to the ability of people to deal with the different landslide processes. The availability of both formal and informal mechanisms such as social networks and warning systems (Kentogan) that play an important role in coping with and adapting to the hazard were also explored.

Data on the respondents' perception to what landslides are, their causes, the available resources to preventing them and the existing measures for disaster management within the community are also discussed in this research.

The weights of evidence modelling method that uses the prior probability of occurrence of an event was used to determine the probability of occurrence of landslides based on the relative contributions of factor themes that are influential in creating slope instability. A sensitivity analysis was carried out on the input factors to the weights of evidence modelling to determine their influence on the occurrence of the fast landslides and creep phenomena taking place in the study area. The results are landslide susceptibility zonation maps.

A summary of the work, methodologies and tools employed by organizations and government agencies involved in various studies and investigations to understand what really happened after the tragic loss of 76 lives in the Gunungraja hamlet 2006 landslide is discussed in this work together with collective independent findings by the author.

The overall vulnerability obtained from the research showed that both villages had comparable vulnerability classes with majority of the respondents with in the moderate class.

A risk index matrix associated with the hazard and vulnerability of the investigated communities was constructed but is not the final result per se. The risk analysis results provided estimates for individual risk levels but did not provide insight on the geographical distribution of the landslide risk to the whole population in the study area. The ultimate objectives can only be fulfilled when proper risk reduction measures are implemented, leading to an observed decrease of casualties.

Keywords: Hazard, Vulnerability, Perception, coping mechanisms and risk

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I remain wholly responsible for the conclusions, interpretations of facts and the shortcomings of this work.

Table of contents

List of figures

List of tables

Abbreviations

BMG	Badan Meteorology and Geophysical station
CVGHM	Centre for Volcanology and Geological Hazard Mitigation
DEM	Digital elevation Model
ECBP	Emergency Capacity Building Project
FGD	Focus group Discussions
IFRC	International Federation of Red Cross and Red Crescent societies
OCHA	Office for the coordination of Humanitarian Affairs
PGIS	Participatory GIS
SMCE	Spatial Multi-Criteria Evaluation
VCA	Vulnerability and Capacity analysis

1. Introduction

1.1. Background

Landslides are one form of land degradation which occur mostly in the mountainous and hilly areas of the world. They are defined as "the movement of a mass of rock, earth or debris down a slope" (Cruden, 1991). Some landslides can travel long distances over slopes damaging structures and elements that lie in their paths while others are less destructive and confined. Consequences of mass movements include loss of life and property damage plus severe economic setback especially in developing countries. The extent of potential damage varies enormously.

In Indonesia, landslides have occurred in and around towns that surround or are located on the slopes of the mountains and hill slopes. The landslides are mainly triggered by rainfall or earthquakes and aggravated by human activities such as deforestation, cultivation and construction. These factors destabilize the already fragile slopes (CONTOUR, 2001; Dai et al., 2002; Marfai et al., 2008). Despite the existing landslide hazards, large populations continue to live or are forced to live in areas which are highly prone to such geomorphic processes because of the fertile volcanic soils that are good for agriculture and the very high population pressure especially in Java. The concentration of infrastructure, property and increasing population density all make the society more vulnerable to landslides, even those of small magnitude (Blochl and Braun, 2005). Different people, groups and communities are seen to have different meanings and interpretations of vulnerability to landslides.

Blaikie et al (1994) define vulnerability as the characteristics of a person or a group of people in terms of their capacity to anticipate, cope with, resist and recover from the impact of a hazard. The degree to which populations and their property are vulnerable to a hazard varies over space and time. There is a need to assess vulnerability in reference to specific spatial and temporal scales. Measures such as terracing have been applied to reduce the impact of landslide disaster. But there is a need to understand the risk in terms of perception and the coping mechanisms for improved mitigation and preparedness actions. People tend to develop mechanisms to counter the effect of hazards. These mechanisms can only become effective solutions if they are incorporated / adopted during planning stages by all stakeholders and the local government.

To obtain knowledge on how and why some groups are more vulnerable than others requires community participation. Investigating into people's perception of their vulnerability can produce useful information that could be incorporated into the decision making process to help mitigate the landslide problems. The aim of this research is to perform a vulnerability analysis for 2 villages in Banjarmangu sub district, central Java province, Indonesia, using a participatory GIS (PGIS) approach based on the community knowledge. The focus will be mostly on the dominant form of landslide processes and their effects on the communities in the study area.

1.2. Research Problem

Landslides have severe negative impacts to not only human population but also their property and infrastructure. Population pressures have led to rapid developments taking place on hill slopes and the surrounding areas down slope. Modification of the hillsides has destabilized the materials that constitute them leading to negative impacts such as loss of life and injury to people and their livestock as well as of damage to lifelines, critical infrastructure, agricultural lands, housing, private and public assets.

In Banjarnegara Regency, Indonesia, a number of catastrophic landslides have occurred (United Nations Office for the Coordination of Humanitarian Affairs (OCHA), 2006). For example, on January 4th 2006 two landslides resulted in the destruction of properties, infrastructure and loss of human lives. These events buried 102 out of 184 houses (OCHA, 2006). Measures to address such a problem have not been effective due to a top-down approach which does not consider input from the concerned affected community. The knowledge community members possess about landslide mitigation and response is vital since their ideas suit their needs. However, the problem lies on how that local knowledge can be considered or mobilised in disaster management.

This study focuses on analysis of community structural and social vulnerability to the landslide hazard and its strategies to the effects of occurrence. Changes in the frequency and intensity of and exposure to landslides require a vulnerability assessment.

1.3. Motivation

Available land for human settlement and their activities such as agriculture is becoming scarce. Large populations are left with no choice but to move to the steep mountainous areas which are prone to geomorphic processes. This makes them and their property vulnerable to landslide events. To address these problems, there is a need to involve communities and groups of people especially those that are settled in these natural or man-made hazard prone areas.

In many developing countries such as Indonesia, community based approaches have been carried out to address mainly natural resource problems. The few that have handled natural hazards have often underestimated or overlooked the landslide processes because they frequently occur in combination with other events such as floods, earthquakes or volcanic eruptions (Aleotti and Chowdhury, 1999; Glade, 2003; Papathoma-Kohle et al., 2007). They have also concentrated mainly on hazard assessment and risk evaluation. Several methods and techniques have been developed to assess vulnerability to landslides (Tarantino et al., 2007; Van Beek and Van Asch, 2004). Most of these methods and techniques are too generic (Guzzetti et al., 1999) where as others require substantial amounts of data and powerful computers for processing (Chacón et al., 2006; Tarantino et al., 2007). Such studies in developing countries like Indonesia are faced with the problem of data availability; which is often unreliable and inappropriate. These studies are also based on a top-down approach; that does not sufficiently take into account the aspirations, capabilities and constraints of the local communities. A need to address the problems that arise as a result of occupying hillside terrains through community-based approaches is therefore required.

1.4. Research objectives

The purpose of this study is to analyse vulnerability and peoples' perceptions to landslides including the coping mechanisms employed using a participatory approach with Sijeruk and Kalilunjar villages as case studies. The proposed methodology will attempt to develop approaches for hazard assessment, risk perception and vulnerability assessment.

1.4.1. Specific objectives and research questions

1. To develop a community based hazard analysis based on catastrophic past events experienced by the village communities
    a. What is the local peoples' knowledge about the occurrence of landslides?
    b. Is there a possibility that the 2006 landslide pattern could recur and potentially damage any part of the Sijeruk community?
    c. Is there a relationship between the rainfall and landslide events in the study area?
    d. Which factors are directly or indirectly correlated to slope instability and what are their contributions to landslide susceptibility of the study area?
2. To explore the possibility of representing the village risk perception spatially
    a. What are people's perceptions surrounding the occurrence of the hazard in the study area?
    b. How to integrate the community risk perception into vulnerability assessment
    c. Assessing gender perceptions surrounding landslide occurrences
3. To identify and evaluate the coping strategies and landslide measures employed by the communities in both villages.
    a. What are the peoples' current actions/capacities to reduce and cope with the impact of the hazard?
    b. What are the government regulations and practices in relation to landslide hazard management
4. To carry out a vulnerability analysis based on socio-economic and structural parameters
    a. Which indicators of vulnerability are relevant for the analysis and application at village level?
    b. How to acquire adequate data for the factors contributing to and needed for vulnerability analysis?
    c. What criteria need to be used to develop vulnerability assessment in a poor data environment?
5. To evaluate the associated risk using the hazard susceptibility and vulnerability information obtained above.
    a. To what levels of risk are the people in the two villages?

1.5. Hypothesis

- The occurrence of a large landslide which caused many damage and casualties leads to a major change in risk perception among the local population and to a reduction of the vulnerability as people are willing to change their behaviour structurally.

- PGIS is effective in eliciting information and spatial components that are relevant to landslide risk assessment.

1.6. Research conceptual framework

The conceptual framework (figure 1-1) for this study is based on a vulnerability assessment at village scale. For this study, the analytical framework links the community's local knowledge to the elements at risk, hazard perception plus the adaptive measures. The involvement of local knowledge from the community people is fundamental in achieving feasible, equitable and lasting solutions to better manage disaster situations. The quality of decisions on what affects the community can be improved by the inclusion of a broad range of stakeholders who can bring important local knowledge and relevant perspectives to the planning process. Involvement of stakeholders especially the local community creates a sense of ownership and commitment to the process (Groenendijk and Dopheide, 2003). Integration of local and scientific knowledge will provide better results in landslides vulnerability assessment.

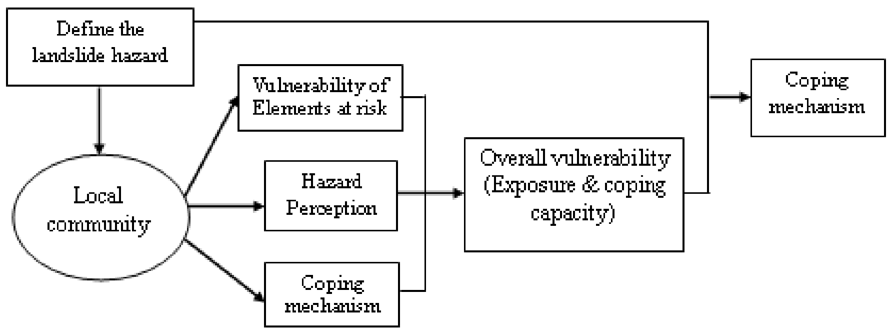


Figure 1-1: Research conceptual framework

Identification of damaged elements at risk helps to determine their vulnerability. Some factors such as the social factors will be used to determine vulnerability depending on age, gender, seniority, education, health, and socio economic status among others. Physical elements such as building structures will also be considered.
Capturing information regarding people's perception of risk is valuable in understanding their behaviour. It provides a view into what people value and the importance they place on certain factors. People make different decisions based on their own perception of risk which in turn is founded in their own education, experience, fear and emotional capacity.

1.7. Organization of the Thesis

The whole thesis comprises of eleven chapters as shown in figure 1-2. Introduction of the research, literature review, the study area and methodology are contained in chapters one to four respectively. Chapter five constitutes a reconstruction of the 2006 landslide event in Sijeruk village plus the analysis of the rainfall within the whole study area. Chapter six deals with hazard mapping and analysis to obtain a landslide susceptibility map. Chapters seven and eight consider local knowledge from the questionnaire survey in terms of perception and coping mechanisms. Chapter nine analyses the physical and social vulnerability of the elements at risk and chapter ten talks about risk. Chapter eleven is the final and last chapter and it talks about the conclusions, recommendations and study limitations. Chapter five to nine constitute the five main parts of the whole research work.

2. Literature review

2.1. Definitions

Hazard: UNISDR (2004) defines hazard as a potentially damaging physical event, phenomena or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. When these natural hazard events have drastic effects on human beings, they then constitute into a disaster (Blaikie et al., 1994). Twigg (2004) states that when a significant number of people are affected by a hazard, and are incapable of regaining or coping with losses, then that's a disaster.

Vulnerability: Vulnerability can be interpreted from various points of view as reported in the reviews by Cutter (1996), Glade (2003) and Siambabala (2006). Some definitions of vulnerability include:

Hollenstein (2005) expresses vulnerability as the expected loss for a given element at risk following a natural event which is a function of nature, event type and intensity and often requires a multi disciplinary approach to be estimated.

Blaikie et al (1994) define vulnerability as the characteristics of a person or a group of people in terms of their capacity to anticipate, cope with, resist and recover from the impact of a hazard.

According to Turner II et al. (2003), vulnerability can be described as a function of three overlapping characteristics that include exposure, sensitivity and adaptive capacity with interaction.

The above definitions show the dynamic nature of vulnerability which should be assessed taking into consideration temporal and spatial aspects (Papathoma-Kohle et al., 2007).

Risk: It's defined as the probability of harmful consequences or expected losses resulting from the interaction between natural or human induced hazards and vulnerable conditions. The level of risk is seen as a result from the intersection of the hazard with the value of the elements at risk by way of their vulnerability since people consciously place themselves at risk from natural hazards such as landslides due to lack of alternatives, dynamic nature of the hazard, unpredictability of the hazard, etc (Glade et al., 2005).

According to Fuchs (2009), a functional relation between the hazardous event and the elements at risk exposed is prerequisite for risk. Exposure defines the susceptibility of the elements at risk to be affected by the hazard due to their location in the area of influence of the process and lack of physical resistance (Fuchs, 2009). The relationship between hazard, elements at risk, vulnerability and risk is shown in figure 2-1 below.

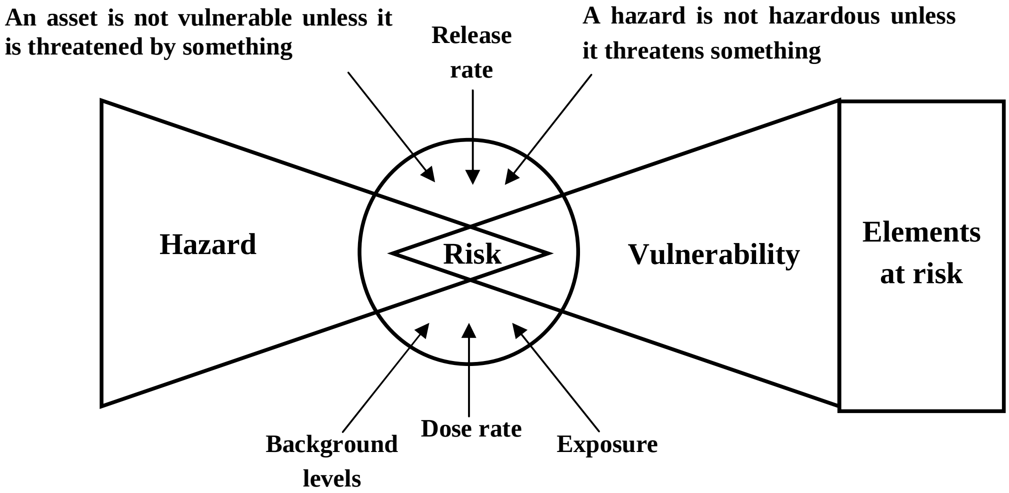


Figure 2-1: Conceptual relationship between hazard, elements at risk, vulnerability and risk (Alexander 2002 in Glade 2005, Fuchs 2009)

Risk assessment and management of landslide comprises of the estimation of the level of risk, deciding whether or not it's acceptable, and applying appropriate control measures to reduce the risk when its levels can't be accepted (Dai et al., 2002). The present context not only includes the analysis of the landslide hazard and risk, but also vulnerability identification of specific stakeholders. Examples of the types of magnitude that a building can be subjected to depending on the type of landslide process are shown in figure 2-2 below.

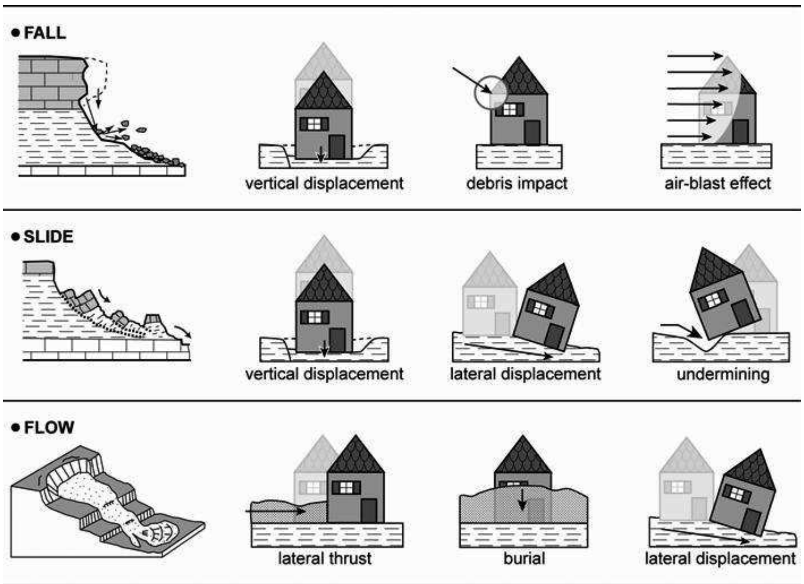


Figure 2-2: Types of landslide processes plus associated impact on buildings (Puissant et al., 2006)

2.2. Vulnerability Assessment

Vulnerability assessment comprises a systematic evaluation of households, livelihood, groups of people, a community or system with respect to a hazard (Villagran de Leon, 2006). It can be applied across a full range of land use planning and management tools providing fundamental data upon which emergency-response plans are based (Deyle et al., 1998). Despite all the limitations, complex and sometimes even unsolved problems, it is an economic and political necessity to assess vulnerability to landslides (Glade, 2003).

Vulnerability assessment to a given landslide involves understanding its interaction with the affected elements and the community. For landslides, the damage and losses depend on factors such as run out distance, volume and velocity of sliding, elements at risk (population, buildings and other structures), their nature and proximity to the slide (Dai et al., 2002). Social factors such as wealth and housing characteristics also play a significant role in determining vulnerability on parts of some population subgroups (Cutter et al., 2000). Polsky et al.(2003) proposed a set of eight steps for conducting vulnerability assessment. These include:

a) Definition of the study area in tandem with stakeholders

b) Becoming aware of the study area and its contents

c) Hypothesizing who is vulnerable to what

d) Developing a causal model of vulnerability

e) Finding indicators for the components of vulnerability

f) Weighting and combining the indicators

g) Projecting future vulnerability

h) Communicating vulnerability creatively.

Assessment of vulnerability is somewhat subjective and largely based on the statistics of historic records (Galli and Guzzetti, 2007). It has been carried out by first analyzing historical disasters, identifying and systemizing the vulnerable conditions from damages and losses experienced by different communities (Villagran de Leon, 2006).

Landslide vulnerability is still considered a difficult process since it depends on different damage degrees from the different types of landslide processes that need to be evaluated separately and also the level of risk due to landslides is often several orders of magnitude lower than those of other hazards (van Westen et al., 2006). A number of studies have tried to examine both risk and community vulnerability and very limited have tried vulnerability specifically (Papathoma-Kohle et al., 2007).

Wood et al.(2002) generated a vulnerability methodology from a community planning process that integrated inputs from stakeholders and technical advisors. This process was applied particularly to hazards such as landslides, liquefaction and tsunami inundation associated with earthquakes. The advantage of this method is that it can be repeated in various areas thereby building networks of resilient communities.

The assessment of landslide hazard and risk has become a major topic of interest for many professionals as well as community and local administrations in many parts of the world

(Aleotti and Chowdhury, 1999). To achieve the goal of determining the risk posed by existing or future slope failures, information on landslide hazard and vulnerability is required (Castellanos Abella, 2008; Galli and Guzzetti, 2007).

2.3. Vulnerability concepts

Several concepts relating to vulnerability have been developed. Bohle (2004) explains the concept of vulnerability as one with a double structure having an external and internal side (figure 2-3). The external side is related to exposure while the internal side is related to coping capacities. The influences of the exposure side of vulnerability include human-ecological perspectives, political economy approaches and entitlement theory and those of the internal side include action theory approaches, crisis and conflict theory and models of access to assets. In this model, there is a relationship between vulnerability, coping capacities and assets such as infrastructural, economic, socio-political, ecological and personal. Also with this model, there is less vulnerability when people control more assets that increase their capacities to cope with risks and the related disasters. This model helps to explain the causes and origins of vulnerability.

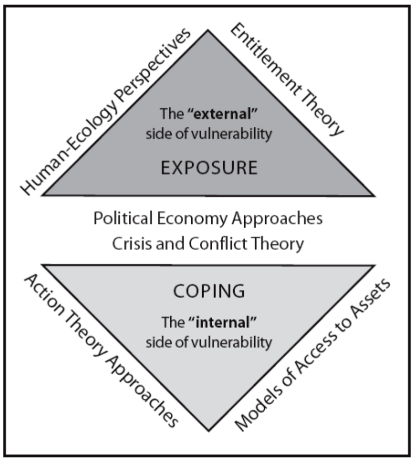


Figure 2-3: The two sides of vulnerability

Birkmann and Bogardi 2004 and Cardona 2001 (cited in Birkmann (2006)), developed an onion model (BBC) (figure 2-4) regarding risks and vulnerabilities. This model is a combination of their conceptual works. It considers environmental, social and economic spheres in defining vulnerability, coping capacities, risk and their reduction measures. The framework has linkages between sustainable development and vulnerability reduction, underlining the necessity to give account to environmental considerations on which human conditions depend (Villagran de Leon, 2006). It also promotes a problem solving perspective within three key thematic spheres that include how to link vulnerability, human security and sustainable development, the need for a holistic approach to disaster risk assessment and debate on developing casual frameworks for measuring environmental degradation in the context of sustainable development (Birkmann, 2006).

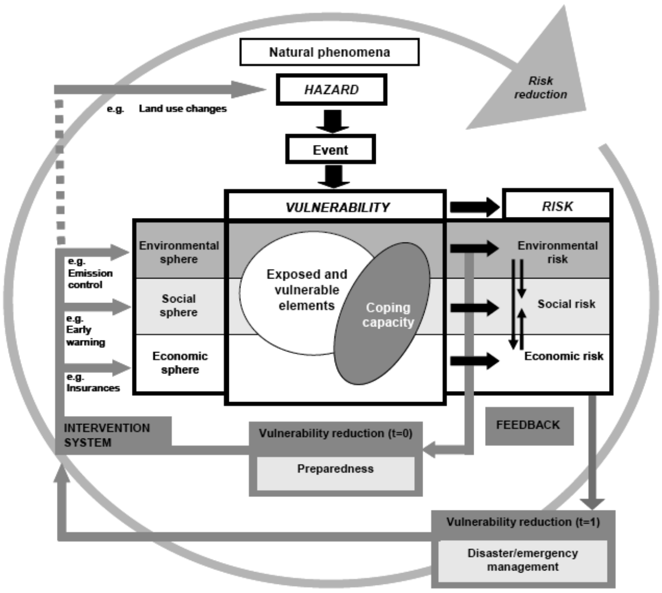


Figure 2-4: The BBC conceptual model (Birkmann, 2006)

2.4. PGIS and Vulnerability Assessment

Participatory development is defined as a partnership which is built upon the basis of dialogue among the various actors, during which the agenda is jointly set and local views and indigenous knowledge are deliberately sought and respected (UNDP 1998 cited in Kienberger & Steinbruch 2005). In this practice, the participants are more of actors than beneficiaries. This practice combines a range of geo-spatial information tools and methods such as satellite imagery, aerial photography, sketch maps, Participatory 3D models (P3DM), Global Positioning Systems (GPS), and Geographic Information Systems (GIS) to represent local knowledge in a spatial format; there by aiding discussion, information exchange, analysis, decision making and advocacy (Rambaldi et al., 2005). PGIS brings about community empowerment (processing own spatial information) through measured, user-friendly and integrated applications of geo-spatial technologies and communication among stakeholders (Kienberger and Steinbruch, 2005; Rambaldi et al., 2005). According to Twigg (2004), participatory approaches in disaster management are valuable because:

- They enable people to explain their vulnerabilities and priorities, allowing problems to be defined correctly and responsive measures to be designed and implemented.
- The principal resource available for mitigation or responding to disasters is people themselves and their local knowledge and expertise.
- Participatory work takes a multi-track approach dealing with the complexity of disasters and the diversity of factors affecting people's vulnerability to them.
- The process of working and achieving things together can strengthen communities' thereby increasing people's potential for reducing their vulnerability and empowering them to tackle other challenges, individually and collectively.

- Participatory risk reduction initiatives are likely to be sustainable because they build on local capacity, the partnerships have "ownership" of them and they are more likely to be compatible with long term developments.
- Participatory approaches maybe more cost-effective in the long term because they are more likely to be sustainable and the process allows ideas to be tested and refined before adoption.
- External agents cannot cope alone with the enormous risks facing vulnerable populations. Local people can bring a wealth of resources, especially knowledge and skills, to help reduce risk.
- Finally, working with local people can help professionals to gain a greater insight into the communities they seek to serve, enabling them to work more effectively and produce better results.

Today, different agencies (ActionAid, 2004; ADPC, 2004; MDC Inc, 2009) use different methodologies to carryout community based vulnerability studies but the application of PGIS is still in its infant stages. Evidence shows that majority risk management and response programs carried out have had top-down approaches that have failed to address specific local needs of vulnerable communities. They ignore the potential of local resources and capacities and in some cases have increased people's vulnerability (Kienberger and Steinbruch, 2005). PGIS enables the vulnerable people to get involved in planning and implementing measures along with local, provincial and national entities through partnership (Kienberger and Steinbruch, 2005; Peters Guarin, 2008; Rambaldi et al., 2005). According to McCall (2004), participation is the essence and key to P-mapping and PGIS; that has the potential to put the community on equal status with experts. It may be the only resource that local groups especially the resource poor have ownership of.

2.5. Perceptions

The way in which the characteristics of a natural event are perceived, the nature of personal encounters with the hazard and factors of individual personality in combination, account for the variation of people's perception of a specific natural hazard and appear to be independent of or have relatively minor overall influence on the common socio-economic indicators (Kates, 1971). Kates (1971) , further highlights that the perceptions of magnitude, frequency, duration and temporal spacing appear to be the most significant from the many possible characteristics of the natural event while recentness, frequency and intensity appear most critical for personal experience. The most relevant personality factors include fate control, differential views of nature and tolerance of dissonance creating information. According to (Kates, 1971), the perception of a hazard can be divided into three groups

a) Acceptance

This includes fatalistic tendencies where the people living in the hazard prone area treat the hazard as a part of their lives or an act of God.

b) Domination

This involves having a controlling influence of the hazard through scientific research such as engineering or use of technology.

c) Adaptation

It requires one to adjust to the environmental conditions by looking at both the human and physical systems during response.

The interaction of the human use and natural event systems creates hazard events that people perceive then respond to. How the affected population reacts can modify both systems mentioned above (Kates, 1971) (Figure 2-5).

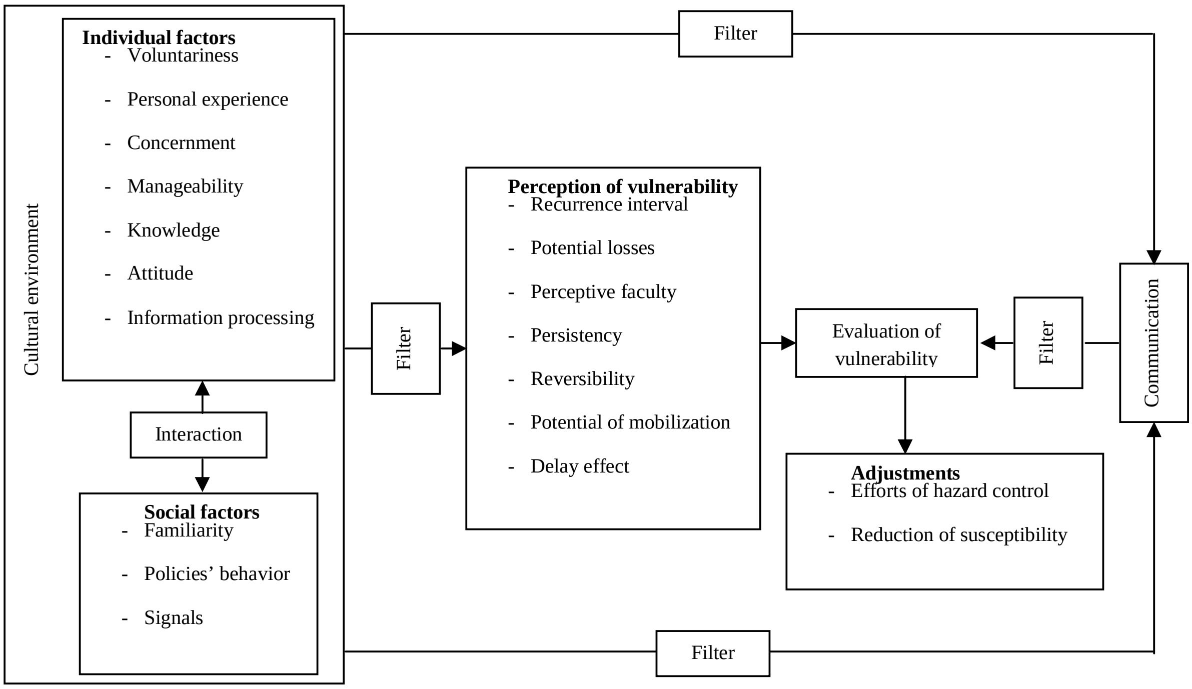


Figure 2-5: Interaction of human use and natural events (source: Kates 1971)

There is a general tendency to imply that lay people perceive while the technicians and experts know (Nathan, 2008). In this research, reference is made to the lay local people and not technical experts who represent modern moral authorities. Exploring people's perceptions of the disasters that affect them helps to draw a clear picture of the local vulnerabilities and also to understand them from the point of view of the people living under such conditions (de Dios 2002). This is so since human behaviour determines to an extent the degree of vulnerability. According to Dwyer et al. (2004), the role of perception can be significant when studying social vulnerability measures. If people perceive risk to be real, they will act accordingly (Slovic, 2000). Hence, obtaining/gathering information about people's perception is valuable in understanding their behaviour. Perception of risk / hazard provides a view into what people value and what importance they place on certain factors in the event of an actual natural hazard impact (Dwyer et al., 2004). Such information is useful in determining how people will recover if these factors are affected during a hazard event. According to (Chen et al., 2008), risk perception is necessary for hazard mitigation. Once understood, disaster and vulnerability can be analyzed together with past experiences and the current situation in order to predict the future.

2.6. Coping strategies

Blaikie et al (1994) defines coping as the manner in which people and organizations act using existing resources within a range of expectations of the situation to achieve various ends. Twigg (2004) refers to coping mechanism or coping strategies as the application of indigenous knowledge in the face of hazards such as landslides. Coping strategies are sometimes referred to as capacity. When people know that an event will occur in future because one has happened in the past, they often find ways of how to deal with it (Douglas, 1985 in Blaikie 1994). The choice of skills and resources applied varies according to the nature of the hazard threat, the capacities available to deal with it and to a variety of community and individual priorities that can change during the course of the disaster (Twigg, 2004). They are also dependent on the assumption that the event will follow a similar pattern and the people's action will be reasonable guide for similar events (Blaikie et al., 1994).
According to O'hare and Rivas (2005), the coping ability of a community faced with hydro-meteorological hazards such as a landslide is a function of three factors which include the:

1. Frequency, duration and intensity of the hazard and whether its effects will increase or decrease with climate change
2. Vulnerability of the community; reflected in its ability to cope with the hazard
3. Adaptive community responses that are influenced by the technical resources available to raise the community's capacity to handle the hazard effects (mitigation).

The adaptive capacities can be seen either as 'hard' or 'soft'(O'hare and Rivas, 2005). Hard adaptation involves a "top-down" approach to the problem while its vice-versa for the soft adaptation. The differences between hard and soft approaches include:

Table 2-1: Adaptive capacity approaches

	Hard approach	Soft approach
1	Solutions are seen through application of physical measuring and monitoring techniques	Call for greater community awareness and participation
2	Comprises of structural management programs that involve large engineering works and designs	Non-structural solutions to the disaster are recommended
3	Examples include hazard warning systems and installation of physical structures to be able to tolerate the effects.	Examples include landuse planning, risk assessment, Government support and insurance support.

Modified from O'Hare, 2005

2.6.1. Vulnerability and capacity assessment

Capacity is defined as "the ability of vulnerable areas, populations, institutions and livelihoods to resist and recover from the negative impacts of hazards" (E.C.B.P, 2009). They can also be referred to as material, attitudinal, cultural and spiritual strengths existing within a community that can be used to mitigate, prepare for and cope with damaging effects of hazards such as landslides. Capacities are the positive conditions and resources which increase the ability of a community to deal with hazards and risk.

Participatory vulnerability and capacity assessment is a systematic process that involves communities and other stakeholders in an in-depth examination of their vulnerability and at the same time empowers or motivates them to take appropriate actions (ActionAid, 2004). With a VCA, a greater understanding of the nature and different levels of risk faced by vulnerable people is explored for use in decision making on ways to achieve safe conditions whether short or long term (E.C.B.P, 2009). A VCA also helps in finding means of how to maximize local capacities and resources in supporting the local development process (de Dios 2002; E.C.B.P, 2009).

A range of VCA tools have been developed and tested by NGO’s with emphasis on participatory and people oriented approaches (E.C.B.P, 2009; Peters Guarin, 2008). Such NGO’s include Oxfam, Action Aid, international federation of the Red Cross (IFRC), etc. Unlike in GIS where the level of risk is deducted by integrating various layers of information; a VCA uses historical analysis of the disaster data to provide the information about the levels of risk (E.C.B.P, 2009; International Federation of Red Cross and Red Crescent societies, 2006).

3. Study area

3.1. Location and extent

The study area (figure 3-1) is located in a mountainous area in Banjarmangu sub district Central Java province in Indonesia. It comprises of two neighbouring villages - Sijeruk and Kalilunjar; found in the south eastern part of the sub-district that is located in the Merawu catchment. The population of these two villages is 5,041 people comprising mostly of small farmers or agricultural labourers with 2,225 people living in Sijeruk and 2,816 people in Kalilunjar. Geographically, the study area is bound by latitude 7.346^{o} to 7.311^{o} S and longitude 109.693^{o} to 109.726^{o}E. It has an altitude ranging between 349 – 1237 meters above sea level with an annual precipitation average of about 3777mm.

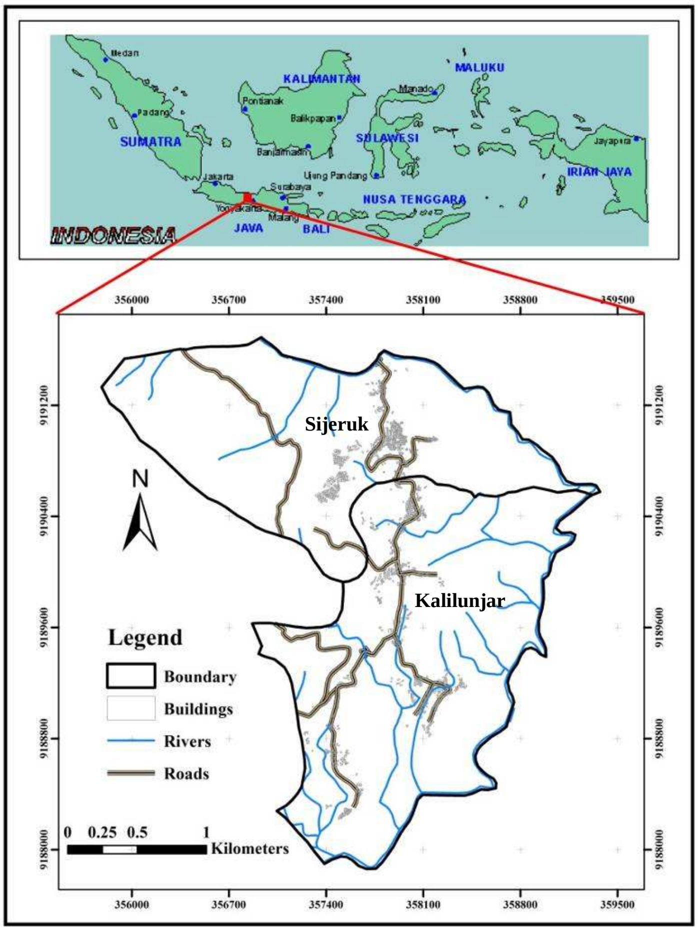


Figure 3-1: Location of the study area

3.2. Geology and geomorphological units of the study area

Within the study area, the geology comprises mainly of five formations – based on a map of scale 1:100,000 and DEM visualization. The most prevalent geologic unit contains some quantities of clay that renders it susceptible to slope failure. Some structural discontinuities appear in the central part of the study area. The formations are presented in table 3-1 and figure 3-2.

Table 3-1: Geological units of the study area

Code	Geological unit	Lithology	Landform
Tmph	Halang formation	Tuffaceous sandstone, conglomerate, marl and claystone	Severe mass wasting
Tptb	Breccia member of Tapak formation	Volcanic breccia and tuffaceous sandstone.	Monoclinical ridge
Tmpi	Intrusives	Dioritic rocks, gabbro porphyry	Volcanic cone severely dissected
Qjo	Patukbanteng Jeding Morpholet	Lahar and alluvium consisting of volcanic debris.	Volcanic cone severely dissected
Tmp	Penosogan Formation	Alternating conglomerate, sandstone, claystone, marl, tuff and rhyolite.	Volcanic cone severely dissected

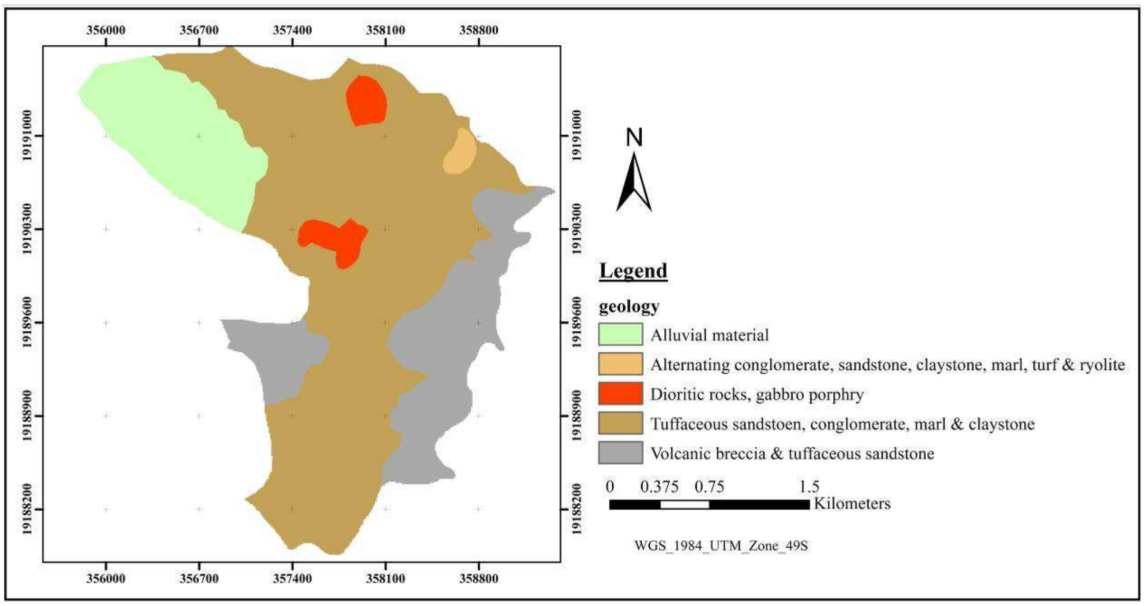


Figure 3-2: Geological map of the study area

3.3. Topographic condition

The study area was classified into seven classes based on the USDA classification to better understand its topographic condition. As can be seen in table 3-2, Kalilunjar village is mainly dominated by a hilly topography (38%) in the north-south direction while the main topographic condition in Sijeruk is moderately sloping (33.61%) in the central and eastern parts. It should also be noted that not much of the area in both villages is flat (2.25% Kalilunjar and 1.58% Sijeruk). Figure 3-3 shows a topographic visualization of the study area.

Table 3-2: Slope classes within the two villages of the study area

Village	Description	Slope Gradient Classes (^{o})	Hectares	Percentage
Kalilunjar	Flat	0 – 3	8.5	2.25
	Undulating	3 – 8	37.77	9.99
	Moderately sloping	8 – 15	90.69	23.99
	Hilly	15 – 30	143.64	38
	Moderately steep	30 – 45	78.22	20.69
	Steep	45 – 65	19.14	5.06
	Very steep	> 65	0.03	0.01
	Total		377.99	100
Sijeruk	Flat	0 – 3	4.83	1.58
	Undulating	3 – 8	39.05	12.80
	Moderately sloping	8 – 15	102.52	33.61
	Hilly	15 – 30	84.03	27.55
	Moderately steep	30 – 45	60.63	19.88
	Steep	45 – 65	13.91	4.56
	Very steep	> 65	0.05	0.02
	Total		305.02	100

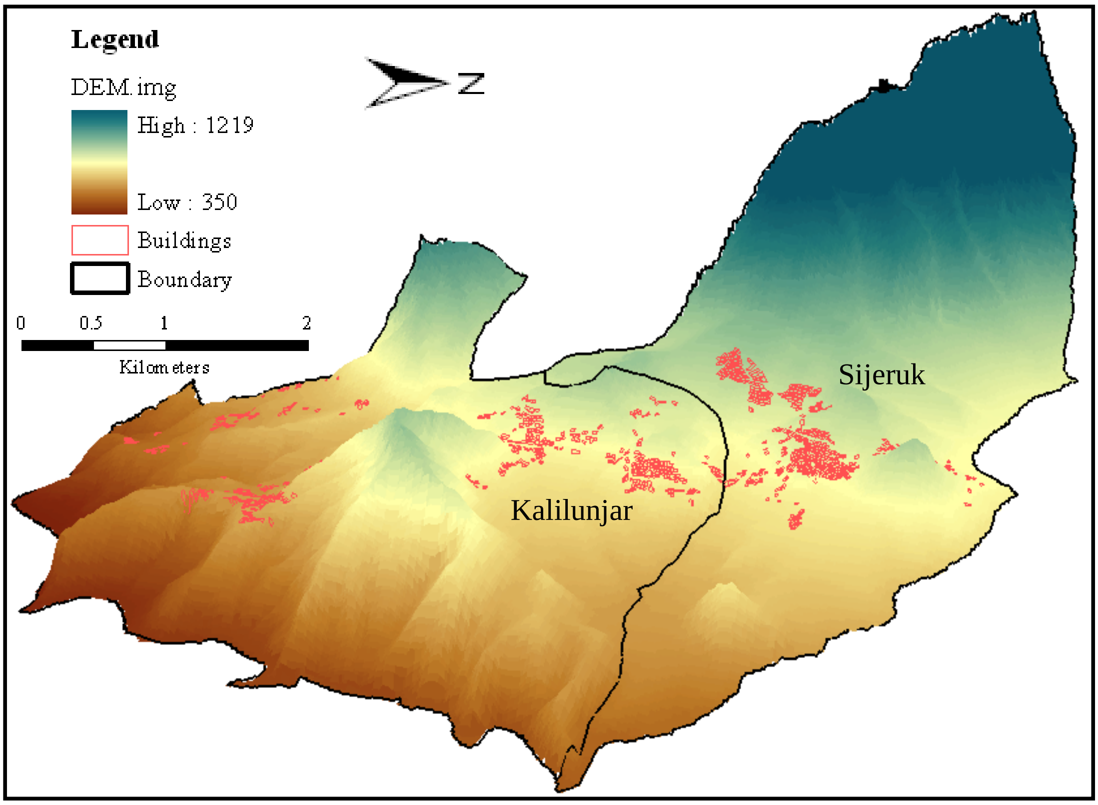


Figure 3-3: Topographic visualization of the study area

3.4. Landslide Casual factors

The factors that influence the rate of slope movement can be grouped into 2 origin types; preparatory and triggering factors (Griffiths, 1999). Preparatory factors make the slopes susceptible to movement without actually initiating them while triggering factors are external stimuli that produce change in the stress-strain relationship in the slopes resulting in movement. Among the main factors that control land sliding are geological and geomorphological conditions, climatic, weathering and manmade factors. Some of these factors are discussed below in relation to the study area. This kind of information complements indigenous knowledge and is essential for managing the environment. Also the causes listed below often occur in combination.

3.4.1. Land use

A 2009 Landsat image was classified and land use composition of the study area are shown in figure 3-4 and table 3-3 respectively. The northern moderately sloping terrain in Kalilunjar is dominated by mainly mixed cropping and rice fields and in the northeast the moderately steep slopes contain natural forests and mixed cropping. To the east of this same village, river Merawu acts as a boundary and the settlements are mainly found in the central part that is between hilly and moderately sloping terrain.

In Sijeruk, the natural forests are predominant in the west on mountain Pawinihan whose terrain is moderately steep to steep. The rice fields are found mainly in the eastern part of this village while the settlements are located in the central part in the north-south direction. Both the rice fields and settlements are within the moderately sloping terrain. Mixed cropping in Sijeruk village is randomly distributed within the moderately sloping to hilly terrain. Mixed cropping consists mainly of an intercropping of salak, cardamom, and the albacia tree. Figure 3-4 shows the main land cover types in the study area.

Table 3-3: Major land use types in the study area

Village	Land use types	Hectares	Percentages
Kalilunjar	Forest	31.41	8
	Rice fields (Terraced)	40.59	10
	Settlement	18.18	5
	Water	19.53	5
	Shrubs & Bushes	49.5	13
	Mixed cropping	229.23	59
	Total	**388.44**	**100**
Sijeruk	Forest	13.05	4
	Rice fields (Terraced)	81.63	26
	Settlement	16.47	5
	Water	12.42	4
	Shrubs & Bushes	36.72	12
	Mixed cropping	153.99	49
	Total	**314.28**	**100**

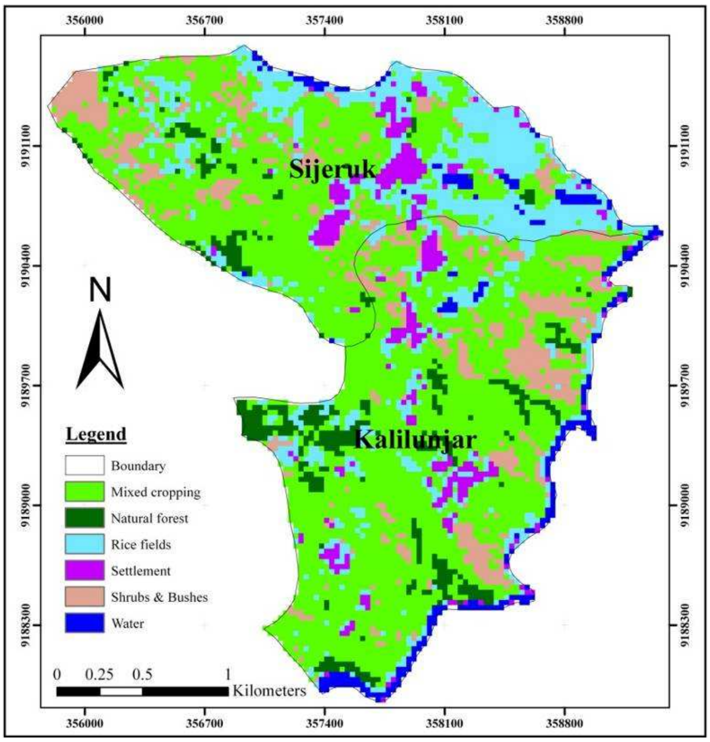


Figure 3-4: Major land cover types in the study area

Terrace - bench fields have been established since cultivation is being done on the slopes. Majority of the people in the two villages are both commercial and subsistence farmers.

3.4.2. Seismicity

Seismic activity can increase the possibility of land sliding in many ways. It causes the loss of strength in slope materials and also makes a slope to become unstable by inertial loading (Msilimba, 2007; Msilimba and Holmes, 2005). According to (Keefer, 2002), the number and volume of landslides triggered by any given earthquake depends on the earthquake magnitude, although geologic and topographic conditions also play an important role.

Although some structural discontinuities pass through both villages, Sijeruk has felt the effects of the earthquakes that are occurring in the adjacent villages unlike Kalilunjar. The magnitudes of these earthquakes in and around Kalilunjar are not big enough to cause major slope failures. Not a lot of information could be extracted from the data provided by Badan Meteorology and Geophysical station (BMG) apart from the magnitude, location and depth of the events recorded for the period between 2004 and July 2009. Even if damage from earthquakes is not localised it can be concluded that no significant seismic activity is taking place in both villages. Its mainly in the neighbouring villages though the magnitudes are too low to have a major effect on both Sijeruk and Kalilunjar. A correlation analysis of the seismic activity associated with landslide occurrence could not be established due to limited data. Therefore seismic activity was ruled out as a trigger mechanism. Table 3-4 shows the events recorded in Kalilunjar village between 2004 and 2009.

Table 3-4: Seismic events in the study area

No.	Date	Time	Latitude (S)	Longitude (E)	Depth (m)	Magnitude
1	5th January 2006	22:07:09	7.33	109.72	33	2.4
2	24th May 2009	09:56:01	7.34	109.71	5	3.5

Source: BMG, 2009

3.4.3. Precipitation

Rainfall is one of the significant factors in the occurrence of landslides. Its infiltration on a slope may result in changing the soil suction and positive pore pressure or main water table, reducing shear strength of both rock and soil (Lan et al., 2003).

Due to the relatively high altitude, precipitation values in the study area are high with an average of 312mm per month. There is one distinct wet season (October – March) that dominates over the dry season (June to September). The high average annual rainfall rate and the rain season cause a high moisture content which should be seen as predisposing factors creating a low margin of instability in the study area. More discussion about this in later chapters. Figure 3-5 shows the average monthly rainfall within the study area.

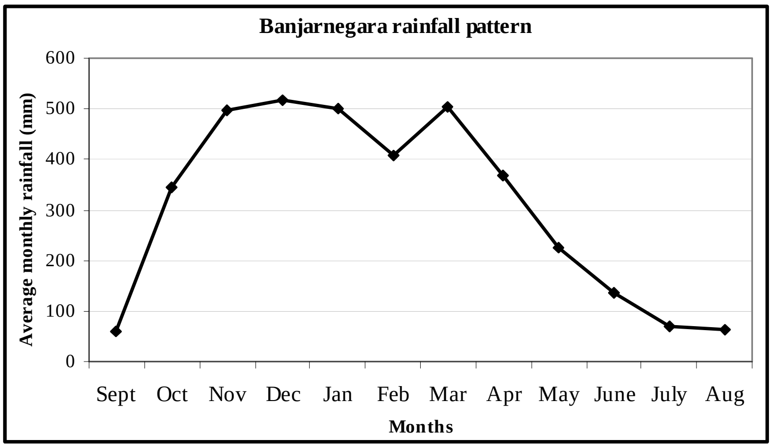


Figure 3-5: Average monthly rainfall within the study area

3.4.4. Human activity

Although landslides are a natural geologic process, their occurrence is also controlled by human activities which increase the margin of slope instability. This is done for various reasons including digging away large parts of the slope to create room for houses and road construction, construction of foot paths, dam building and building of terraces for agricultural practices. In the study area, the houses are constructed at the base, along or on top of steep cut slopes, old fill slopes and on existing old landslide areas.

3.4.5. Deforestation

It is considered as a preparatory causal factor to land sliding. According to Butler (1978) (cited in Msilimba, 2007), the manner of deforestation and subsequent ground treatment affects the degree and rate of strength reduction. In the study area, logging is taking place in both natural and man-made forests but is very predominant in the man-made forests where the albacia tree - the main specie, is prematurely harvested due to increased demand for its wood.

4. Research methodology

4.1. Methodology

The study was carried out in three phases: pre-fieldwork, fieldwork and post-fieldwork as shown in figure 4-1. Activities in the pre-fieldwork phase included identification of the available data, design of the questionnaire, and preparation for the fieldwork. All these together were used to come up with a sampling design to be used during fieldwork.

For both the investigated communities, the following procedures were carried out during the fieldwork phase.

a) Contact with the local authorities and discussing with them the objectives of the fieldwork

b) Field observation visit to the landslide areas in the company of the local authorities

c) Collection of socio-economic data at household level by means of the questionnaire designed in the pre-fieldwork phase

d) Mapping of critical infrastructure such as schools, public buildings etc, using a topographic map and GPS

e) One day focus group discussions in each village where participation was open to both women and men.

Secondary data from the relevant offices was also collected during this phase to compliment the primary data.

The post-fieldwork phase contained a lot of activities that included: image interpretation for the landslide inventory map, creating a database for the analysis, integrating and modelling in a GIS of both the primary and secondary data collected. A final risk map is obtained in the end. Finally conclusions and recommendations are drawn inline with the research interests. Overall, the research process takes into consideration knowledge, perception and adaptive capacity of the community in relation to the landslide hazard taking place in the study area.

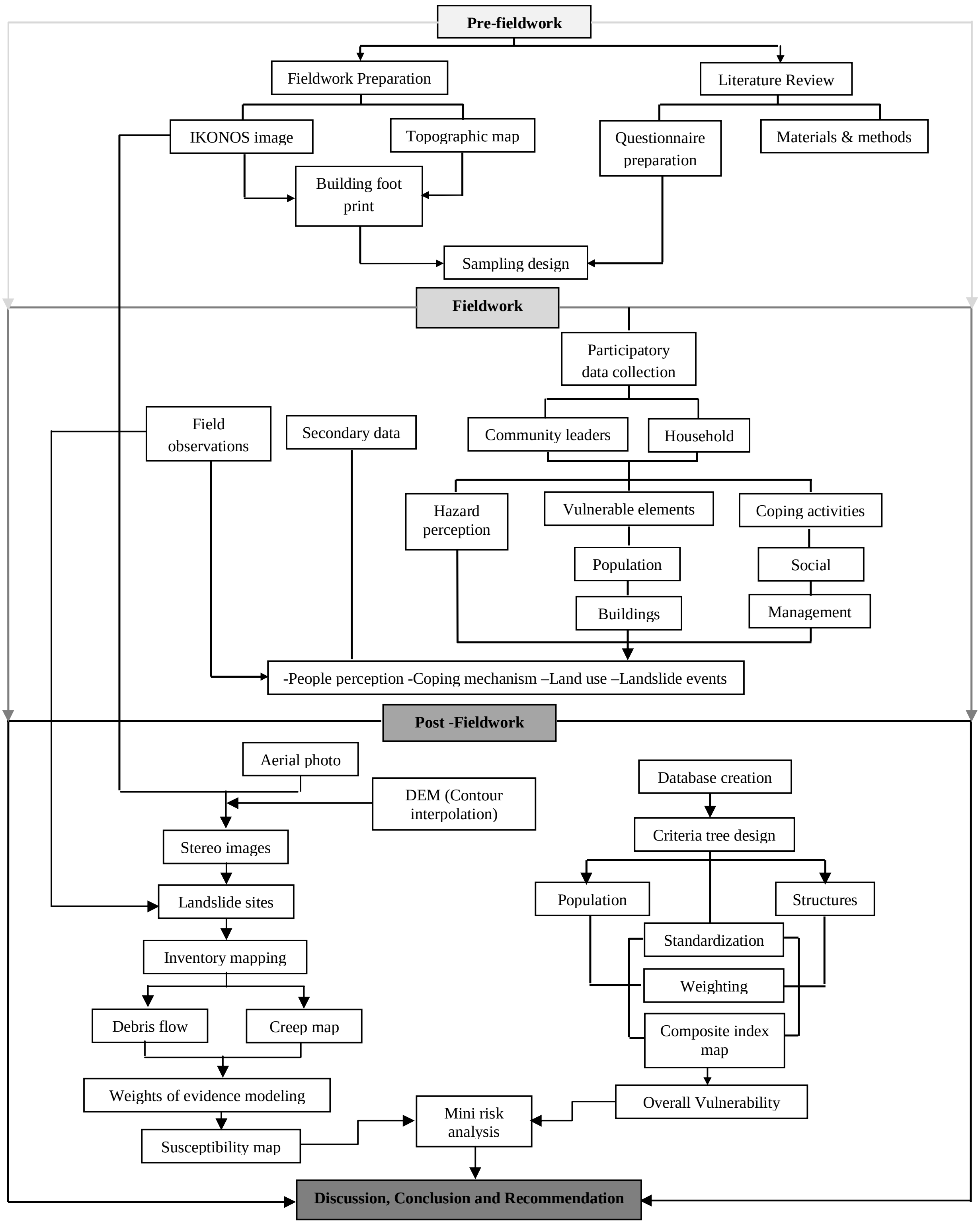


Figure 4-1: Flow chart of the research process

4.1.1. Materials

The initial step of the whole process involved searching for, obtaining and assessing the data necessary for the research as shown in table 4-1 below.

Table 4-1: Data requirements

Parameters	Attributes	Source
Occurrence		
1. Landslides	Type, magnitude, time, etc	Image interpretation, field survey, landslide incident reports from the village office and by interviewing people
Environmental parameters		
2. Topographic map	DEM (10m pixel size)	Bakosurtanal at scale of 1:25,000
3. DEM derivatives (Slope / aspect maps)	Slope classes, angle / direction	DEM at 10m pixel size
4. Temporal land use maps	Changes in land use, vegetation density	Field surveys, image interpretation – IKONOS 30m resolution
5. Geology	To assess potential risk due to the geological setting	Geological Research and Development Centre, Bandung at a scale of 1 : 100.000
Triggering factors		
6. Rainfall	Precipitation, duration and intensity from 2003 - 2009	BMG – Geophysical institute
7. Seismic data	Location, magnitude and time of occurrence from 1999 – 2009	BMG - Geophysical institute
Others		
8. Census data	Population characteristics	Village office – yearly data
9. Buildings	Foot print map and structural types for sampled buildings	Image interpretation, field surveys
10. IKONOS image	Elements at risk mapping	Geo-serve at 30m resolution

Some of the parameters needed to make a landslide susceptibility map had to be extracted from the obtained data as shown in table 4-2 below:

Table 4-2: Data preparations

	Parameter	Process
1	Land use	Supervised classification of the IKONOS image and validated during fieldwork
2	Lithology	Used the geology map provided by Geological Research and Development Centre plus image interpretation of the colshadow grid
3	River network	Digitized from the topographic map
4	Road network	Digitized from the topographic map
5	Slope gradient	Created from the DEM
6	Landslide locations	Image interpretation and digitisation from both aerial photos and IKONOS imagery

4.2. Data collection

The community in this research was the main source of information to achieve the proposed objectives. Field surveys were undertaken to get an insight into the spatial distribution and characteristics of the past landslide events and the elements at risk. Two main data collection activities were carried out during fieldwork:

1. Primary data collection based on questionnaire interviews at household level, focus group discussions at community level and field observations for verification.

2. Secondary data collection which involved gathering reports and additional information from literature review and particular institutions / offices from within the study area as shown in the table 4-1.

4.2.1. Interviews

Interviews by means of a structured questionnaire were conducted with 108 respondents from Sijeruk (46 respondents) and Kalilunjar (62 respondents) villages. This was carried out in order to obtain the degree of awareness to landslides amongst the populations, to gauge their perceptions with regard to the causes and also review their coping strategies.
Historical profiling of the landslide events was done with the help of the village officers. Table 6-1 shows an inventory of the events that were recorded to have happened or are still happening in form of creep.

4.2.2. Focus group discussions

These discussions were used to obtain information regarding landslide trends, past occurrences, loss of lives and property, preparedness plan, relief and post management programs implemented in the past, their effectiveness and decision making process in local disaster management. During the discussions, there was difficulty in communication due to language barrier.

4.2.3. Field observations

These were undertaken to observe and record key features such as land use and location of past landslide events.
A summary of the information sources used during fieldwork to obtain the required information are shown in table 4-3 below.

Table 4-3: Data information sources

Information source	Target group	Purpose
Questionnaires / Structured and semi structured interviews	Households	These were used to obtain information on the people's impressions of what landslides are, where they occur, the threat from future landslides.
Focus group discussion	Zone leaders and selected community persons	Here information regarding landslide trends, past occurrences, loss of life and property, etc plus the criteria for assessing the hazard was obtained through discussions
Field observation	Selected community persons	They consisted of taking GPS readings of locations of past landslides, critical facilities, etc

Modified from Peters Guarin (2008)

4.3. Sampling method

A representative sample size was obtained by using a selective – random sampling strategy. This type of sampling strategy was applied because the survey couldn't cover all the households in the two villages of the study area. A total of 108 respondents – 46 from Sijeruk and 62 from Kalilunjar were obtained. For each sampled household, one individual, usually the head of the house, was selected. In the absence of either the head or an adult, any member from that particular household older than 20years was selected as a respondent. Also two focus group discussions – one in each village were held. With the guide of a blown out image of the study area, the focus group discussions were used to gain and evaluate landslide knowledge about the communities in the study area.

5. Reconstruction of the 2006 landslide event

In this chapter, a reconstruction of the January 4th 2006 landslide events is carried out. The disaster mechanisms, causal relationships to the events are also discussed to an extent. Land use / Landcover change for three different years is analysed to examine the conversion from wet to dry cultivation. And finally the rainfall events in the study area are analysed in relation to the occurrence of the landslides using the Gumbel distribution and rainfall thresholds for the initiation of landslides are also determined.

On 4th January 2006, two landslides occurred in the Gunungraja hamlet, Sijeruk village, Banjarnegara district, central Java Province. The first event occurred around 1am with the initiation point in the upper slopes of the Pawinihan Mountain with a scarp of 100m length and 50m width size. The second event happened at 5am in the morning and its initiation point was in the middle slopes with approximately 150m long and 50m wide size. These landslides have so far been the worst disaster in the history of the regency that resulted in the death of 76people, 14 injuries and 13 missing. Approximately 102 housing units were destroyed. Destruction was also extended to farmland, places of worship, and a school. The Pawinihan Mountain has a slope between 15 – 60% and the affected community was located on the southeast slopes with 5 – 15%.

Strange rambling noises / sounds followed by shaking were heard by some people in the community at around 1am in the night. The chief of the hamlet then issued a warning alert by use of the kentogan – it's a wooden gadget used to give a warning signal. More than half of the community population responded and left their homes for either the village office or the mosque to pray while others stayed inside their homes. After a few hours with nothing happening, even those who had left their homes returned only to be trapped by the second landslide that happened at 5am on the 4th January 2006. Figure 5-1 shows images of the 2006 Gunungraja landslide, search and rescue efforts plus media coverage of the event.

Sunday
The Jakarta Post
January 8, 2006

Search called off for landslide victims

Slamet Susanto
The Jakarta Post/Banjarnegara

Rescue workers on Saturday called off the search for bodies buried in the Banjarnegara landslide disaster, with the total death toll now at 58. Revising down earlier estimates that over 100 people had gone missing, the search and rescue *Antara* news agency.

Local government officials announced the estimate after a meeting of chiefs of hamlets in Sijeruk village. At the meeting it was revealed that the total number of residents in the village was 655, with 525 now living in temporary shelters, 43 who worked in other cities and 13 who were at the hospital.

As of Saturday, the search and rescue team there had recovered 78 bodies after flash floods smashed into three districts in Jember regency on Sunday. "The last body found today was identified as Sumiati, a tofu trader in the Bunot Market here," said Edy Susilo, the spokesman for the Jember disaster team, on Saturday.

He said the team would expand slides for fear of further disasters, but many residents are choosing to stay, saying they said they could not leave behind their cattle and other valuables.

Regarding the spread of disease in refugee shelters in three districts in Jember regency, Edy said 700 of some 7,000 people taking refuge in the shelters were currently suffering diseases including

Figure 5-1: (a) - First movement happened at 0100 hours and the second and biggest one at 0500 hours; (b) - Search for victims using heavy equipment; (c) - Example of news coverage of the disaster

5.1. Causal relationships

This community was susceptible to this hazard due to a number of circumstances including:

- Relatively high rainfall conditions prior to the mass movements. These are investigated further in this chapter.
- A steep slope comprised of lava and alluvium with soil weathering of clay-colored silt 2-5 meters thick, that facilitated easy movement for the slide material.
- The weak field contact between the hard and impervious bedrock of andesitic lava which provided a sliding surface to the top weathering soil of loose clay-silt.
- The time of failure when the residents were still in their homes
- Extensive self built housing units at the base of the Pawinihan mountain range without planning or regulation

5.2. Disaster mechanism

There was an increase in the soil water content at the contact between the weathered rock and the andesitic lava layer; after 15days of constant rainfall amounting to 449.9mm. This reduced the weak soil material above the already saturated lava layer (further investigations on how exceptional the rainfall was, is carried out later in this chapter). The first landslide in the upper slopes accumulated in the middle slopes and added weight; hence increasing its instability. The middle slope material together with the first landslide material moved further down, hence the occurrence of the second landslide at 5am that caused damage to the Gunungraja hamlet settlements in the valley. Figures 5-2 and 5-3 show the situation map of the 2006 landslide movement and the cross section respectively. No previous records of such massive landslides in and around the hamlet were found.

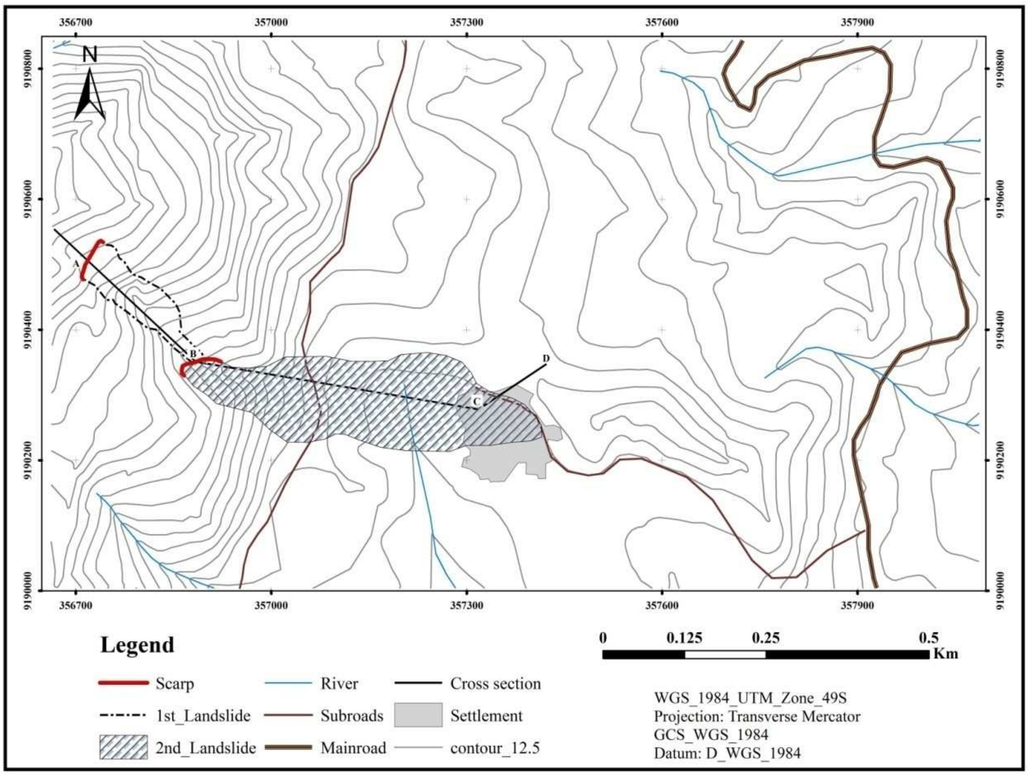


Figure 5-2: Situation map of the 2006 mass movement in Gunungraja hamlet, Sijeruk village

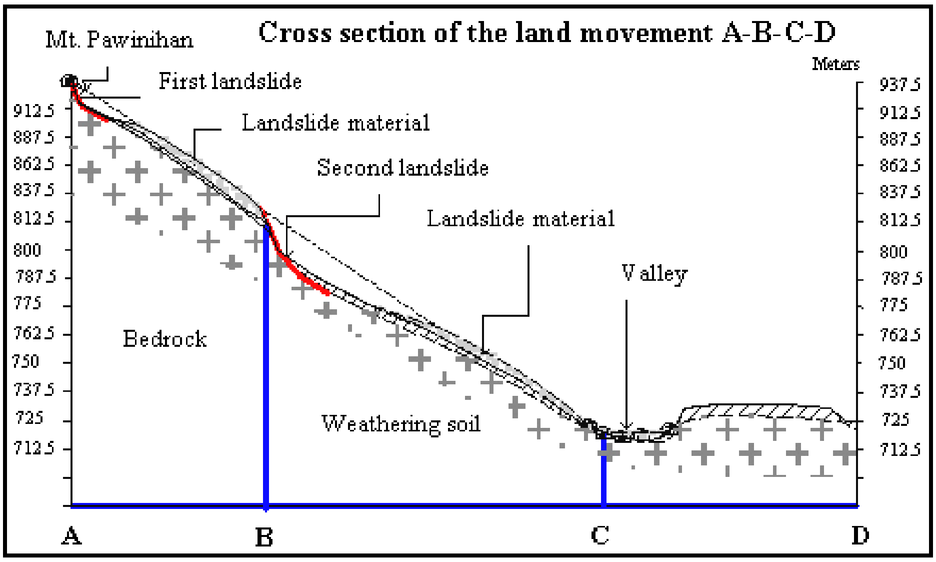
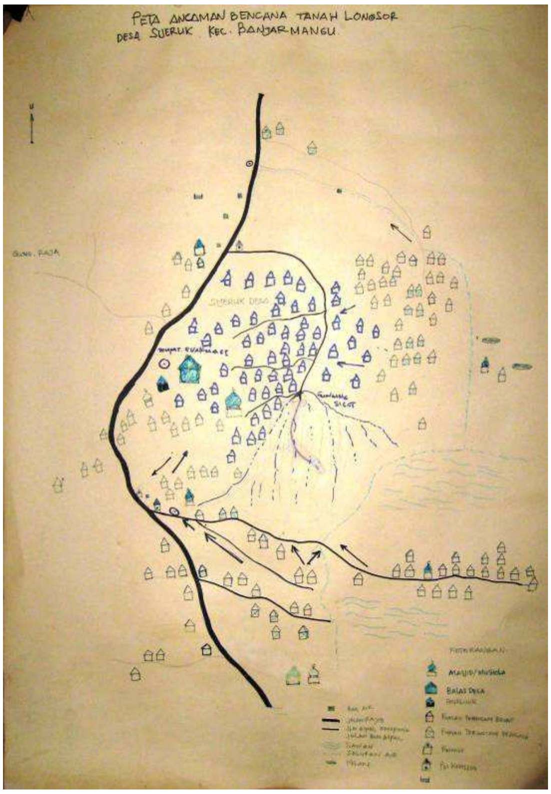


Figure 5-3: Cross section of the 2006 mass movements (modified from CVGHM, 2006)

The local authorities in Sijeruk together with some members of the community were able to map the landslide situation of the 2006 event according to their knowledge as shown in figure 5-4.



Legend

Water storage	Mosque
Main road	Village office
Tarmac road	Medical centre
Gravel road	Highly damaged house
Rice field	Moderately damaged house
Drainage network	??
Fish pond	Security post

Figure 5-4: Situation map of the 2006 landslide event by the community

5.3. Reconstruction and rehabilitation

Rehabilitation and reconstruction refer to the provision of support during and after a disaster for the quick recovery of the community functions (van Westen, 2009). Many activities are involved during rehabilitation and recovery but this section looks at how areas of reconstruction where defined. Considering the creep nature of the land condition in Sijeruk, a team from the National University of Pembangunan (UPN) in Yogyakarta was asked to conduct geological studies to obtain relatively safe locations for the displaced people. From the many locations identified to re-locate the displaced people, three locations where surveyed for suitability and their initial land use type included:

a) Gunungraja and Belongan locations

Mixed thick vegetation cover with salak as the dominant type that is harvested every 15days and small partitions of banana, coconut, bamboo and albacia.

b) Duren location

Irrigated rice fields planted two times a year.

A number of factors were considered during site selection and they included: rainfall, slope, field carrying capacity and the seismic activity among others in each location. The Gunungraja location west of Sijeruk village was recommended by the UPN team but with restrictions such as good and proper drainage for surface flow. All locations did not meet the ideal criteria but the National University of Pembangunan (UPN) geological team recommendations were used as primary reference and integral part of the post-disaster rehabilitation. The total area selected included 36.105m^2 (Gunungraja) west of Sijeruk and 15.848m^2 (Belongan) in Kendaga.

Distribution of plots was done by means of raffle drawing and house development was carried out in mutual cooperation (gotong royong) based on a relocation policy. In this policy, those who had complete house damage were provided with a complete new house while those whose houses were partially damaged, were given shell houses without doors and windows with the intention that they use the windows and doors from the old houses.

Even with the UPN recommendations put in place, the area of the relocation village west of Sijeruk is considered vulnerable. Clear signs that part of this land is creeping are given by a number of visual indicators such as cracks in the walls of buildings and on the road surface. Also in February 2009, part of the road leading to this village experienced a debris slump. Nothing has been done up to date apart from minor repairs. With all that is taking place and also after the 2006 event, the community is now more aware of the danger associated with mass movements as highlighted in the coping mechanism chapter.

5.4. Rate of creep movement

The Centre for Volcanology and Geological Hazard Mitigation (CVGHM) in Bandung, Indonesia, installed monitoring stakes along the main road in the study area to monitor the rate of movement of the creeping mass using Leica geodetic GPS receivers. The distribution of the monitoring stakes is shown in figure 5-5 below. There is no correspondence between the creep bodies showed in the map and the monitoring stakes since the creep bodies were mapped during the present research and the monitoring stakes were only placed along the main road.

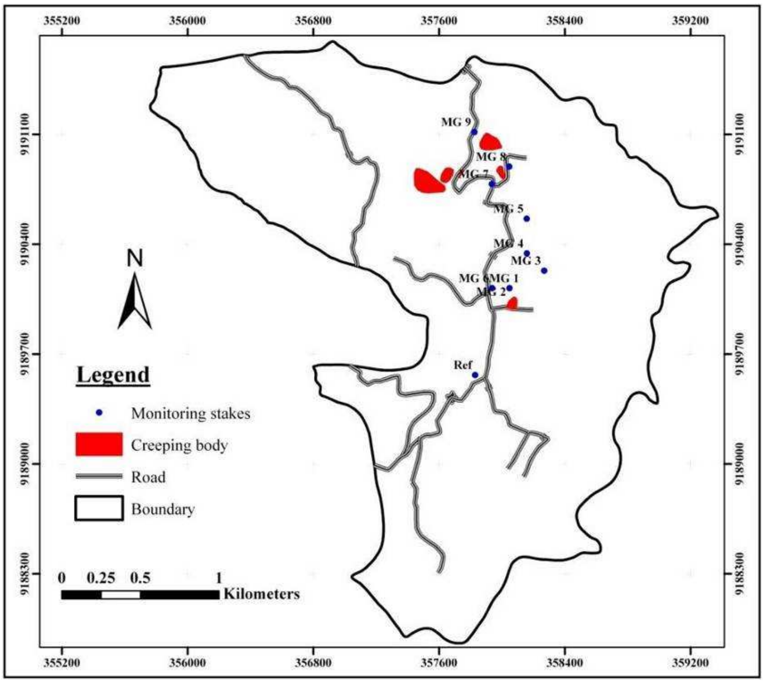


Figure 5-5: Location of the monitoring skates in the study area

The results from this survey indicated the depth of the sliding layer to be generally shallow to deep with characteristic debris slumps and cracks. The research highlighted the factors leading to this type of instability as:

- The physical properties of the Kemirigan rock which dip in the direction of the fairly steep slope
- Cutting of the slope to make provision for widening the road since large vehicles use this same road and their large tonnage adds to the burden creating vertical or horizontal vibration
- High and prolonged rainfall that increases the pore water pressure and decreases the soil shear strength
- Malfunctioning or absence of channels parallel to the road to drain off surface water which later drains through and acts as a lubricant

All the above singularly or in combination are believed to contribute to the increase in the rate of creep.

5.5. Landuse / Landcover change

The analysis of land use change revolves around what causes the change and also what its impacts are. Land use change may involve changes in the mix and pattern of land use in the area or changes in the intensity of the use as well as alterations of its characteristic attributes (Briassoulis, 2000). Land use change in the study area was analyzed on the basis of information obtained from Landsat images of 1991, 2001 and 2009 plus participatory discussions with the respondents to the questionnaire survey. Six main land use categories were used during the analysis as shown in table 5-1. Analysis revealed an overall much higher increase in mixed cropping (Kalilunjar 75.78Ha and Sijeruk 70.74Ha) and forest cover (Kalilunjar 18.09Ha and Sijeruk 9.99Ha) while there was a tremendous decline in the shrubs and bushes class in both villages (Kalilunjar 75.78Ha and Sijeruk 83.88Ha). Increase in both forest cover and mixed cropping is in agreement with the discussions held with the respondents. They pointed out that they were advised to change from wet to dry cultivation in order to decrease the creep phenomena taking place in their area. The increase in mixed cropping is also due to the change from mono cropping of the traditional crops with poor economic potential to mixed cropping. Most people have resorted to intercropping their original crops with the albacia tree whose wood is on demand. Due to the high demand for the albacia wood, most people harvest it at 5years instead of the 8years when it's fully mature. This leads to poor implementation of the afforestation projects.

From table 5-1, it can be observed that in both villages, there is an abrupt increase of the mixed cropping land cover class for the period 1991-2001 with Kalilunjar village having a higher percentage increase. Another abrupt change worth mentioning is that of the shrubs and bushes class which again in the same period in both villages, decreases. Much of the shrubs and bushes class in both villages was converted into the mixed cropping class. This is because the communities in both villages have taken on planting the albacia tree whose demand is commercially high.

Increase in the water class in Sijeruk may be due to people taking on fish farming to supplement their income sources while its decrease in Kalilunjar is because of the wet to dry conversion process that the community is embracing. The spatial resolution of the images may have affected to an extent the precision of the analysis.

Figure 5-6 shows the land use changes that occurred at the 2006 landslide location for the analysed years. The red rectangle shows areas that changed from shrubs and bushes to mixed cropping between 1991and 2001 and the yellow circle in 2001 shows where the original disaster village was located while in 2009 it shows what the current land use is – mainly mixed cropping and some rice fields. Also for the period 1991-2001, there is some increase in the forest cover class in the upper slopes close to the first scarp yet in the same area, for the period 2001-2009 rice fields and some settlements are introduced in the place of mixed cropping. From the above analysis it can be concluded that change in land use could have in one way or another contributed to the cause of the landslide.

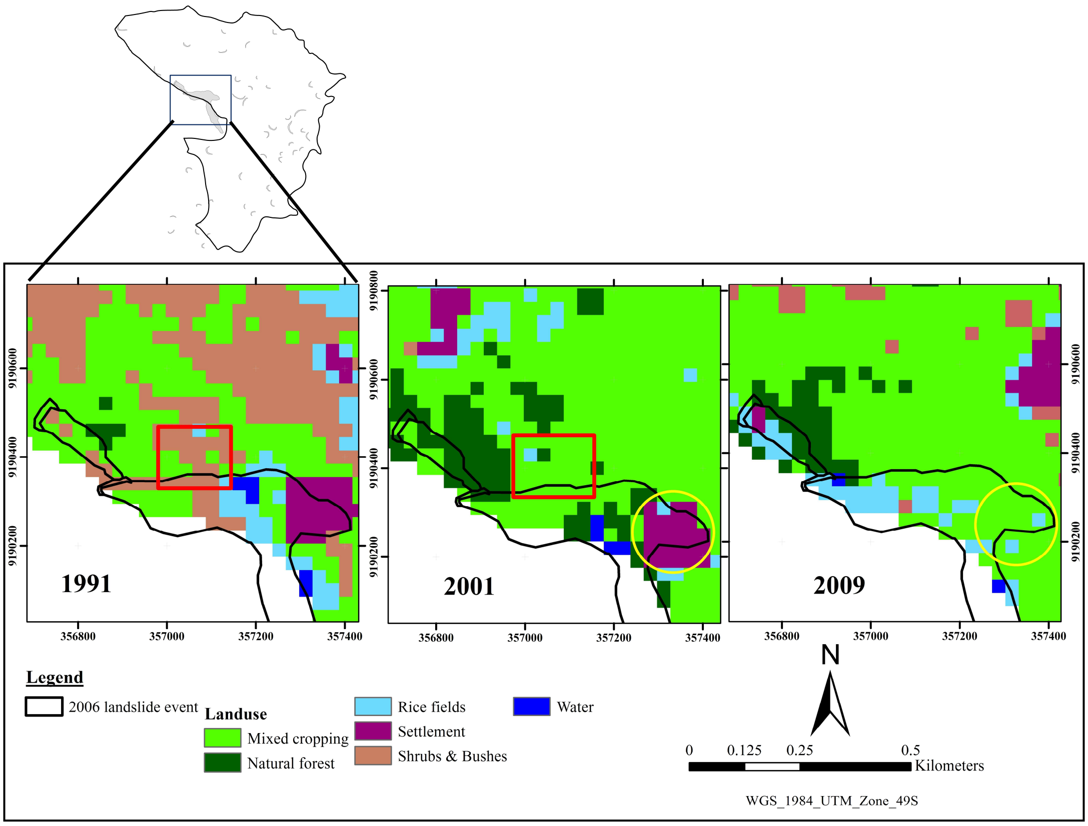


Figure 5-6: Land use change at the 2006 landslide site

Table 5-1: Land use change between 1991, 2001 and 2009

Village	Land use types	Hectares per analyzed year						Overall change (Ha)
		1991	**%**	**2001**	**%**	**2009**	**%**	
Kalilunjar	Forest	13.32	3	43.56	11	31.41	8	18.09
	Rice fields	59.85	15	48.06	12	40.59	10	-19.26
	Settlement	29.88	8	15.57	4	18.18	5	-11.7
	Water	20.16	5	8.19	2	19.53	5	-0.63
	Shrubs & Bushes	111.78	**29**	0.9	**0**	49.5	13	-62.28
	Mixed cropping	153.45	**40**	272.16	**70**	229.23	59	75.78
	Total	**388.44**	**100**	**388.44**	**100**	**388.44**	**100**	
Sijeruk	Forest	3.06	1	18.63	6	13.05	4	9.99
	Rice fields	76.86	24	80.46	26	81.63	26	4.77
	Settlement	23.76	8	16.92	5	16.47	5	-7.29
	Water	6.75	2	4.32	1	12.42	4	5.67
	Shrubs & Bushes	120.6	**38**	26.01	**8**	36.72	12	-83.88
	Mixed cropping	83.25	**26**	167.94	**53**	153.99	49	70.74
	Total	**314.28**	**100**	**314.28**	**100**	**314.28**	**100**	

5.6. Rainfall analysis

In general, rainfall is well known as the most important and frequent trigger of landslides. A trigger is “an external stimulus that initiates the movement of a landslide (Wieczorek 1996 in (Segoni et al., 2009)). The environmental preparatory factors related to rain and landslides include: build up of high water pressure into the ground, change of ground water conditions due to infiltration and soil characteristics plus a decrease in the soil suction value (Giannecchini, 2006).

Data recorded daily at the BMG rain gauge in Kalilunjar were obtained for the period of 1987 to 2008. There is only one rain gauge for the whole study area, so it was taken as the reference station since measurement of rainfall for landslide investigation should be site specific to each slope failure. Interaction with the local people revealed that there was not a lot of variation across the area especially during the wet season though scanty showers do occur in Sijeruk and are not evenly distributed over the whole area. Figure 3-5 shows the average monthly rainfall distribution within the study area.

Analysis of the rainfall events from 1st December 2005 to 7th January 2006 shows a gradual build up of antecedent rainfall and not a sudden influx. The characteristics of the rainfall in the study area are such that they are less intense but prolonged events. Such rainfall can be said to be sufficient to induce failures. The rainfall for the above mentioned period was summed up in durations of 2, 5, 10, 15 and 20 days to see which combination gave a peak value on the day of the landslide. Figure 5-7 shows no outstanding rainfall peak on the day when the landslide occurred. But looking at the 10 and 20 day summations, it can be seen that much as there is no peak, the graphs are increasing unlike the other graphs which show a decrease in the rainfall on the day of the slide. However, rainfall peaks can be seen for the 2, 5, and 15 day graphs a day before the event. This leads to a conclusion that an accumulated amount of rainfall over a number of days was available and it may have drastically reduced the critical threshold tolerable by the slope in the upper reach which exerted pressure in the middle reach resulting in the catastrophic consequences.

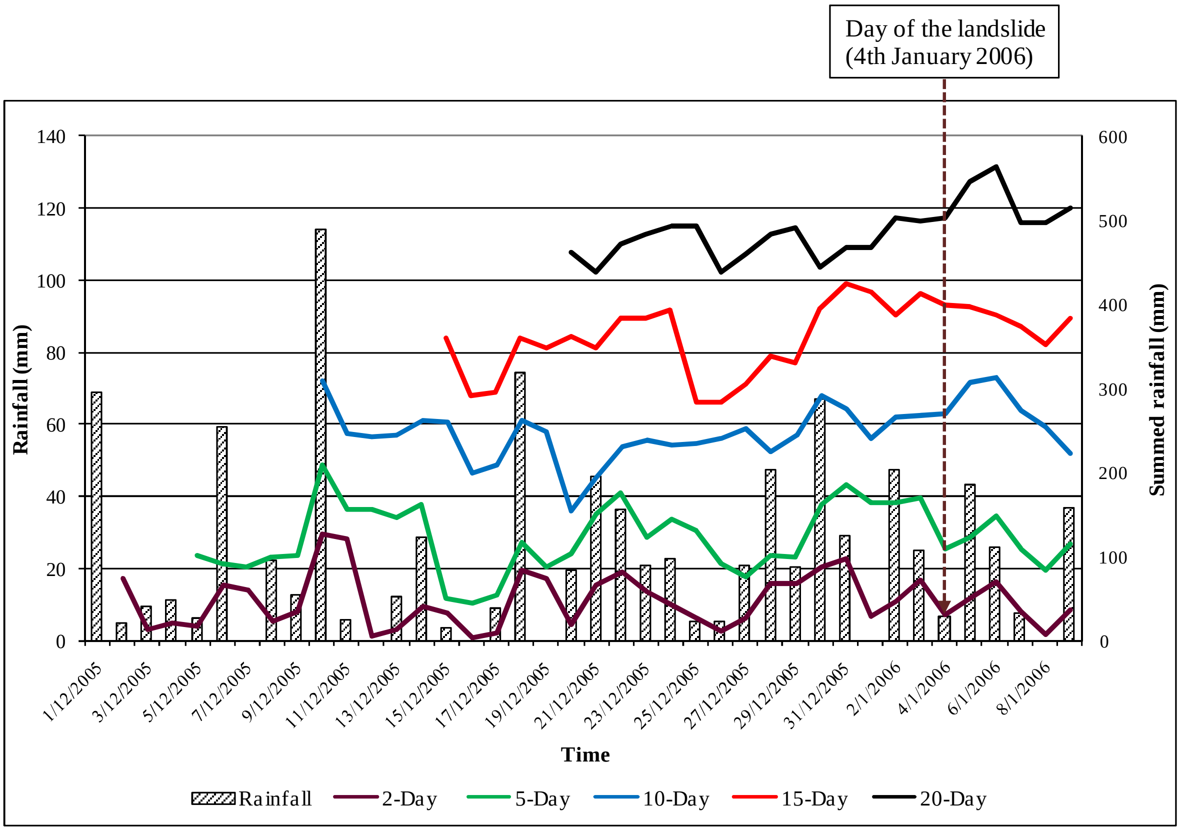


Figure 5-7: Graph showing 2, 5, 10, 15 and 20 day rainfall summations prior to the landslide event

5.6.1. Rainfall threshold values

Reichenbach (1998), defines a threshold as the minimum or maximum level of some quantity needed for a process to take place. The maximum threshold represents the level above which a process will occur or where there is 100% chance of occurrence of the process at any time when the threshold value is exceeded. While the minimum thresholds are usually established to delineate the lowest level below which the process is unlikely to occur (Crozier 1997 in (Dahal and Hasegawa, 2008)).

Precipitation thresholds used for landslide triggering help to separate events that were a result of rainfall from those that failed due to other causes. They can be defined empirically by statistically studying rainfall conditions that resulted in slope failure (Aleotti, 2004; Guzzetti et al., 2004) and physically by obtaining rainfall events for which rainfall measurements, location and time of slope failure are known. These are used to link regional or local rainfall measurements to local terrain characteristics such as slope gradient, soil type and lithology through a hydrological model (Crosta, 1998; Terlien, 1998). They also require detailed knowledge of the boundary conditions which are usually not available. Empirical rainfall triggering thresholds have been proposed at global, regional and local scale (IRPI, 2009). The rainfall parameters that are usually investigated include antecedent rainfall, total rainfall, rainfall intensity and duration (Aleotti, 2004; Chen et al., 2006; Giannecchini, 2005; Marchi et al., 2002).

In this study, cumulative antecedent rainfall was considered. A comparative analysis was performed to study the relationships between daily and antecedent 10, 15, and 20-day antecedent rainfall. The landslide incidences used in this analysis together with the associated rainfall are shown in table 5-2. These are events not associated with creep. When compared with figure 3-5, these events are seen to have happened during the wet season where there is a general assumption that most slope failures are bound to occur; hence, highlighting the role of precipitation.

Table 5-2: Landslide incidences and their associated daily rainfall

Event date	No. of landslides	Daily rainfall (mm)
29th January 2004	1	30.3
30th November 2004	1	55.2
30th December 2004	1	146.5
4th January 2006	2	37
22nd April 2007	1	33.4
1st February 2009	1	82.2

Graphs were made from the above combinations as shown in figures 5-8. In each combination, the minimum probable threshold below which no landslides are initiated is given by the solid black line which was visually fitted on each plot. The relationships between the combination of daily and the different antecedent rainfall days are defined by equations 5.1 to 5.3.

$$T_1^{10} = R_1 + 0.73R_{10} - 120 \quad \ldots\ldots (5.1)$$

$$T_1^{15} = R_1 + 0.58R_{15} - 150 \quad \ldots\ldots (5.2)$$

$$T_1^{20} = R_1 + 0.42R_{20} - 160 \quad \ldots\ldots (5.3)$$

Where:

T_a^b = Threshold,

R_1, a = Daily rainfall and

$R_{10, 15, 20}$, b = Antecedent rainfall (10, 15, and 20 days).

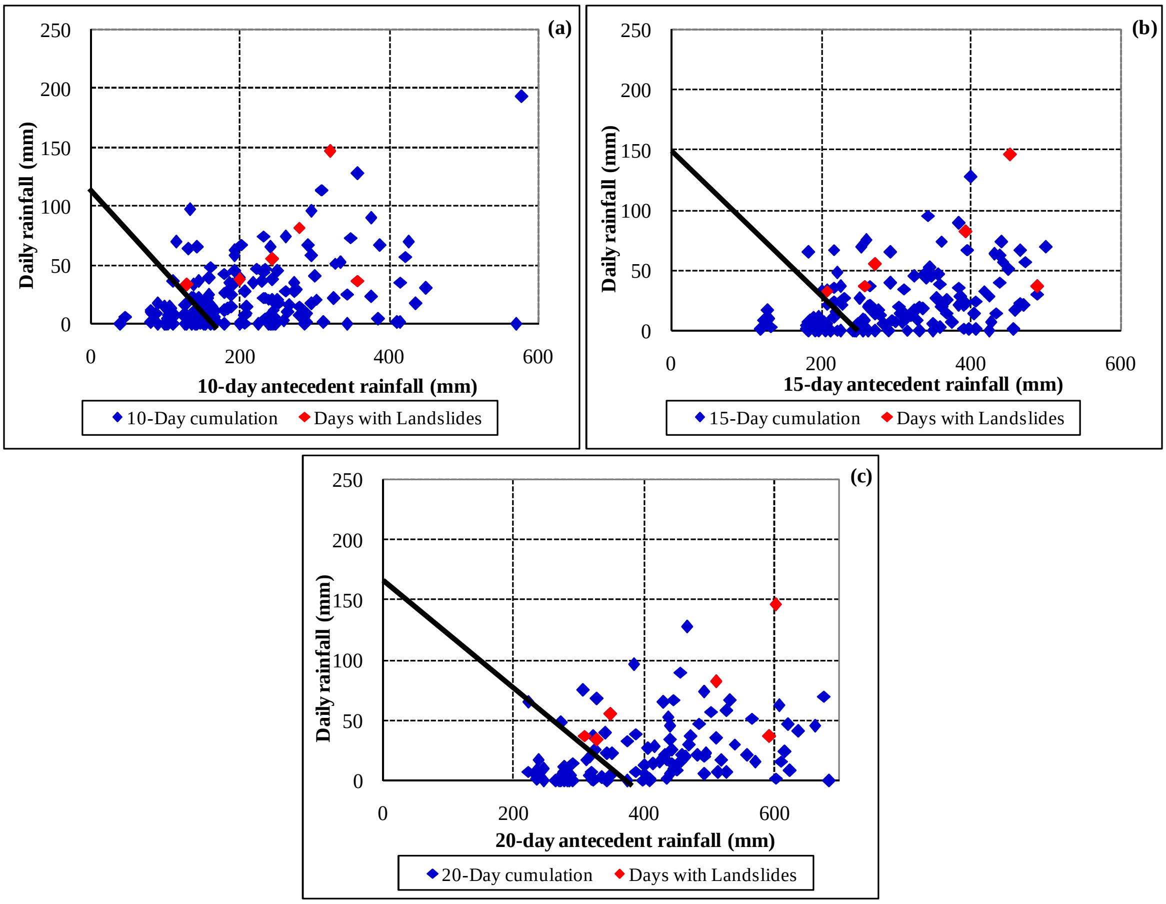


Figure 5-8: Scatter plots based on the daily and 10, 15 & 20 day prior rainfall

From the equations, it can be deduced that the daily rainfall contributes more than the antecedent especially in the initial stages of the rainy season. For example in figure 5-8 considering the 10-day antecedent rainfall, 50mm of daily rainfall is required to initiate a landslide in comparison to the 70mm antecedent rainfall.

Further analysis was carried out using 3-day plus 10, 15, and 20 day antecedent rainfall events. Again the lower probable thresholds were fitted visually on the scatter plots as shown in figure 5-9. From the analysis, the trend shows that the 3-day antecedent rainfall contributes more than the 10, 15, and 20-day antecedent rainfall as clearly shown in equations 5.4 to 5.6.

$$T_3^{10} = R_3 + 0.79R_{10} - 150 \quad \text{(5.4)}$$

$$T_3^{15} = R_3 + 1R_{15} - 190 \quad \text{(5.5)}$$

$$T_3^{20} = R_3 + 0.44R_{20} - 190 \quad \text{(5.6)}$$

Where:

T_a^b = Threshold,

R_3, a = 3-day antecedent rainfall and

$R_{10,\,15,\,20}$, b = Antecedent rainfall (10, 15, and 20 days).

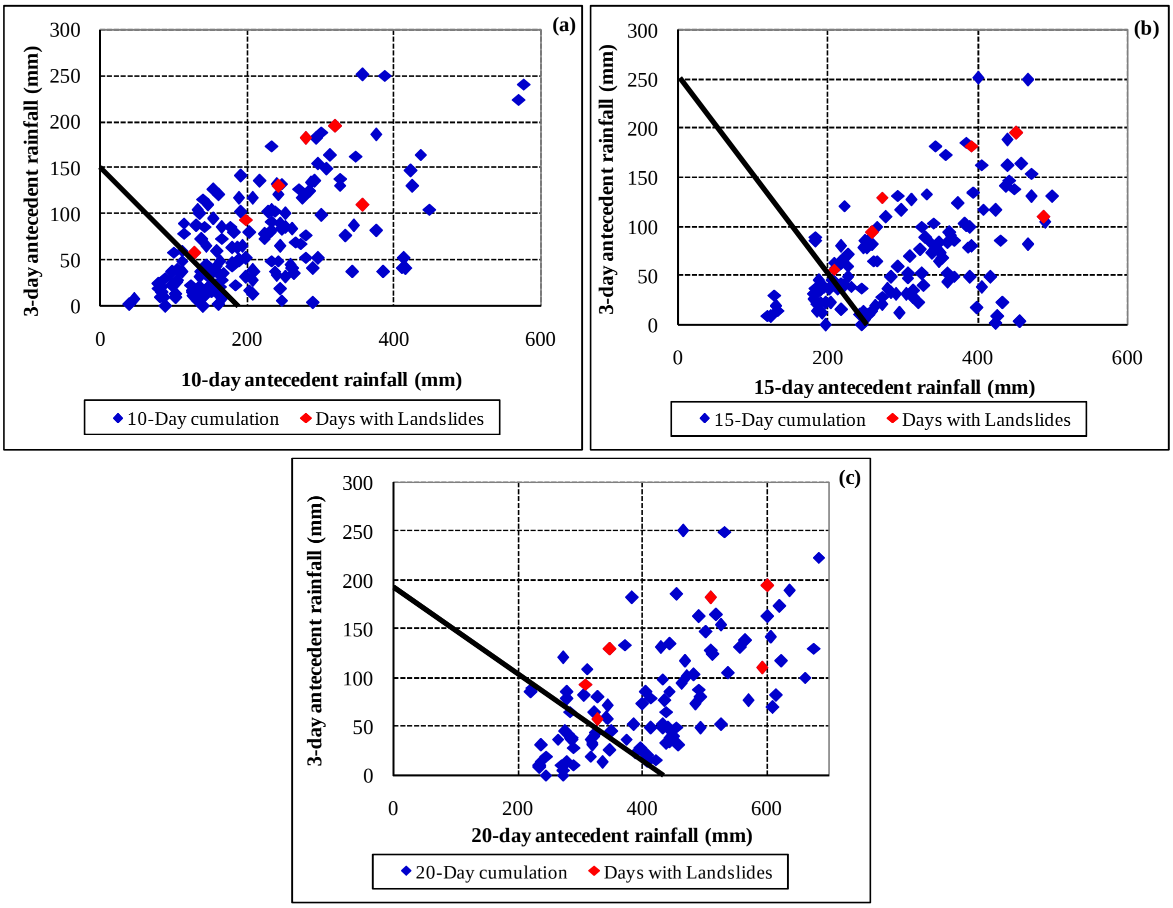


Figure 5-9: Scatter plots based on the 3-day and 10, 15 & 20 day prior rainfall

Quantifying the influence of antecedent rainfall is difficult especially in the study area where the rainfall station is a non self recording type. Also the lack of adequate representative landslide data presents clear uncertainty which could be reduced if sufficient additional information is available.

5.6.2. Gumbel distribution

The Gumbel distribution is commonly known as the extreme value distribution and is used in environmental sciences to model risk associated with extreme rainfall (Koutsoyiannis, 2003). Its temporal probability plots are the most widely used distribution functions designed to use existing data records to show the relationship between rainfall occurrences and their return periods. This helps to anticipate what's going to happen and get prepared but does not result in the altering of the course of human actions. The Gumbel distribution method considers the maximum rainfall value in a year. During the analysis, the largest monthly rainfall over a period of 22years (1987-2008) in the study area was used to make the Gumbel distribution. Data was provided by the BMG that is located in Kalilunjar village. The procedure of obtaining the Gumbel distribution is shown below and the results in table 5-3.

5.6.2.1. Steps to calculate the Gumbel distribution

1. The left probability for each observation was calculated using equation 5.7.

$$P_L = \frac{R}{N = 1} \quad (5.7)$$

2. The return period was then determined using equation 5.8.

$$T_r = \frac{1}{P_R} = \frac{1}{1 - P_L} \quad (5.8)$$

3. To determine the plotting position for each observation, equation 5.9 was used.

$$Y = (-\ln(-\ln(P_L))) \quad (5.9)$$

Where:

P_L = Left sided probability that a certain rainfall amount is lower than the one considered

P_R = Right sided probability that a certain rainfall is higher than the one under construction

T_r = Return period

Y = Plotting position for each observation

R = Rank of a given rainfall value

N = Number of observations

From table 5-3, we can see that the lowest maximum daily rainfall occurred in 2003 and amounted to 85mm while the highest maximum daily rainfall occurred in October 2005 with 203mm. The probability that an amount of rainfall greater than 85mm might be received is 0.96 and the return period is about 1year. It can be concluded from table 5-3 that as the rainfall increases so does the left probability and return period.

It is assumed that the 2005 rainfall amount could have induced the landslide event that happened early January 2006 by accumulation process. The return period for this rainfall peak is 23years so in average, every 23years a rainfall amount of 203mm is expected though it could happen in subsequent years. A probability graph was constructed using results from table 5-3 as shown in figure 5-10. In this figure, rainfall values 193 and 203mm are seen as extreme values in comparison to the other values. They are believed to influence a lot the outcome of the analysis results and eventually the prediction of the return periods.

Table 5-3: Gumbel distribution process (1987-2008)

Year	Rainfall (mm)	Sorted	Rank (R)	P_L (R/(N+1))	P_R (1-P_L)	T_r (1/(P_R))	Y (-ln(-ln(P_L)))
1987	122	85	1	0.04	0.96	1.05	-1.14
1988	90	90	2	0.09	0.91	1.10	-0.89
1989	95	93	3	0.13	0.87	1.15	-0.71
1990	97	95	4	0.17	0.83	1.21	-0.56
1991	95	95	5	0.22	0.78	1.28	-0.42
1992	120	97	6	0.26	0.74	1.35	-0.30
1993	150	107	7	0.30	0.70	1.44	-0.17
1994	130	109	8	0.35	0.65	1.53	-0.05
1995	145	112	9	0.39	0.61	1.64	0.06
1996	107	120	10	0.43	0.57	1.77	0.18
1997	112	121	11	0.48	0.52	1.92	0.30
1998	123	122	12	0.52	0.48	2.09	0.43
1999	146	123	13	0.57	0.43	2.30	0.56
2000	130	126	14	0.61	0.39	2.56	0.70
2001	137	130	15	0.65	0.35	2.88	0.85
2002	109	130	16	0.70	0.30	3.29	1.01
2003	85	137	17	0.74	0.26	3.83	1.20
2004	193	145	18	0.78	0.22	4.60	1.41
2005	**203**	146	19	0.83	0.17	5.75	1.66
2006	93	150	20	0.87	0.13	7.67	1.97
2007	126	193	21	0.91	0.09	11.50	2.40
2008	121	203	22	0.96	0.04	**23.00**	3.11

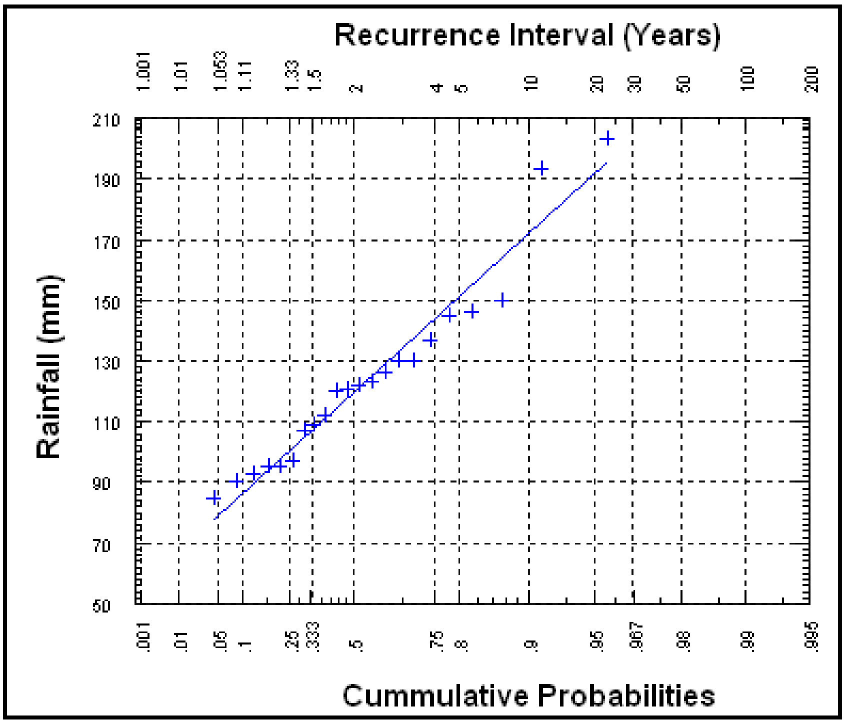


Figure 5-10: Gumbel probability distribution

If more concrete data and information of past landslide events in the area are available, then no doubt, that using the Gumbel probability plot, rainfall return period can be used as a temporal probability for the occurrence of hydro meteorological events such as landslides.

5.7. Conclusion

As earlier indicated, rainfall is one of the most important natural triggering factors of landslides. Its infiltration into the soils leads to an increase in pore pressure and a decrease in shear strength which may lead to slope instability and eventually slope failure. Here, the effect of rainfall over a larger period is important, hence the analysis of rainfall thresholds taking into account periods of 10-20 antecedent rainfall days. A satisfactory amount of data is needed if rainfall return periods are to be considered using the Gumbel method in order to have a fair level of confidence in the results (Capecchi and Focardi, 1988 in (Petrucci and Gullà, 1998)).

Quantifying the influence of antecedent rainfall is not easy especially in situations where the data is inadequate and presents clear uncertainty which could be reduced if additional sufficient information is available.

There is a need to correlate the creep monitoring results with geological and hydro geological characteristics of the study area in order to obtain a better understanding of the ground motion phenomena taking place. Work should also be done on the soils to test its cohesion and angle of internal friction. Concerning landslides, a slope stability back analysis should be performed to assess their safety and functional design. According to Eberhardt (2003), examples of slope analyses include: investigating potential failure mechanisms, determining slope susceptibility to different triggering mechanisms, testing and measuring the different support and stabilization options.

6. Landslide hazard mapping and analysis

This chapter deals with the landslide hazard and analysis. Assessment of some landslide contributing factors such as slope gradient, slope aspect, etc that are used to predict future occurrence of the landslide phenomena in the area is also carried out. Also a discussion of the landslide inventory mapping carried out and the weight of evidence method used to obtain the susceptibility maps is contained in this chapter.

Landslides are defined by Crozier (1999 (b)) as “a downward or outward movement of a mass of slope-forming material under the influence of gravity, occurring on discrete boundaries and taking place initially without the aid of water as a transportational agent. Varnes 1978 classified mass movements based on the type of movement and material involved though additional descriptions exist such as state of activity, rate of movement and water content. All these are important when dealing with landslides as they help to distinguish between the characteristics that are relevant to the intended end use of the study.

6.1. Landslide activity in the study area

Data on the landslide incidences was first obtained from the respective village offices and supplemented with the questionnaire and personal accounts. Most of the village office records contained information about the extent of damage as well as the day on which a particular incident happened and the location even for the isolated events. The sites were visited for visual assessment and getting the GPS coordinates but in some instances it was difficult to precisely locate the site as no associated scar or evident damage was noted. The landslides in the study area can be categorized into two classes:

a) Slow moving / creeping landslides that cause no casualties but large scale damage to both infrastructure and agricultural land.

Creep phenomena were observed in the central part of the whole study area. This slowly progressing deformation is evident from the wall cracks of people’s houses, hanging house foundations and the curvatures of the tree trunks. It’s mainly observed in areas covered by the Halang formation which comprises of tuffaceous sandstone, conglomerate, marl and claystone (figure 3-2). Majority of the people in the area reason that the creeping may either be due to the contribution of ground water which could be lubricating the underlying layers or the improper disposal of waste water from the community households. Characteristic examples of destruction by creep in the study area are shown in figure 6-13.

b) The rapid moving type with rock, earth and debris flow that has casualties and large numbers of damage.

This type of landslide is mainly triggered naturally by rain or by human activities such as mining as shown in figures 6-14.

During fieldwork, collection was done of the registered landslide events that impacted infrastructure in the study area as shown in table 6-1.

Table 6-1: Landslide damage to infrastructure

Date	D	W	M	DeH	DaH	PD	OS	Action taken
Sijeruk								
1985	0	0	0	2	6	1	0	Relocated
1993	0	0	0	0	1	0	0	-
1997	0	0	0	4	0	2	0	-
1998-1999	0	0	0	0	2	0	1- Mosque	Relocated
2005	0	0	0	0	2	1	0	Relocated
1/4/2006	**89**	-	13	**102**	79	-	0	Relocated
Kalilunjar								
1997	0	0	0	1	1	-	-	-
2003	0	0	0	0	0	0	2- School buildings	
29/1/2004	0	0	0	1	0	0	0	Repaired
30/11/2004	0	0	0	0	1	0	0	Repaired
30/12/2004	0	0	0	0	1	0	0	Repaired
22/4/2007	0	0	0	0	0	1	0	Repaired
7/11/2007	0	0	0	0	0	1	0	Repaired
7/12/2007	0	0	0	0	0	1	0	-
7/13/2007	0	0	0	0	0	1	0	-
1/2/2009	0	0	0	0	0	0	Road blocked	Material cleared
6/2/2009	0	0	0	0	0	1	0	Repaired
3/6/2009	0	0	0	0	0	1	0	Repaired

D-Dead, **W**-Wounded, **M**-Missing, **DeH**- Destroyed houses, **DaH**- Damaged houses, **PD**- Partial damage, **OS**- Other structures

Source: Fieldwork 2009

Not a lot of emphasis is placed on the landslides occurring in the agricultural areas since they are kind of isolated from the residential area and they mainly affect individuals. The most affected are the rice fields with the water supply passing through the system from terrace to terrace and is mainly irrigation with a small percentage of rain-feeding. The mechanism is such that the backward scouring of water is not prevented, which then cuts into the base as water flows from one terrace to another (Gerrard and Gardner, 2002) (figure 6-1). Also the softening of material in the terrace risers may be a factor. The series of mass movements that occurred in the agricultural land in the study area in 2004 together with the landslide points visited during fieldwork are shown in figure 6-2 below. The green points show the series of landslide events that occurred in agricultural land in the study area in 2004 while the blue points show the landslide points that were visited during fieldwork.

Figure 6-1: Example of back slope terrace failures

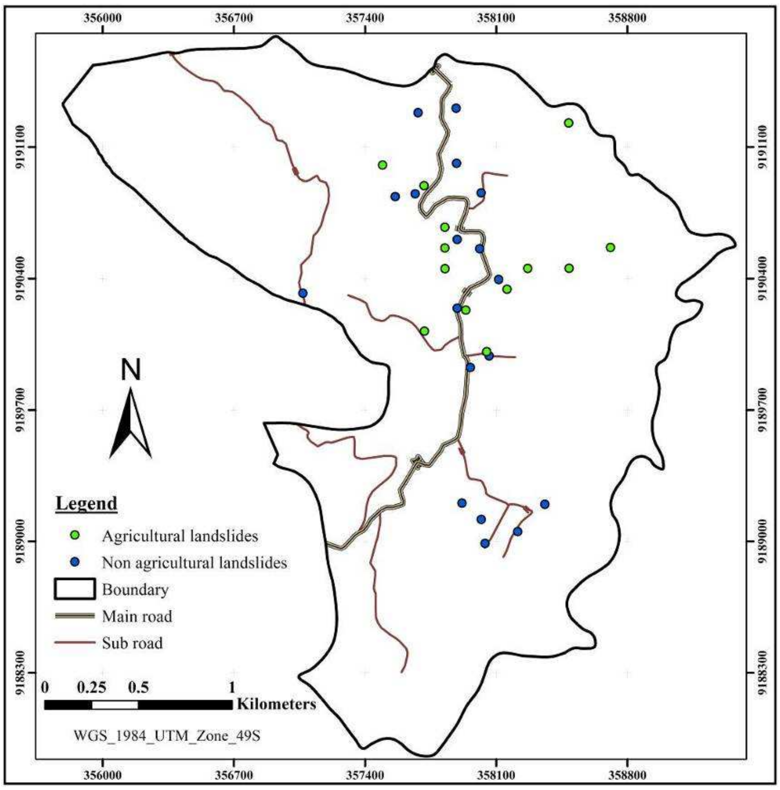


Figure 6-2: 2004 landslide events in agricultural land plus other landslide events

6.2. People's knowledge on landslide occurrences

Knowledge on past landslide occurrence is vital in explaining the trend of landslides occurrences in an area. It can be used to enhance the community's capacity to prepare for and cope with the disaster. According to McCall et al. (1992), people usually remember the most devastating and most recent events.

The two villages involved in the study had the following definitions for a landslide:

- Massive movement of soil down the slope.
- Movement of mass under the influence of too much waste water.

- Movement of soil that has no support such as vegetation to hold it together.

Even without using the academic language, the respondents clearly showed that they had full knowledge of what landslides are. They were fully aware that they occurred mostly during the rainy season and their responses were in agreement with the rainfall data from BMG. This shows that the local people are observant of the changes taking place in their physical environment. Other causes such as mining, earthquakes and river under cutting were also cited. The results of the ranking of the dangers associated with different disasters within the study area are shown in figure 6-3.

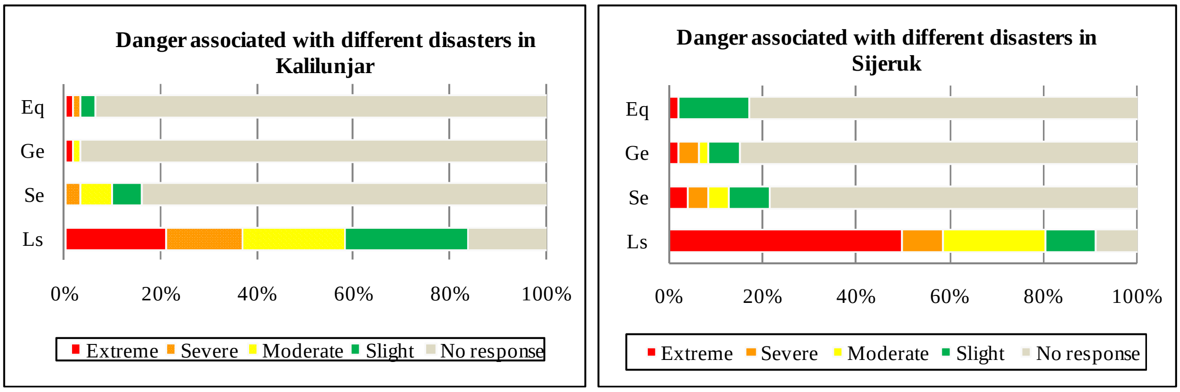


Figure 6-3: Danger associated with different disasters in the study area. Eq- Earthquakes, Ge- Gully erosion, Se- Soil erosion, and Ls- Landslides.

From figure 6-3, it can be seen that 50% of the respondents in Sijeruk believe that the occurrence of the landslides in their village is extreme compared to the 21% in Kalilunjar. This is attributed to the most recent devastating 2006 landslide event that happened in Sijeruk where a sizeable number of people died and property worth millions lost (table 6-1).

Using a print out of the different landslide processes, the respondents were asked to rank them against each other. This was used to test their awareness about these processes and whether they categorized them as landslides. The results are shown in figure 6-4 below.

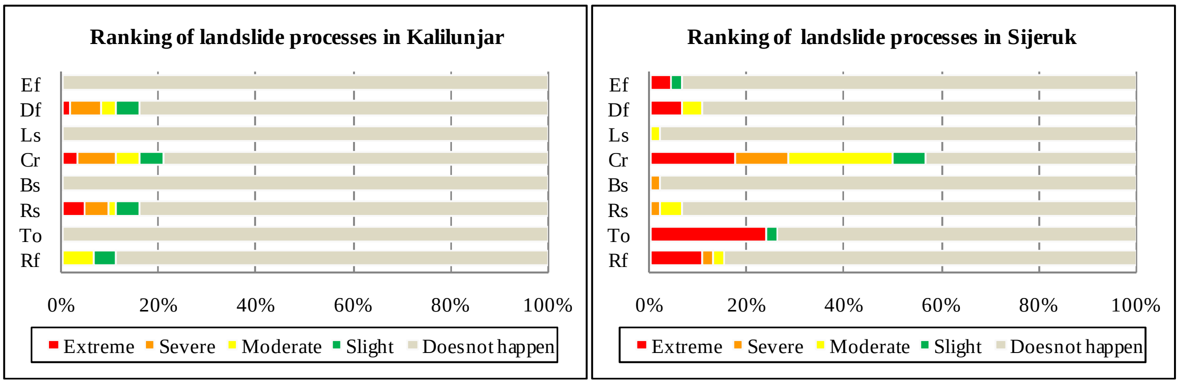


Figure 6-4: Ranking of the landslide processes. Ef- Earth flow, Df- Debris flow, Ls- Lateral spread, Cr- Creep, Bs- Block slide, Rs- Rotational slide, To- Topple, and Rf- Rock fall.

Using figure 6-4, it can be seen that the creep phenomena is better understood in Sijeruk with 17.4% of the respondents ranking it as extreme to the 3.2% in Kalilunjar. This could be attributed to the extensive damage it is inflicting on infrastructure especially houses and the roads. The respondents in Sijeruk also ranked rock toppling (24%) as a common occurrence in their village. This is mainly attributed to the rock mining taking place close to the main road (figure 6-14). Most respondents were fully aware of the locations where landslides have occurred and also where they might occur in future. For those living near or within the danger prone areas much as they are aware of their situation, they have no alternative since they are inhabiting ancestral land and can only take refuge in a safe place when the situation worsens and return after sometime.

Figures 6-5(a) and 5-4 show examples of landslide maps that the focus group discussion (FGD) participants in Kalilunjar and Sijeruk respectively made. Because of the language problem, instead of the desired landslide hazard map, the participants produced landslide inventory maps. Hence the need to obtain susceptibility maps based on expert knowledge as will be seen further in this chapter.

(a)

(b)

Figure 6-5: (a) Community landslide inventory map for Kalilunjar village and (b) Landslide event records in Sijeruk village

Not all the events in figure 6-5(a) can be seen in figure 6-2. This is because they might have passed unnoticed by the wider community; hence, not being registered in the village registry though some of the FGD participants had knowledge of them. This is in line with what McCall (1992) noted that people usually remember the most devastating and most recent events. In this case "most devastating events" is ruled out since no severe damage to property and infrastructure was reported at that time.

6.3. Landslide susceptibility mapping

A susceptibility map is used to divide an area into zones according to different levels of susceptibility to slope movement. It is used to ascertain the relative likelihood of land sliding considering susceptibility categories based on the method used. Depending on the availability of data, landslide susceptibility can be mapped using a number of different methods as highlighted by (Guzzetti et al., 1999). In the present study, the weights of evidence method is used. The process involved first identifying then mapping of a set of factors which are directly or indirectly correlated to slope instability as highlighted in the sub sections below. The relative contribution of each of these factors to slope failure is estimated and ends with the classification of the study area into susceptibility zones (Aleotti and Chowdhury, 1999; Guzzetti et al., 1999; van Westen et al., 2006). For the topographic information, automatic data capture especially from the Digital Elevation Model (DEM) was used.

Four steps were followed in order to produce the susceptibility map.

-Obtaining a landslide inventory map showing recent activity distribution and combining the factor maps (lithology, geomorphology, slope aspect, land use etc)

-Overlaying the landslide inventory with the combined factor map

-Grouping factor combinations in a way that defines the levels of damage

-Produce a landslide susceptibility zone map from the grouped combinations

All this was done using ILWIS 3.3 software.

6.3.1. Landslide inventory maps

Landslide inventory maps are data sets that represent landslide events. They show the locations and outlines of landslides that have happened in an area. These maps are important input data for predicting the location of future landslide occurrence since they contain the spatial attributes and state of activity, type and subtype of the past landslide events. By interpreting an aerial photo of 1973 (Scale 1:20,000) and IKONOS image (acquired august 2006 after the January event), plus field investigations in October 2009, two landslide inventory maps for the study area were produced by on screen digitizing and using epipolar stereo pairs generated in ILWIS. The first inventory map is based on the fast / rapid type of landslide processes while the second map is based on the creep phenomena observed in the study area. Scarps were used during the analysis for the fast landslide map while the body was used for the creep map as shown in figure 6-8.

6.3.2. Analysis of the landslide casual factors

The selection of environmental casual factors for susceptibility assessment depends on the landslide type, terrain type and availability of existing data and resources (van Westen et al., 2008). It’s also essential to have a good understanding of the different failure mechanisms taking place in the area of interest. Based on field observations, the casual factors were selected as land use, lithology, geomorphology, plus DEM derivatives such as slope gradient, slope aspect and flow accumulation.

6.3.2.1. Land use data

Human activities such as deforestation, cultivation on steep slopes and road construction cause changes in the land cover and land use of an area which play an important role in the stability of slopes (van Westen et al., 2008). As highlighted in section 5.5, most of the study area is covered by mixed cropping of mainly salak and albacia trees. The root system of the salak plant is shallow so it may generally not reach the failure surface. According to van Westen 2008, root reinforcement dominates over all the vegetation effects in its contribution to slope stability. So in this case, if the root of the plant is not deep enough then to an extent, the vegetation cover adds weight to the mass hence an increase in the instability of the mass. The land use map of the area (figure 3-4) was obtained from image interpretation of a 2009 Landsat image. Six classes were obtained and they included settlement, rice fields, mixed cropping, natural forest, shrubs & bushes, and water. During the interpretation and production of the map, factors such as regular shape for settlement, rows of vegetation for terraces / agricultural land were considered.

6.3.2.2. Lithology

The geological units are traditionally converted into classification that gives more information on rock composition and rock mass strength. Additionally, structural information, as the orientation of the discontinuities in rocks has an influence on the susceptibility to landslides (van Westen et al., 2008). The lithology of the study area consists mainly of tuffaceous sandstone, conglomerate, marl and claystone within the Halang formation. This factor map was generated by digitizing a scanned geological map of 1:100,000 scale. It is assumed that the clay content makes the Halang formation more prone to the creep type of movement where it’s concentrated. The fast moving types are randomly distributed within other formations. In this case, structures were not considered due to their dormant nature. The resultant map is shown in figure 3-2.

6.3.2.3. Slope gradient

It’s in response to gravity that earth material moves down a slope. This movement of material can range from extremely slow barely recognisable / perceptible over the years to very fast and rapid destroying all that lies in its path. The velocity with which the material moves depends on many factors of which slope gradient is among. Burrough (1986) defines slope gradient as “the maximum rate of change in altitude” expressed either in degrees, radians or percentages. As slope gradient increases, the susceptibility of the slope to landslide occurrence also increases. Although landslides usually occur in steep slopes, they may also occur in low relief areas. The slope gradient factor map shown in figure 6-7(d) was derived from the DEM covering the study area; after which it was classified into seven classes.

6.3.2.4. Slope aspect

No general agreement exists concerning slope aspect although the relationship between it and mass movements has been long investigated (Carrara et al 1991 in (Ercanoglu et al., 2004)). Slope aspect is defined as “the compass direction of the maximum rate of change in altitude (slope gradient) (Burrough, 1986). In general, it’s related to the physiographic trend of an area or the main precipitation direction (Ercanoglu et al., 2004). Slopes that receive more rainfall in comparison to others are bound to be more susceptible to landslide occurrence. Slope aspect also has an influence on the vegetation condition of slopes. Usually north facing slopes are cooler and more humid while the south facing slopes are warmer and arid (Wilkinson and

Humphreys, 2006). Figure 6-6(b) shows the slope aspect factor map that was derived from the DEM and after classified into eight classes using the USDA classification.

6.3.2.5. Geomorphology

According to Klimaszewski, 1982 & De Graaff et al, 1987 in (van Westen et al., 2008), geomorphological maps show land units based on their shape, material, processes and genesis. The geomorphology units of the study area were obtained by quantitative analysis of terrain forms from the DEM as shown in figure 6-7(c). There is no universal accepted legend for geomorphological maps.

6.3.2.6. Drainage: Flow accumulation

In a GIS environment, flow accumulation is seen as the total number of cells that would contribute water to a given cell based on the accumulated weights for all cells flowing into each down slope cell on a grid DEM. Flow accumulation is a measure of the land area that contributes surface water to an area where this water can accumulate. In the event of rainfall, water flows from the convex curvature areas and accumulates in to the concave areas. This parameter was considered during the analysis in order to define the locations where water accumulates. These areas are believed to have a high likelihood of landslide occurrence due to excess water. Flow accumulation was derived from the DEM and later classified into five classes as shown in figure 6-6(a). The classes represent the number of small streams flowing into a bigger stream.

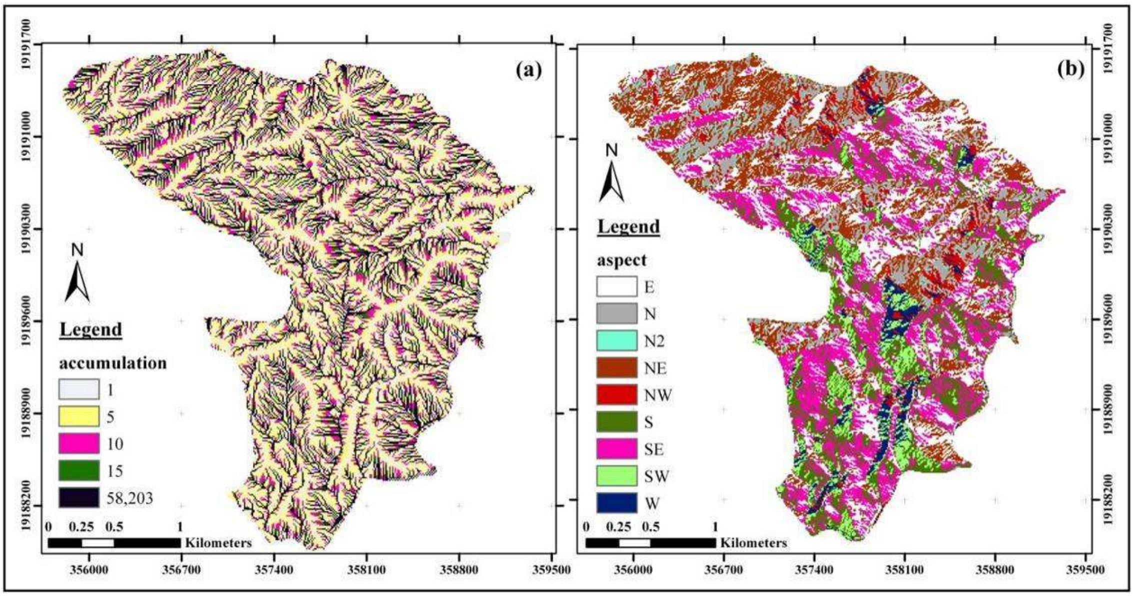


Figure 6-6: (a) Accumulation and (b) Aspect maps of the study area

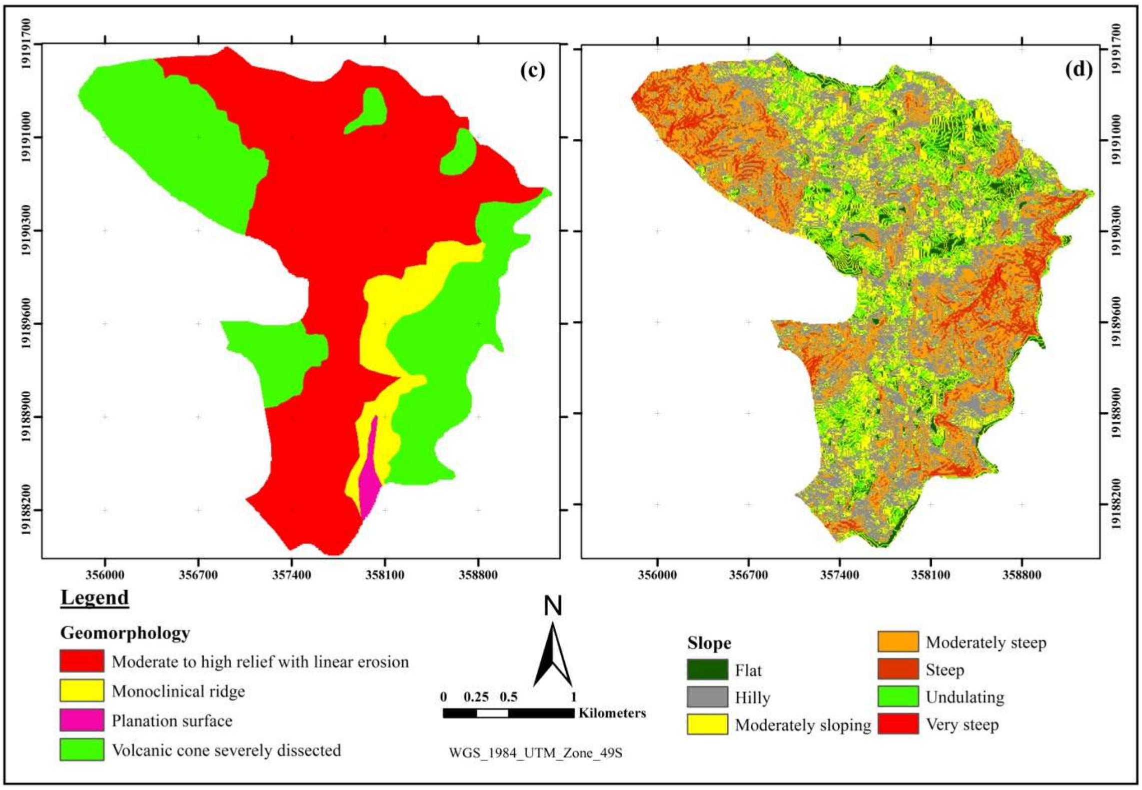


Figure 6-7: (c) Geomorphology and (d) Slope gradient maps of the study area

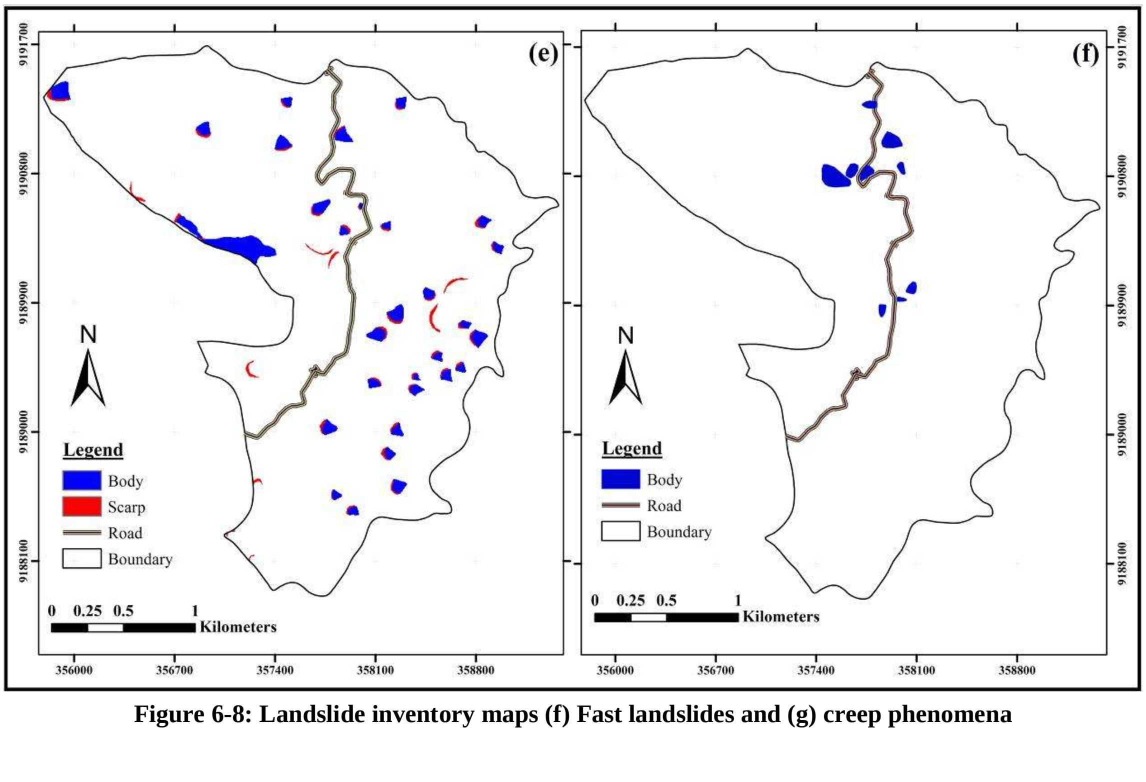


Figure 6-8: Landslide inventory maps (f) Fast landslides and (g) creep phenomena

6.4. Weights of evidence model

The weight of evidence model synthesized from Bonham-Carter (1994) was applied to the landslide susceptibility analysis. This method uses the prior probability of occurrence of a landslide event to find its posterior probability based on the relative contributions of evidential input parameters that are influential in creating slope instability (Bonham-Carter, 1994; Mathew et al., 2007).

In the weights of evidence method, values estimated for each factor are calculated using two weights. They include the presence (+W) and absence (-W) weights from which the contrast factor (C_w) is derived. It's expressed as the difference between the weights W+ and W-. For each factor, +W indicates the importance of the presence of a class for predicting landslides while the negative weight gives the importance of the absence of the landslide predicting factors. Also very strong negative factors indicate a negative association between the factors used in the analysis and the landslide inventory i.e. there will be no landslide if the factors exist. These weights are defined as shown in equations 6.1 and 6.2.

$$W_i^+ = Log_e \frac{P(B_i \mid S)}{P(B_i \mid \bar{S}} \quad \text{......} \quad (6.1)$$

$$W_i^- = Log_e \frac{P(\bar{B}_i \mid S)}{P(\bar{B}_i \mid \bar{S})} \quad \text{......} \quad (6.2)$$

Where, B_i = presence of a potential landslide conditioning factor

$\bar{B}_i$ = absence of a potential landslide conditioning factor

S = presence of a landslide and

$\bar{S}$ = absence of a landslide

The positive weights for all classes of the factor maps that occur together in a certain location and the negative weights of all the other classes that do not occur in that location are then added to produce a final weight map. The steps followed in the weights of evidence modelling using a script (appendix 2 - 1) are shown in figure 6-9.

Although several studies have been carried out using the weights of evidence modelling (Aleotti and Chowdhury, 1999; Chung and Fabbri, 1999; van Westen, 1993), it has its own short comings that include:

- Only taking into account those landslide conditioning factors that can be easily mapped, hence over simplifying the factors

- Assuming that all landslides in a given study area occur under the same combination of factors while using bivariate statistics. Whereas each landslide type has its own casual factors and should therefore be treated separately.

The advantage of this method is that it's simple and less time consuming.

For the fast landslides, analysis was limited to only scarps of recent activity in order to produce the susceptibility map while for the creep phenomena, the body of the moving mass was used. Due to insufficient available information, analysis was limited to only fast landslides and creep phenomena. Scripts (appendix 2) were used to generate the weights for each map since manually carrying out the process is long and time consuming.

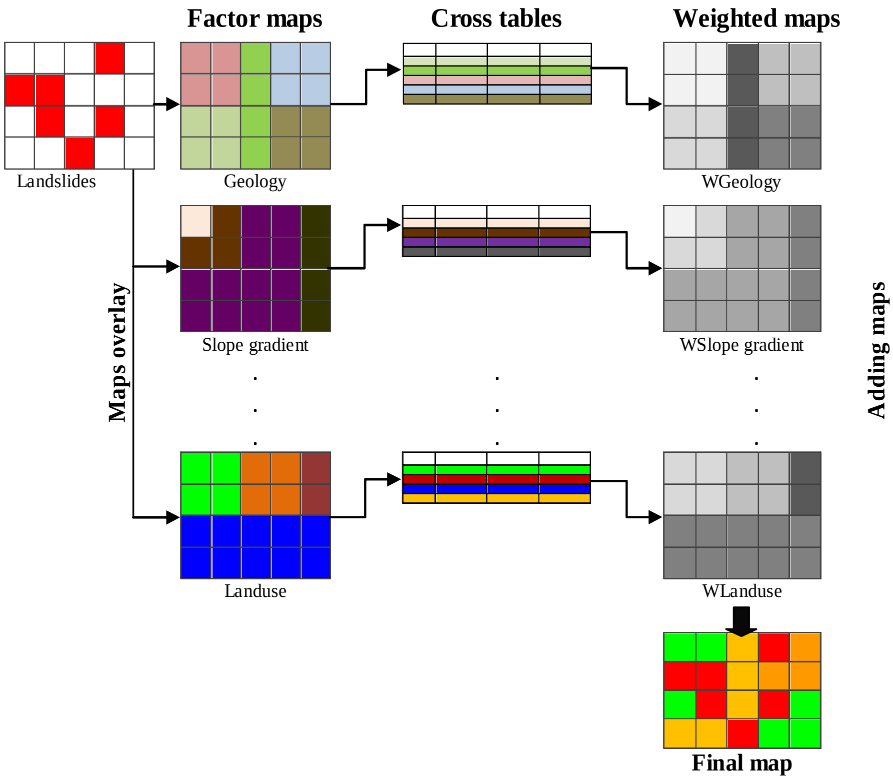


Figure 6-9: Schematic representation of the weights of evidence method implemented in GIS (adopted from Castellanos 2008)

6.4.1. Weights of evidence modelling results

The factor weight maps were summed to compute the success rate curve which helps to illustrate how well the estimators perform.

6.4.1.1. Sensitivity analysis of the landslide influencing factors

A sensitivity analysis was performed to estimate which factor has more influence on the occurrence of the two landslide phenomena analysed in this work. This was done by excluding one input factor during each run. The results are shown in figure 6-10.

From figure 6-10(a), it can be deduced that for the fast landslides, there is not a lot of variations with all the factors except for the slight difference where the slope is not included. This implies that for the fast landslides, slope plays an important role in their occurrence. Figure 6-10(b) shows the sensitivity analysis for the factors causing the creep phenomena. It is evident that land use is the most influencing factor on the occurrence of the creep phenomena, while the least contributing factor is geology.

Visually determining the most influencing factor especially for the fast landslides is not so obvious. To better understand the differences, the area under each curve was calculated for each landslide phenomena as shown in table 6-2. The highlighted factors are the major contributing factors to the occurrence of the fast landslides and creep respectively.

Table 6-2: Percentage area under the curves in figure 6-9 above

	Area (%)	
Input factors	**Fast landslides**	**Creep**
All factors	73	85.8
No slope	**66.4**	85.2
No Geology	71.7	85.7
No Geomorphology	72.6	86.1
No land use	74.4	**79.2**
No Aspect	73	85.7
No Accumulation	72.7	86.1

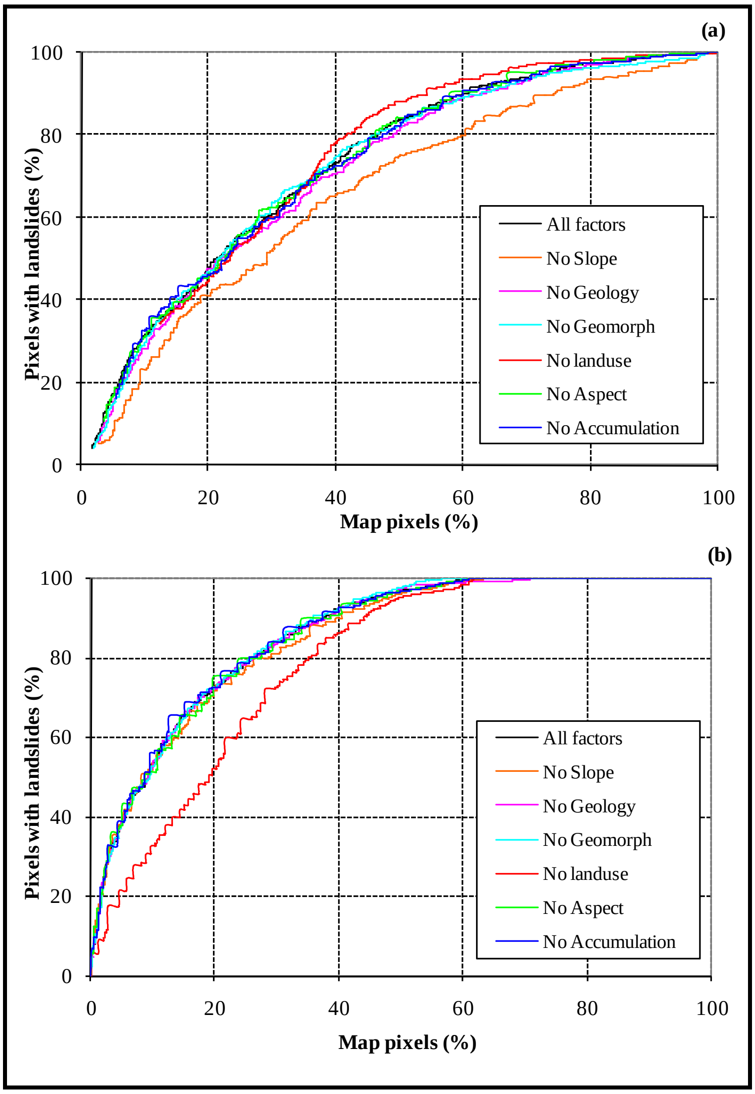


Figure 6-10: Sensitivity analysis of the landslide contributing factors using success rate curves - (a) fast landslides and (b) Creep phenomena

The final weight maps obtained using the “all factor” curves were classified into classes ranging between low to high susceptibility zones as shown in figures 6-11. From this figure, susceptibility breaks where fitted in order to obtain susceptibility classes for the two landslide phenomena being analysed.

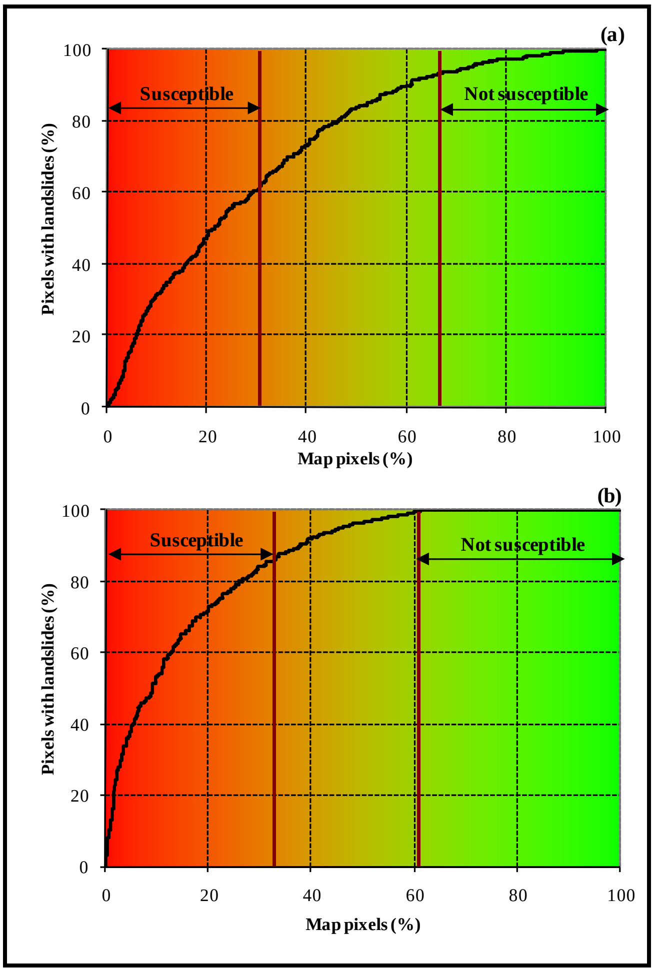


Figure 6-11: Susceptibility breaks for (a) fast landslides and (b) Creep phenomena

The four classes used in the susceptibility maps are explained below and the resultant maps are shown in figure 6-12.

Low susceptibility - It indicates areas for which the combination of factors is less likely to have adverse effects on the occurrence of landslides. Such areas are suitable for development but landowners should be informed of the existing hazard.

Moderate susceptibility - It shows areas for which the combination of the factors may influence to an extent the instability of the slope. Such areas can be inhabited only after a thorough investigation has been carried out. These investigations may include geological / geotechnical studies, special construction techniques and appropriate protection measures.

High susceptibility - It indicates areas with a high probability of the occurrence of landslides and is not suitable for development. In principle, no construction to be used to shelter humans should be allowed in this area.

Very high susceptibility **–** This shows the areas where the scarps and bodies for the fast landslides and the bodies for the creep phenomena where mapped. This class highlights to an extent how accurate the inventory mapping was.

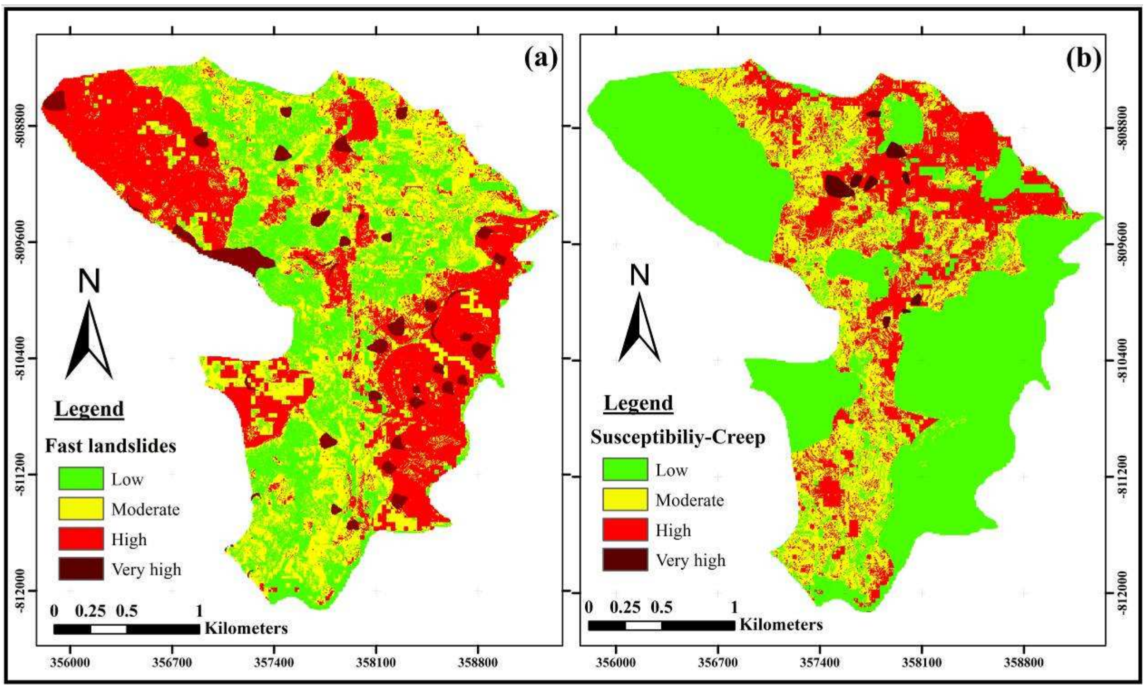


Figure 6-12: Landslide susceptibility map (a) fast landslide events and (b) creep phenomena

The results of the weights of evidence method strongly depend on the number of landslide events introduced and on the quality of the landslide inventory map (Thiery et al., 2007). Looking at both susceptibility maps shows kind of an inverse of the susceptibility classes. This is because for the creep map, only the visited areas that had creep signs were used in the analysis. Improvement of both maps is possible if thorough mapping especially for the creeping bodies is done.

If an area is characterised by rare events, then the probabilities of the input factor maps will also be low and the results will have to be interpreted with caution as is the case in this research.

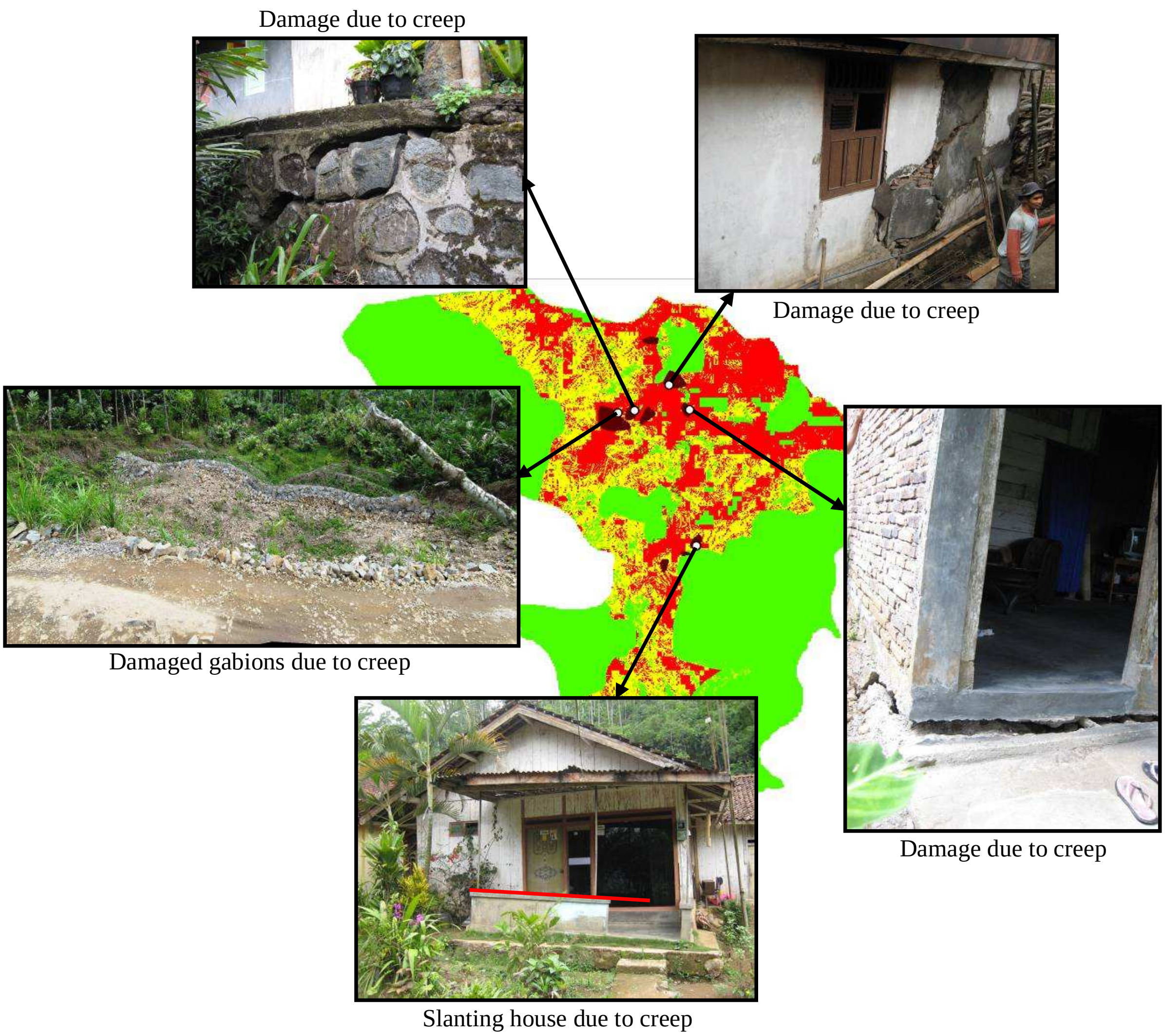


Figure 6-13: Visual indicators of damage by creep phenomena in the study area

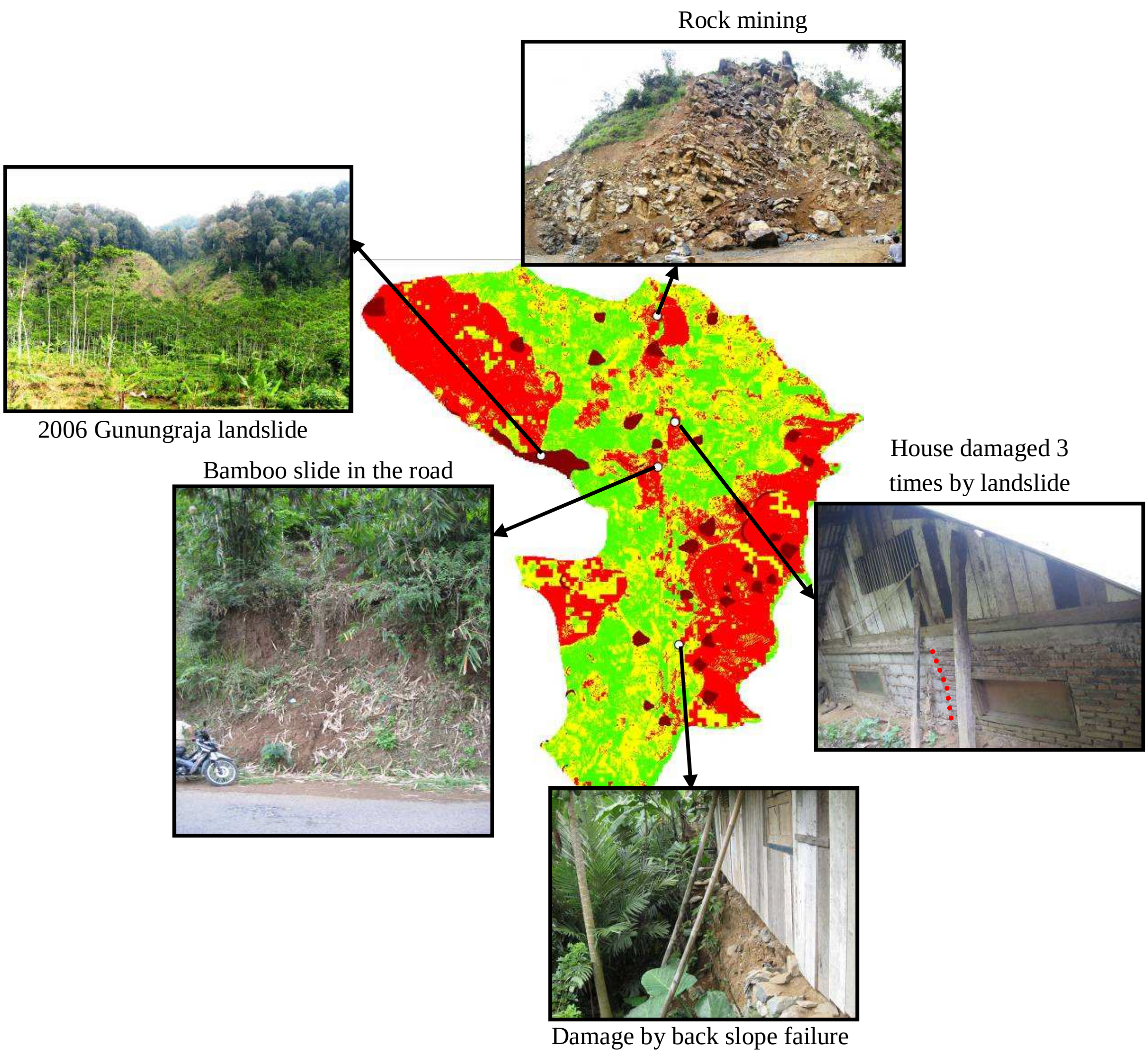


Figure 6-14: Visual indicators of damage by debris flows in the study area

6.5. Conclusion

In this chapter, the objective was to map and analyse the landslide hazard plus to assess the influencing factors. When selecting the triggering factors, it's advisable to carry out a sensitivity analysis to examine their influence on landslide occurrence. The factor which differs from the common pattern should be critically looked at as it may contain the answer to the problem. Based on the results obtained, it can be concluded that the success rate curve is good when indicating how well a model fits the data used.

From the results, it can also be concluded that the areas underlain by the tuffaceous sandstone, conglomerate, marl and claystone are most susceptible to the creep phenomena while the other lithological units are more susceptible to the fast landslides with land use and slope gradient as the most influencing factors for the creep phenomena and fast landslides respectively.

It can also be concluded that using just the historical records of known landslides, the trend of the threat can be determined to an extent.

The susceptibility maps obtained can be used for planning, site selection and policy making for hazard mitigation since they reflect the relative hill-slope stability and danger zones. The can be used to determine which people, facilities and recourses are potentially at risk from the hazard, where they are located and what might be the strategy to reduce their vulnerability. It’s therefore imperative that remedial and preventive measures be designed to protect the life and property of the communities from future landslides. While the mass movements in Kalilunjar are not as dramatic as those in Sijeruk, the economic consequences are tremendous because of the impact the losses have on individuals.

7. Analysis of perception of landslides

This section investigates the concept of perception using the responses from the open ended and semi structured questions included in the survey questionnaire during data collection. It analyses the possible variables that are assumed to have a correlation with the way populations perceive their physical environment. This section also tries to ascertain the people's perceptions on the causes and rate of occurrence of the hazard, the danger prone areas, gender and future damage by the hazard in their locality.

According to WBGU (1995), people's perception of environmental problems is one of the important requirements for changes of environmentally harmful forms of production and consumption. People's perceptions have a major bearing on how they deal with natural hazards. Investigations of perceptions and attitudes among the local people can facilitate their involvement and provide critical information that can be used together with technical and scientific data. These perceptions are dependent on the peoples' distance to the hazard and their intelligence and education.

7.1. Causes of landslides

Analysis of the causes of landslides is central in addressing the misconceptions in traditional local knowledge (Msilimba, 2007). During the survey, there was no differentiation between the causes and contributing factors to the occurrence of the hazard as this would confuse the respondents especially those with low education levels. From table 7-1, the results suggest superficially that much of the communities in both villages in general are aware of the landslide hazard. 89.9% of the respondents (90.3% in Kalilunjar and 89.1% in Sijeruk) perceived heavy rainfall as the cause of landslides in their area. Other causes such as seismic activity, deforestation, road construction, mining, river undercutting, soil structure and farming activities were also perceived as causes. During the survey, observations provided evidence that practical awareness is not as high as it appears in the questionnaire. The community misidentifies the cause of the problem and accommodates the inconvenience of the creep phenomenon as part of everyday life.

The respondents highlighted the wet season (between October and March) as the time when they expect the rate of movement to increase together with heavy rains for long periods.

Table 7-1: Perceived causes of landslides

Village	Measurement	What do you think are the causes of landslides?								
		HR	**D**	**SA**	**RC**	**FA**	**M**	**RU**	**SS**	**Total**
Kalilunjar	Count	56	1	2	1	1	1	0	0	62
	% within village sample	90.3	1.6	3.2	1.6	1.6	1.6	0	0	100
	% of Total sample	51.9	0.9	1.9	0.9	0.9	0.9	0	0	57.4
Sijeruk	Count	41	1	0	0	1	1	1	1	46
	% within village sample	89.1	2.2	0	0	2.2	2.2	2.2	2.2	100
	% of Total sample	38	0.9	0	0	0.9	0.9	0.9	0.9	42.6
Overall %		**89.8**	1.9	1.9	0.9	1.9	1.9	0.9	0.9	100

KEY: HR-Heavy rainfall, D- Deforestation, SA-Seismic activity, RC-Road Construction, FA- Farming activities, M- Mining, RU- River undercutting, SS- soil structure

Source: Fieldwork 2009

7.2. Danger prone areas

From table 7-2, majority of the respondents perceived steep slopes (80.6% - 34.3% in Sijeruk and 46.3% in Kalilunjar) as the areas prone to landslides. Deforested (8.3%) and cultivated marginal (9.3%) lands where also highlighted as danger prone areas. The results demonstrate that the respondents have an understanding of which areas are prone to landslides and are unsuitable for habitation but some still occupy these same areas. This may be due to the fact that they have no option since they not only inherited the land but also own property there.

The perception of people that steep slopes are the danger prone areas is in accordance with the fast landslides sensitivity results where slopes play an important role.

Table 7-2: Perceived danger prone areas

Village	Measurement	What are the danger prone areas?					
		Deforested land	Steep slopes	Cultivated marginal lands	Along the river	Don't know	Total
Kalilunjar	Count	7	50	3	1	1	62
	% within village sample	11.3	81	4.8	1.6	1.6	100
	% of Total sample	6.5	46	2.8	0.9	0.9	57
Sijeruk	Count	2	37	7	0	0	46
	% within village sample	4.3	80	15	0	0	100
	% of Total sample	1.9	34	6.5	0	0	43
Overall %		8.3	**80.6**	9.3	0.9	0.9	100

Source: Fieldwork 2009

7.3. Increase in the rate of occurrence

A relationship between landslides as the type of degradation taking place was made together with its rate of occurrence (table 7-3). This was to determine if the responses were consistent or random. For example, if the respondents cited landslides as the degradation taking place in their area, then they should be able to indicate whether the rate of occurrence has increased, decreased or stable. Most respondents indicated that the rate of occurrence of the hazard had not increased (59.7% Kalilunjar and 50% Sijeruk). This may be because the creep phenomenon that is mainly taking place in the study area is occurring slowly and only producing gradual distortions and damage to property so the population does not easily notice the increase unless the cracks in their houses widen enough to need renovation. The respondents that indicated not knowing whether the rate of occurrence of the hazard had increased or not, may have not stayed long enough in the study area to observe what is taking place in their physical environment.

Table 7-3: Cross table of rate of occurrence and landslides as type of degradation

Village	**Type of land degradation taking place: Landslides (%)**	**Has the rate of occurrence increased than before? (%)**			
		Don't know	No	Yes	Total
Kalilunjar	Other types of land degradation	1.6	6.5	1.6	9.7
	Landslide: High frequency	11.3	50	22.6	83.9
	Landslide: Medium frequency	0	1.6	3.2	4.8
	Landslide: Low frequency	0	1.6	0	1.6
	Total	**12.9**	**59.7**	**27.4**	**100**
Sijeruk	Other types of land degradation	4.3	8.7	2.2	15.2
	Landslide: High frequency	2.2	39.1	34.8	76.1
	Landslide: Medium frequency	2.2	2.2	4.3	8.7
	Landslide: Low frequency	**8.7**	**50**	**41.3**	**100**

Source: Fieldwork 2009

7.4. Gender and landslide knowledge

The achievement of environmental protection and management requires common values among all groups of which women are apart (Msilimba, 2007). A cross table (table 7-4) was made in order to analyze if the respondent's gender had an effect on their knowledge of the landslide hazard. Of the 44.4 percent female respondents, up to 41.7% indicated heavy rainfall, 1.9% seismic activity and 0.9% road construction as the causes of landslides in the study area. Both male and female respondents had comparable knowledge on the causes of landslides which is contrary to the accepted view that men are better informed on environmental issues than women (Patel 1994 in (Msilimba, 2007)). The respondents' knowledge can be attributed to their interaction with the environment through cultivation since most of them are farmers.

Table 7-4: Gender perceptions on the causes of landslides

Landslide causes	**Gender of respondent**		
	Male (%)	Female (%)	Total (%)
Heavy rainfall	**48.1**	41.7	89.8
Deforestation	1.9	0	1.9
Seismic activity	0	1.9	1.9
Road construction	0	0.9	0.9
Farming activities	1.9	0	1.9
Mining	1.9	0	1.9
River undercutting	0.9	0	0.9
Soil structure	0.9	0	0.9
Total	55.6	**44.4**	100

7.5. Future damage

The damage caused by a landslide event when it strikes an individual's property is less devastating than when a whole community is destroyed. Using a five-point rating scale that ranged from 1 (not of any consequences – quite unlikely) to 4 (threat to persons / property by landslide most serious – very likely) with a "Don't know" option, the respondents were asked to rank their concerns that the hazard posed to personal property and the community at large.

A comparison of the responses at personal and community level was made and the results are shown in table 7-5. The diagonal numbers in table 7-5 indicate the same likelihood that both individual households and the community at large will experience a devastating landslide event in the next ten years. The reason to explain this might be due to clustering in the residential areas where the houses are built close to each other such that the collapse of one will lead to a chain collapse of the surrounding structures.

Figures 7-1 and 7-2 show the distribution of the responses with the background map showing the fast landslides susceptibility map in both villages. The dark blue oval shapes highlight examples of the differences in perception of the respondents towards personal and community damage while the brown circles show examples of areas where the respondents believe that not only will their property be damaged in the next ten years, but the community at large. Experiencing the 2006 Gunungraja landslide might have influenced some of the respondents' belief especially in Sijeruk; that both private and community property is at risk from a landslide in the next ten years. When asked if they are willing to relocate to other villages, most respondents noted that landslides were also occurring in those neighbouring and adjacent villages so there was no need for them to leave the current area.

Table 7-5: Ten year future damage

Village	10 Year house devastating landslide	10 Year community devastating landslide					
		Very unlikely	Quite unlikely	Don't know	Quite likely	Very likely	Total
Kalilunjar	Very unlikely	**4**	0	0	0	0	4
	Quite unlikely	0	**13**	1	2	3	19
	Don't know	0	0	**8**	5	2	15
	Quite likely	0	1	0	**12**	0	13
	Very likely	0	1	1	2	**7**	11
	Total	4	15	10	21	12	62
Sijeruk	Very unlikely	**1**	0	0	0	0	1
	Quite unlikely	1	**2**	0	4	0	7
	Don't know	0	2	**9**	2	0	13
	Quite likely	0	0	1	**11**	0	12
	Very likely	1	0	1	1	**10**	13
	Total	3	4	11	18	10	46

Source: Fieldwork 2009

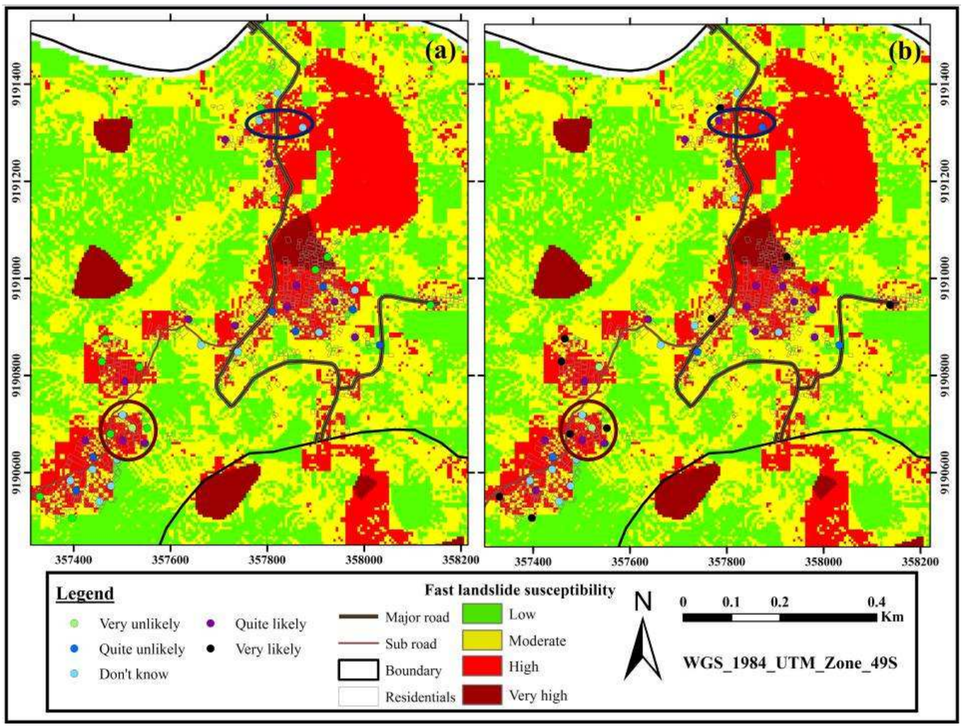


Figure 7-1: Likelihood of a 10 year devastating landslide event to (a) personal property and (b) community in Sijeruk with the debris flow susceptibility map as background

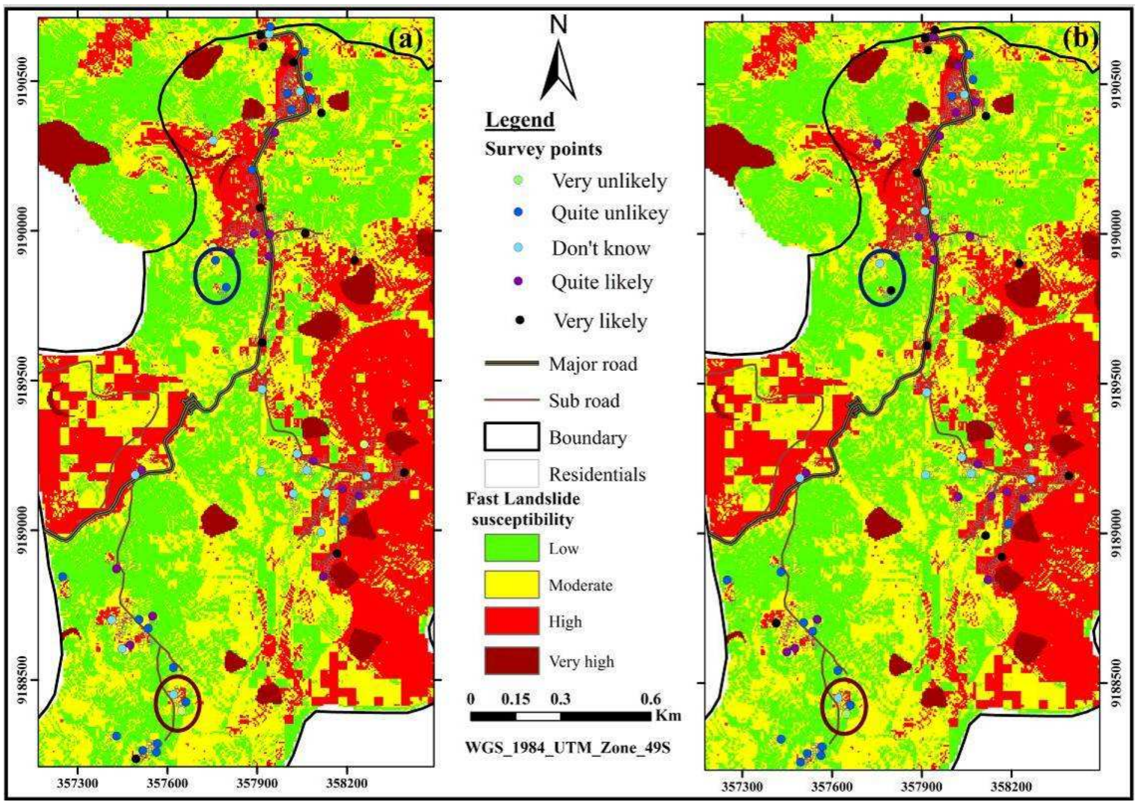


Figure 7-2: Likelihood of a 10 year devastating landslide event to (a) personal property and (b) community in Kalilunjar with the creep phenomena susceptibility map as background

Tables 13-1 and 13-2 (Appendix 3) were complied to better understand figures 7-1 and 7-2 respectively. The painted cells in both tables show points of overlap in the responses. Critically looking at these tables shows that there are some responses that concur with the corresponding susceptibility classes for the two landslide processes. Examples include survey points 1, 13, 25, 31, 37 in Sijeruk and 12, 18, 51, 53 in Kalilunjar. This shows that peoples' perceptions in many cases are comparable to expert knowledge and should be considered / taken into account when selecting possible solutions and not just rely only on alone.

7.6. Conclusion

From this chapter, it can be concluded that most respondents were fully aware of the locations where landslides have occurred and also where they might occur in future. The knowledge was not distinct in terms of gender as both female and male respondents had comparable knowledge on the causes and contributing factors though no differentiation between the two was made as it would confuse the respondents.

It's suggested from the results, that the inhabitants of the study area would benefit from an in-depth knowledge of how human activities aggravate / exacerbate the landslide hazard. It would specifically be beneficial to know the role of cutting down trees (a common practice in the study area) which causes the soil to lose cohesion especially when it rains.

The analysis has also showed that peoples' perception can correspond to expert knowledge, hence the need for its incorporation in research studies such as this.

Whether the populations in the study area accurately perceive the landslide problem or not, they may not be induced to act to prevent it from happening. On the other hand, they may understand that the problem is aggravated by their actions, but the alternatives may be too costly relative to the perceived near term benefits.

8. Coping mechanisms

This chapter explores the landslide coping mechanisms employed by the people in the study area using the data obtained from the coping mechanism section of the questionnaire survey. The general coping strategies have been divided into three phases which include: before, during and after and have also been characterized into social and structural mechanisms. Cross tabulation of variables was carried out in order to access associations and evaluate the consistency of the responses. Active preventive measures applied and implemented at both community and household level in the study area are also highlighted. This chapter also considers the communities' vulnerabilities and capacities through a VCA matrix.

8.1. General coping strategies employed

Coping strategies are often transmitted from generation to generation with in communities and households and are dependent on the assumption that the event will follow a similar pattern and the people's action will be reasonable guide for similar events (Blaikie et al., 1994). Knowledge of the existing coping mechanisms / capacities can help to strengthen planning strategies since they are drawn on existing grass root mechanism. Based on the household questionnaires and field investigations, several coping mechanisms were observed in the study area. The most common strategies developed by the people are shown in table 8-1. It is expected that with the persistent movements taking place in Sijeruk, the people there would have better coping strategies than those in Kalilunjar; but it's not the case. 83% of the respondents in Sijeruk do nothing before the landslides happen in comparison to the 47% in Kalilunjar. Most households don't save their money in preparation for disaster and they also don't have insurance. They claim to lack the resources yet when given to them by the local authority, they only use them for personal gain. For example, when the people are given seedlings, they plant them in their own gardens and not in locations where the rate of movement is believed to be high. Some respondents also argued that since they find the mosques, schools and village offices as safe places to take shelter, there is no need for them to spend energy and resources making their individual houses strong and safe. Majority of the respondents prefer fixing / renovating their houses in case of slight damage to being relocated because majority have inherited the property and have sentimental attachments and don't want to move even when provided with a safe place.

From table 8-1, the most predominant activity employed by the people before an event is planting trees (24.2% Kalilunjar and 10.9% Sijeruk) while during the event, majority first run to a safe place before returning to help those trapped (27.4% Kalilunjar and 37% Sijeruk). After the event, the people concentrate on fixing the house if not damaged (38.7% Kalilunjar and 17.4% Sijeruk). Some of the population attributes the problem to divine causes beyond their control. So all they can do to cope with the hazard is pray to the almighty God.

Table 8-1: Coping mechanisms employed by the people in the study area at different stages

Coping activities employed	Number of responses	
	Kalilunjar (%)	**Sijeruk (%)**
Before		
Social		
Plant trees	24.2	10.9
Sensitize the community on the effects of cutting down trees	1.6	2.2
Be conscious when the rain seasons start	4.8	2.2
Pray to God	12.9	0
Nothing due to lack of resources	46.8	**82.6**
Structural measures		
Construct gabions along the river	8.1	2.2
Construct tripod stand at the house foundations	1.6	2.2
Build terraces especially for the agricultural areas	3.2	0
Construct water channels	4.8	0
During		
Social		
Run to a safe place then after go back to help those trapped	27.4	37
Stay in the house while praying to God	0	6.5
If event is major run to a safe place but do nothing if its minor	1.6	2.2
Nothing	71	**56.5**
After		
Social		
Plant more trees	4.8	10.9
Change from wet to dry cultivation	0	2.2
Move together with others to a provided relocation place	6.5	17.4
Move to another location within the same village if situation is not favourable	29	8.7
Clear the slide material away and resume with daily life	3.2	0
Nothing	14.5	**34.8**
Structural		
Try and build a stronger house with available resources	6.5	2.2
Fix the house if its damaged	38.7	17.4
Renovate the house in case of cracks due to creep	0	4.3
Strengthen the house foundation	1.6	2.2
Build gabions	27.4	6.5

Source: Fieldwork 2009

8.2. Landslide management measures

A number of landslide mitigation measures have been initiated in the study area to minimize the costs involved when landslides strike in the long run. They include afforestation (29% Kalilunjar and 63% Sijeruk), draining water out (12.9% Kalilunjar and 17.4% Sijeruk), terracing (8.1% Kalilunjar and 13% Sijeruk) and wire mesh blanket (35.5% Kalilunjar and 4% Sijeruk). The high percentage use of the wire mesh blanket method in Kalilunjar is due to a lack of distinction between the actual wire mesh blanket and the gabions. When asked where the blankets where placed to prevent the hazard from happening, the respondents would always refer to the gabions placed at the river. The high percentages of landslide mitigation measures in Sijeruk may be due to the high rate of creep phenomena taking place in the area while the low percentages in Kalilunjar are not surprising because most of the events that have happened are localized impacting individuals and not the whole community. The indifference in the mitigation measures is mainly due to lack of resources.

Some inconsistencies were observed from the respondents (table 8-2). For example, when asked if there were any landslide measures being implemented, the respondents that indicated “not knowing” what was being done were expected not to give a response but they did. This type of inconsistencies can be attributed to either a miss-interpretation from the interpreters’ side or a hesitation on the side of the respondents’ about the topic. The values in bold highlight some of the inconsistencies of the respondents.

Table 8-2: Cross tabulation of availability of landslide management measures in use within the study area

Village	Are there any landslide management measures implemented in your area	What is being done to combat landslide occurrences? (%)					
		N	A	T	WMB	DW	DL
Kalilunjar	Yes	30.6	29	8.1	35.5	12.9	1.6
	No	12.9	16.1	8.1	11.3	1.6	1.6
	Don't know / not sure	22.6	**22.6**	**9.7**	**16.1**	**12.9**	0
Sijeruk	Yes	56.5	63	13	4	17.4	0
	No	6.5	8.7	2.2	0	2.2	0
	Don't know / not sure	8.7	**8.7**	**2.2**	0	**2.2**	0

N- Nothing, A- Afforestation, T- Terracing, WMB- Wire mesh blanket, DW- Draining water out, DL- Diversification of land use. **Source: Fieldwork 2009**

The question on which groups were involved in the implementation of the management measures in the study area was asked to determine whether the people themselves were willing to rehabilitate, protect and manage their area or if the measures are being imposed on them. The results are presented in table 8-3. 40.7% of the respondents believed that the community land users are at the forefront of implementing the management measures of which 26.9% are from Sijeruk. Up to 27% of the respondents cited the government leaders, with an equal distribution of 13.8% in both villages. The results show that 24.1% of the respondents believe that individual land users are involved in the management implementation measures.

Table 8-3: Groups involved in the implementation of the landslide management measures

Village	Measurement	What target groups are involved in the implementation of the management measures?				
		Don't know	Individual land users	Community land users	Government Leaders	Total
Kalilunjar	% within village sample	1.6	27.4	46.8	24.2	100
	% of total sample	0.9	15.7	26.9	13.9	57.4
Sijeruk	% within village sample	15.2	19.6	32.6	32.6	100
	% of total sample	6.5	8.3	13.9	13.9	42.6
Overall %		7.4	24.1	**40.7**	27.8	100

Source: Fieldwork 2009

8.3. Landslides in agricultural land

How people deal with landslides in their agricultural land either increases or decreases their crop yields depending on the methods they employ. The occurrence of landslides in agricultural land leads to a deterioration of the functional capabilities of soil; even if land degradation caused by nature is often balanced by formations of new land. In the study area, majority of the people do nothing when landslides occur in their agricultural land (59.7% Kalilunjar and 45.7% Sijeruk). This may be due to lack of resources or knowledge on what to do. The most employed method is that of planting trees (11.3% Kalilunjar and 17.4%) while others just clear the slide material away. The table 8-4 below not only shows results of the activities / methods that the respondents implement, but it also accesses the consistency of their responses.

The variable of how people deal with landslides in their agricultural land was cross tabulated with properties owned in form of cultivable land. The results indicate that some of the respondents were not consistent with their responses. For example in Kalilunjar, 1.6% of the respondents claimed not to have cultivable land but said they planted trees to deal with the hazard. This could also possibly be that, that’s what they could have done if they had land. Owning land has an effect on the way one deals with the hazard.

Table 8-4: Dealing with landslides in agricultural land

Village	Properties owned: cultivable land	How do you deal with landslides in your agricultural land? (%)					
		Nothing	Planting trees	Build terraces	Construct water channel	Clear material away	Total
Kalilunjar	None	8.1	1.6	0	0	1.6	11.3
	Cultivable land	59.7	11.3	1.6	3.2	12.9	88.7
	Total	67.7	12.9	1.6	3.2	14.5	100
Sijeruk	None	21.7	0	0	0	0	21.7
	Cultivable land	45.7	17.4	6.5	0	8.7	78.3
	Total	67.4	17.4	6.5	0	8.7	100

Source: Fieldwork 2009

8.4. Socio-economic benefits of the management measures

A single landslide event may cripple the socio-economic performance of an area by destroying infrastructure, productive capacity and creating irreversible changes in the natural resource base. Then the scarce resources that might have been earmarked for development have to be diverted to reconstruction, thereby setting back the economic growth (Hufschmidt, 2008). For example agricultural productivity may reduce significantly due to loss of top fertile soil and the farmers may have to buy fertilizers to boost their crop yields.

The question on the socio-economic benefits of the mitigation measures being used was asked to determine whether the employed measures where promoting the well being of the people in the study area or not. The results are shown in table 8-5. 88.9% of the respondents cited the reduction in the risk of mass movements of which 52.8% were from Kalilunjar and 36.1% from Sijeruk. Increased crop yields (9.3% in Kalilunjar and 7.4% in Sijeruk) were also indicated as a benefit of the measures that have been undertaken to reduce the impact of landslides in the study area.

Table 8-5: Socio-economic benefits of the landslide management measures

Village	Measurements	What are the socio-economic benefits of the method being used				
		Reduced risk of mass movement	Increased land for cultivation	Collection of surface run-off	Increased crop yield	Diversification of income resources
Kalilunjar	% within village sample	91.9	3.2	21	16.1	12.9
	% within total sample	52.8	1.9	12	9.3	7.4
Sijeruk	% within village sample	84.8	8.7	13	17.4	6.5
	% within total sample	36.1	3.7	5.6	7.4	2.8
Overall %		**88.9**	5.6	17.6	16.7	10.2

Source: Fieldwork 2009

Cross tabulation was made of the management measures being used and the socio-economic benefits to determine which practice has been embraced by the people in the study area. The results are shown in table 8-6. In both villages, afforestation (61.3% Kalilunjar and 71.7% Sijeruk) has been taken on as the main measure to reduce the risk of mass movement. More than 50% of the respondents in both villages also cited the use of gabions (wire mesh blanket) as a common method. Draining out of water from the moving mass was also indicated as a management measure that is being incorporated in the study areas (25.8% Kalilunjar and 19.6% Sijeruk). Some management measures such as diversification of land use are not fully applied by the people especially the farmers as they reduce their yields by reducing cropped area of the commercial crops.

Table 8-6: Cross table of the landslide management measures and the socio-economic benefits

Village	What is being done to combat landslide occurrence?	What are the socio-economic benefits of the method being used? (%)				
		Reduced risk of mass movement	Increased land for cultivation	Collection of surface run off	Increased crop yield	Diversification of income resources
Kalilunjar	Afforestation	**61.3**	1.6	12.9	14.5	9.7
	Terracing	21	3.2	3.2	6.5	4.8
	Wire mesh blanket	**59.7**	3.2	16.1	8.1	9.7
	Draining out the water	25.8	1.6	16.1	4.8	3.2
	Diversification of land use	3.2	0	0	0	1.6
Sijeruk	Afforestation	**71.7**	8.7	13	15.2	4.3
	Terracing	15.2	6.5	4.3	8.7	2.2
	Wire mesh blanket	**58.7**	4.3	8.7	8.7	4.3
	Draining out the water	19.6	2.2	10.9	6.5	2.2
	Diversification of land use	0	0	0	0	0

Source: Fieldwork 2009

Some of the responses were not coinciding with the intended benefit. For example draining out the water cannot have a benefit of "increased land for cultivation" just like the use of the wire mesh blanket cannot have a benefit of collection of surface run off. These and many others are some of the inconsistencies that are observed in the responses.

8.5. Motivation

It was observed that majority of the people in both villages in the study area have limited resources due to their low income levels; so they cannot individually implement some of the landslide management measures on their own. If there is some sort of motivation to encourage the people to take up or start using the available measures, then the implementation and sustainability of such projects will be successful. From table 8-7, 63% of the respondents cited subsidies as the main motivation method being used with 34.3% from Kalilunjar. Social pressure also to an extent (14.8%) has encouraged the people to do something about the landslide problem in their area (11.1% Kalilunjar and 3.7% Sijeruk). Whatever motivation is used, it should be good enough in terms of advantages for the people.

Table 8-7: Types of motivation for implementing the management measures

		What was the motivation?						
Village	**Measurements**	Don't know	Rules and regulations	Subsidies	Social Pressure	Well being and livelihood improvement	Increased profit	Total
Kalilunjar	% within village sample	0	3.2	59.7	19.4	16.1	1.6	100
	% of total sample	0	1.9	34.3	11.1	9.3	0.9	57.4
Sijeruk	% within village sample	6.5	6.5	67.4	8.7	8.7	2.2	100
	% of total sample	2.8	2.8	28.7	3.7	3.7	0.9	42.6
Overall %		2.8	4.6	**63**	**14.8**	13	1.9	100

Source: Fieldwork 2009

8.6. Focus group discussions

They were held in each village with representatives of the communities using a close-up image of their respective villages. The discussions (figure 8-1) were used as a forum for defining the communities' problems and opportunities in regard to the landslide problems. Most of the discussions evolved around the size and location of the past landslide events, the damages and types of losses incurred and the actions the participants think should be taken to reduce the likelihood of future events. An attempt was made to prepare an action plan to develop their local mitigation and coping strategies. It involved understanding who and what is vulnerable to landslides plus what capacities exist within the community to reduce their vulnerability (table 8-8). Such active engagement with communities helps them to define their problems and opportunities (E.C.B.P, 2009).

Figure 8-1: FGD participants 1(a) and 1(b) in Sijeruk village and 2(a) and 2(b) in Kalilunjar village

Table 8-8: Vulnerabilities and capacities in the study area

Landslide Hazard	Vulnerabilities	Capacities
Physical and material • What is vulnerable? • What resources exist to address vulnerability?	• Relocated community in Sijeruk - Creep is taking place causing cracks in their houses and also made the gabions to fail. - No permanent channel to drain the rain and spring water. • People located on higher ground and far from daily resources. - Their chances for experiencing fast landslides is high • Public facilities such as village office, schools: kindergarten and primary, mosque, clean water channel, waste water channel. • Part of the road in Kalilunjar (It has been blocked before by a	• Building of stabilization walls and drainage facilities around houses and also constructing gabions in places known to be unstable. • Village is directly connected with road • Mobile network is available for communication • Warning system (Kentongan) is available in case of any precursory signs • Building of permanent drainage channel • Construct traditional wooden houses (joglo) that are easily replaceable once damaged. • Plant trees that can hold the ground like: albacia, calliandra, sengon, bamboo. • Reduce the number of fish ponds in the study area • Construct gabions along the river.

	landslide).	• Training people in landslide hazard management.
Social and organization • Who is vulnerable? • What resources exist to make them less so?	• Children below 5 years and people 60-90 years old • People with little income / no jobs who have no choice but to live on the marginal unsafe places. • Uneducated and poor people because they don't have much access to information of the natural disasters happening and also have limited chance to get good jobs. • There is no special community organization about landslide defense and its facilities, lack of campaign about initiative towards vulnerable area. Marginal people that have limited access to public resources.	• Free primary and secondary education by government to reduce the number of the uneducated people. • Giving special training skills to the uneducated, poor and teenagers. • Urging people to always respond to the kentogan warnings to which they are familiar with. • Mutual, moral and physical support when a landslide happens • The local government makes socialization among the people through the community building program (karang taruna)
Motivation and attitude • What attitudes lead to vulnerability? • What capacities exist to improve the situation?	• Changing the conservation forest into productive land. • Unplanned farming practices due to lack of knowledge e.g. Albacia requires a minimum of 8 years to be harvested but it's harvested at just 5 years. • Lack of collective mobilization and mutual work among the community (Gotong-royong).	• Active community leadership to influence the people • Make farming competition games (Kelompencapir) to educate farmers on how to cultivate their land. • Agricultural community development helping in the transition from dry season to wet season(government, NGO and stakeholders) • Diversify land use with trees such as calliandra, bamboo, albacia, mahogany, pine and tea. Seedlings are also being given out free of charge.

8.7. Local authority

The local authorities in both villages are aware of the risk from the landslide hazard though they tend to minimize the extent of the problem. To them, defining the risk and non risk areas is political as they too occupy part of the prone areas.

The management practices that they are trying to implement such as constructing gabions or retaining walls and the drainage for excess surface water is technically oriented and insufficient. They have tried to implement preventive participation such as supplying seedlings to plant not only along the river banks especially in Kalilunjar but also on the masses believed to be unstable but majority of the recipients divert the resources to their own agricultural land. Such preventive measures are becoming difficult to implement as they require a mechanism for law enforcement to ensure that the seedlings are utilized to benefit the community at large and not just individuals.

8.8. Active preventive strategies

The enthusiasm for sophisticated technological methods of overcoming disasters such as landslides has led many specialists to overlook and undervalue the effectiveness of local coping strategies and technologies (Twigg, 2004). Some preventive intervention measures undertaken to impede further slope failure and reduce landslide risk in both villages are listed below. They either enhance or limit local coping capacity and they include:

8.8.1. Retaining structures and drainage measures

A very effective way of protecting unstable slopes from sliding is stabilization by drainage. In the study area, there is a weak contact between the hard, impervious bedrock of andesitic lava providing a sliding surface to the top weathering soil of loose clay-silt. So constructing just an embankment may result in a build-up of water in the slope, creating further instability.

In Sijeruk, the community has built retaining walls with provision for proper drainage of the pore water pressure to reduce its force on both the slope and constructed walls in localized areas believed to be moving. While in Kalilunjar, the community has built rock gabions along the river to prevent it from undercutting the slope. Such measures are less expensive and more applicable to developing countries such as Indonesia. And since they are community initiated, then sustainability is guaranteed. Figure 8-2 shows examples of the measures being used in the study area.

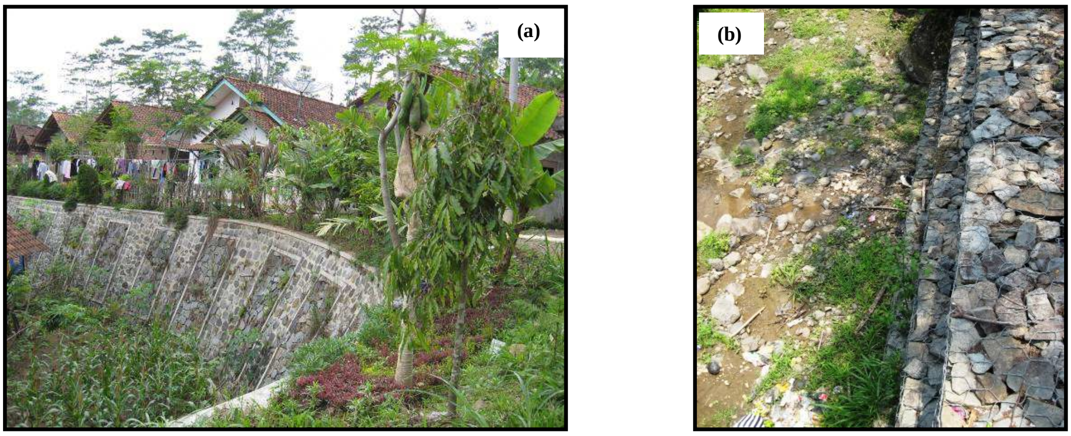


Figure 8-2: Retaining walls constructed with drainage provision in Sijeruk (a), Gabions placed along the river in Kalilunjar (b)

8.8.2. Access

The availability of a good road network within the study area gives the communities better chances of coping – since in the event of a disaster, external assistance can easily have access to the affected areas.

8.9. Community disaster management system

No formal early warning systems have been developed in the study area but the presence of a semi-organized disaster response system increases to an extent the people's chances to survive the effects of a disaster.

8.9.1. Kentogan

It's a traditional warning system sounded to alert the community in case of anything out of the ordinary like say a landslide happening. It's made from wood with a hole in the middle and is sounded by hitting it with a small wooden stick. It's usually placed on houses that are closest to the slopes or in strategic positions. Once sounded, people are able to understand that there is a dangerous situation happening or about to happen; so they should go to common meeting places. With regard to this system, the community has faith in it and still considers it accurate. Figure 8-3 shows an example of the kentogan and a schedule for those responsible to sound it.

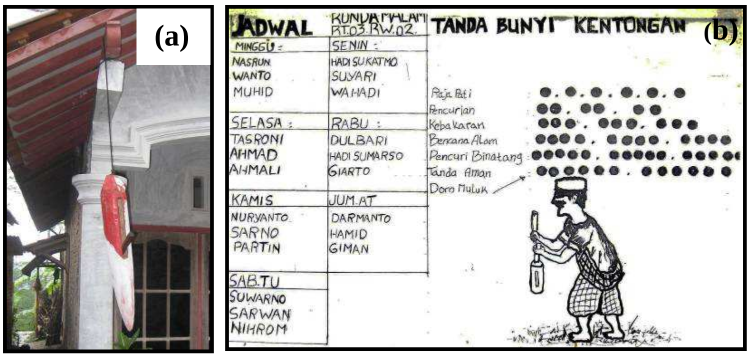


Figure 8-3: (a) Actual kentogan and (b) an example of a schedule to sound it

8.9.2. Gotong Royong

It refers to the spirit of helping each other in good will. Usually, the head of the village mobilizes the community members in order to get something done especially during hard times like when disaster strikes. Gotong royong is seen as a way of improving social cohesion and its activities include constructing or renovating public facilities such as mosques and schools which could be used as evacuation centres.

From the FGD’s conducted in both villages, the participants expressed the need to revive gotong royong as it was now lacking and they believed that its one of the ways in which they can build the village capacity. According to Twigg (2004), the process of working and achieving things together can strengthen communities as it reinforces local organization, builds up confidence, skills, and capacity to cooperate.

8.10. Conclusion

This chapter has explored the existing coping mechanisms in use by the communities in the study area. These strategies have been divided into three phases of before, during and after and also characterized into social and structural mechanisms. The religious element was not explored in depth but the Islamic religion is actively practised by at least ninety five percent of the population in the study area. Though irrespective of the religion, among the respondents there are those who still do nothing in the three phases mentioned above but wait for divine intervention for protection.

Majority of the coping strategies implemented are an initiative of the local authorities though the people have trained themselves to make arrangements within their limits. The community land users especially those in Kalilunjar are willing to carry out the rehabilitation of their area than waiting for government or having individuals dealing with the problem singularly. It has also been observed that the people still have faith in the semi-organized disaster management system that is in place in both villages. Such collective community management measures lead to successful implementation of projects.

9. Vulnerability analysis of elements at risk

This chapter deals with both the physical and social vulnerability of the communities. The physical elements include buildings and essential facilities such as schools and mosques while social vulnerability encompasses elements such as education level, length of stay in the area plus other socio-economic characteristics. The discussion in this chapter is based on the information gathered during fieldwork from 108 respondents who represented a total of 779 people in the study area.

9.1. Introduction

Elements at risk maybe defined as all the valued attributes threatened by the hazard (in this case landslide). They include physical aspects such as structures and infrastructure and socio-economic characteristics of the respondents; that influence the vulnerability of the investigated communities in the study area. This was done by looking at the past landslide impacts on the buildings and the community inhabitants. Some of these are quantifiable while others are not.

9.2. Why live in the area

Reasons for living in the respective villages were determined and the results are presented in table 9-1. Most respondents are staying on ancestral property as represented by 66.7% of the total sample. In Kalilunjar, 35.2% of the sampled population indicated that they were residing on ancestral property, against the 31.5% in Sijeruk. 24.1% of the respondents own property obtained through buying from which majority are from Kalilunjar. Other reasons included easy access and work related.

Table 9-1: Reason for living in the respective village

Village	Measurement	What is your reason for living here?					
		Cheap	Ancestral property	Own property	Easy access	Work	Total
Kalilunjar	Count	1	38	17	1	5	62
	% within Village sample	1.6	61.3	27.4	1.6	8.1	100
	% of Total sample	0.9	35.2	15.7	0.9	4.6	57.4
Sijeruk	Count	0	34	9	1	2	46
	% within Village sample	0	73.9	19.6	2.2	4.3	100
	% of Total sample	0	31.5	8.3	0.9	1.9	42.6
Overall %		0.9	**66.7**	24.1	1.9	6.5	100

9.3. Physical characteristics (Buildings)

Not many studies describe the impact of a landslide on a building. But it can be understood that a building may completely get destroyed, partially damaged or may experience excessive deformation such as inclination without damage during a landslide event (EPFL 2002 in (Papathoma-Kohle et al., 2007)). Some of the factors that play a role during a landslide impact include the building material, its age, size and foundation (Papathoma-Kohle et al., 2007). The location of the building also affects its physical vulnerability. This is not only because of its presence within the high susceptibility zone, but also the characteristics of the neighbouring slope. The impact of landslides on a building can be diverse depending on the type of movement. For example figure 2-2 shows some types of magnitudes that a building can face due to landslide impact. According to knowledgenetwork.ca, a slope with a steady inclination plus uncut forest is safer than one without vegetation and has irregular rise.

9.3.1. Quality of housing

The probability of people being wounded or killed in the event of a natural hazard such as a landslide is largely influenced by their dwelling structures (Cutter and Emrich, 2006). The design of a house can be a very effective way of adjusting to a specific hazard but can also increase the vulnerability of its occupants. When a house is rented, the tenant is usually limited on the condition and maintenance of the dwelling. This includes things such as constructing a retaining wall in case of landslides. Also the house owner is more likely to ignore the maintenance of the structure since she / he is not exposed on a daily basis (Hufschmidt and Crozier, 2008). Data concerning the built environment was collected during the field household surveys and it included information such as the type of roof, wall and floor material that constitute buildings.

The survey showed that most if not all homes are owned by the occupants who take time to repair/renovate their houses in case of damage by the ongoing creep. 78.7% of the houses visited in both villages (42.6% Kalilunjar and 36.1% Sijeruk) were regarded as permanent structures while 21.3 % (14.8% Kalilunjar and 21.3% Sijeruk) were taken as semi-permanent. Permanent structures in this study refer to buildings made up of more than 90% brick-concrete material while the semi-permanent structures have a small percentage of brick concrete material. It was also observed that all houses had clay tiles as roofing material which helps to increase their strength (figure 9-1).

Figure 9-1: Examples of clay tiles roofs in the study area

Figure 9-2 shows the spatial distribution of structures within the study area with the fast landslides susceptibility map as background. It can be seen that most houses in Sijeruk are located within the medium to high susceptible areas while in Kalilunjar some houses are located in the low areas as shown by the circular shape. Figure 9-3 shows the spatial distribution of structures with the creep phenomena map as background. It can also be observed that while majority of the houses in Sijeruk are located in the high susceptibility class, there are some structures in Kalilunjar that are within the low class as indicated by the pink circle.

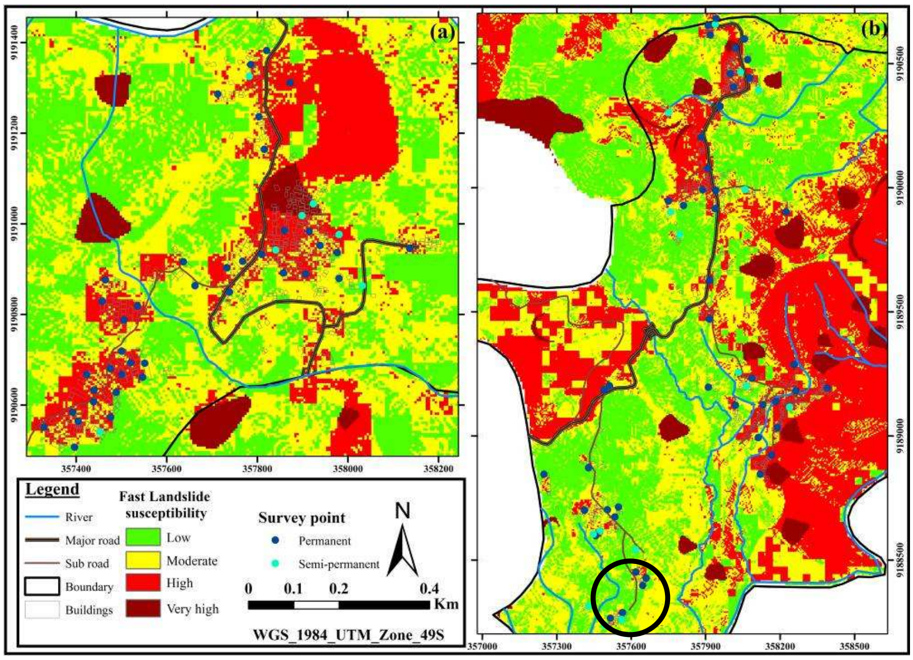


Figure 9-2: Spatial distribution of the type of structures in the study area with the fast landslides susceptibility map as background ((a) Sijeruk and (b) Kalilunjar)

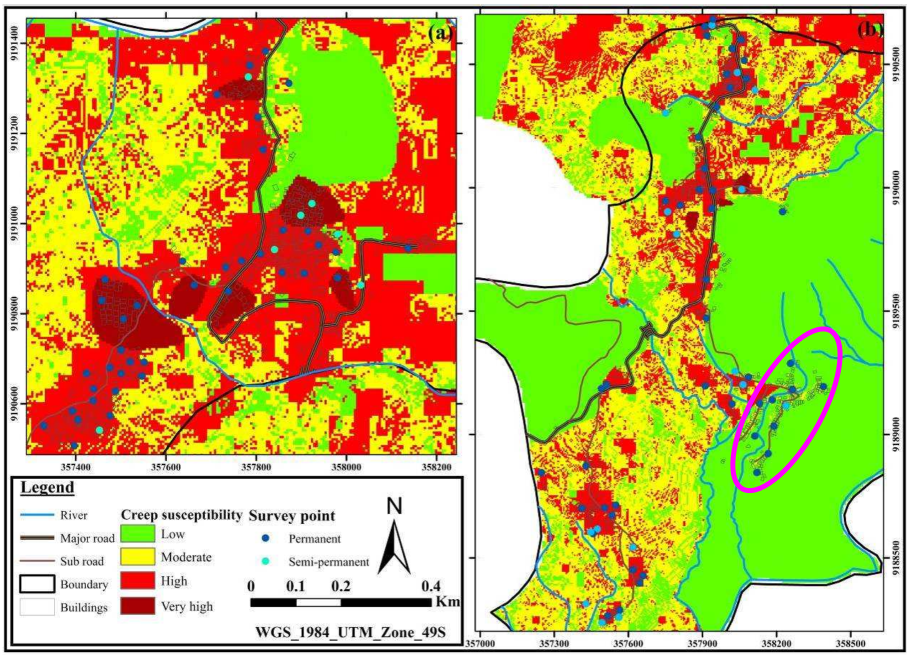


Figure 9-3: Spatial distribution of the type of structures in the study area with the creep phenomena susceptibility map as background ((a) Sijeruk and (b) Kalilunjar)

9.3.1.1. Wall

The nature of the wall facing the slope can either increase or decrease the vulnerability of the building occupants. Absence of openings in the wall decreases this type of vulnerability, though it's also dependant on the volume and speed of the slide material (Papathoma-Kohle et al., 2007). Also the type of material from which the wall is constructed matters a lot. The strength of a brick concrete wall is much more than that of a wooden wall. A brick-concrete wall can withstand to an extent the impact of a certain external force which a wooden wall can't withstand. With this in mind, analysis was made of the types of building wall materials in the study area. From table 9-2, it can be seen that the dominant wall type in both villages is that of brick concrete (71% for Kalilunjar and 67.4% for Sijeruk) for the permanent structures. In Kalilunjar, there are also a sizeable number of wooden houses (16.1%) while in Sijeruk, a sizeable number of concrete-wood (17.4%) exists. Brick concrete refers to structures with all the wall materials made of bricks, sand and cement while concrete-wood refers to a house with the outer walls made of concrete and the inside wall partitions done with ply wood. With wood, the entire house walls where completely wooden.

Table 9-2: Types of building structure

Village	Wall material (%)	Type of structure (%)		
		Permanent	Semi-Permanent	Total
Kalilunjar	Brick Concrete	**71**	0	71
	Wood	0	16.1	16.1
	Concrete wood	3.2	9.7	12.9
	Total	74.2	25.8	100
Sijeruk	Brick Concrete	**67.4**	0	67.4
	Wood	0	13	13
	Concrete wood	17.4	2.2	19.6
	Total	84.8	15.2	100

Source: Fieldwork 2009

9.3.1.2. Floor

The importance of the floor material is to understand the uniformity of the house. A house with a floor connected to the walls can be regarded stronger than a house without a proper floor. Also the floor material indicates the welfare of a particular household. A family whose house has a brick concrete floor is regarded to have a higher / better standard of living than one with a floor made out of earth material. Based on the field results (table 9-3), there were mainly two types of floor materials in both villages; brick concrete the dominant type especially for the permanent structures (71% for Kalilunjar and 84.8% for Sijeruk) and soil. Brick concrete in this study refers to cement and ceramic tiles while soil refers to earth material.

Table 9-3: Cross table of the building structure and floor material

Village	Floor material (%)	Structure type (%)		
		Permanent	Semi-Permanent	Total
Kalilunjar	Brick Concrete	71	19.4	90.3
	Soil	3.2	6.5	9.7
	Total	74.2	25.8	100
Sijeruk	Brick Concrete	84.8	13	97.8
	Soil	0	2.2	2.2
	Total	**84.8**	15.2	100

Source: Fieldwork 2009

9.3.1.3. Combination of wall and floor materials

An attempt was made to assess structural vulnerability based on a combination of the wall and floor materials since different materials have different vulnerabilities. A cross tabulation was generated as shown in table 9-4.

Table 9-4: Cross table of the floor and wall material

Village	Wall material	Floor material		
		Brick Concrete	Soil	Total
Kalilunjar	Brick Concrete	**67.7**	3.2	71
	Wood	12.9	3.2	16.1
	Concrete wood	9.7	3.2	12.9
	Total	90.3	9.7	100
Sijeruk	Brick Concrete	**67.4**	0	67.4
	Wood	10.9	2.2	13
	Concrete wood	19.6	0	19.6
	Total	97.8	2.2	100

Source: Fieldwork 2009

From the above cross table, the highest material frequency of occurrence in both villages is that of brick concrete while other materials had fair distribution though not that significant. Representative structural types within the study area are shown in figure 9-4 below.

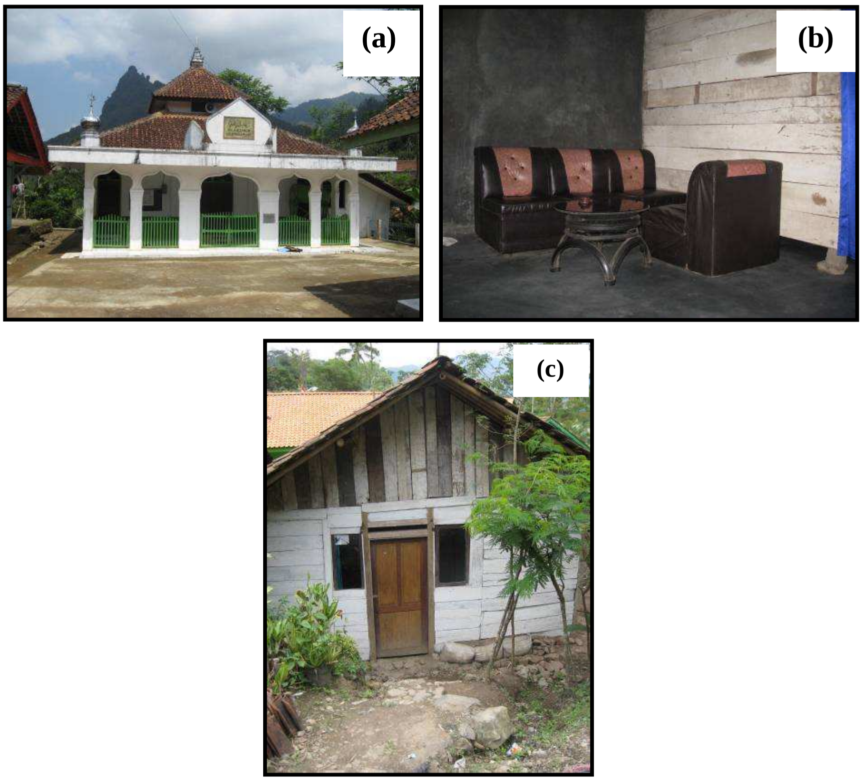


Figure 9-4: Examples of the different types of structures: (a) brick-concrete, (b) concrete wood and (c) wooden

9.3.2. Building use

In the study area, majority if not all of the buildings were mainly used for residential purposes apart from the critical facilities such as schools, mosques and small retail shops located along the main road. Majority of these critical facilities except the retail shops where constructed out of brick concrete. Figures 9-5 and 9-6 below show the location and distribution of the essential critical facilities with the fast landslides and creep phenomena susceptibility maps as background respectively. It can be seen that most of these facilities in both scenarios are located in the high susceptibility areas. This means that their chances of getting damaged are high so something needs to be done in form of preventive measures. Table 13-3 (Appendix 3) explains better the information provided in figures 9-5 and 9-6. As explained earlier, all the critical facilities in both villages apart from one kindergarten and one mosque in Kalilunjar are located in the dangerous areas.

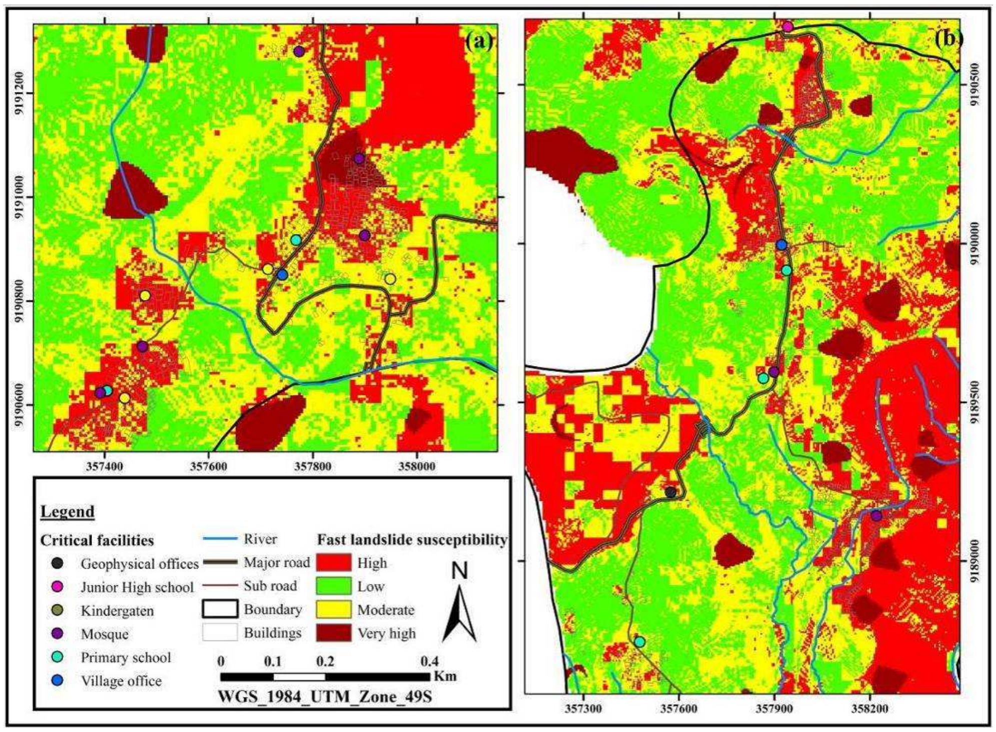


Figure 9-5: Spatial distribution of the critical facilities in (a) Sijeruk and (b) Kalilunjar with the fast landslides susceptibility map as background

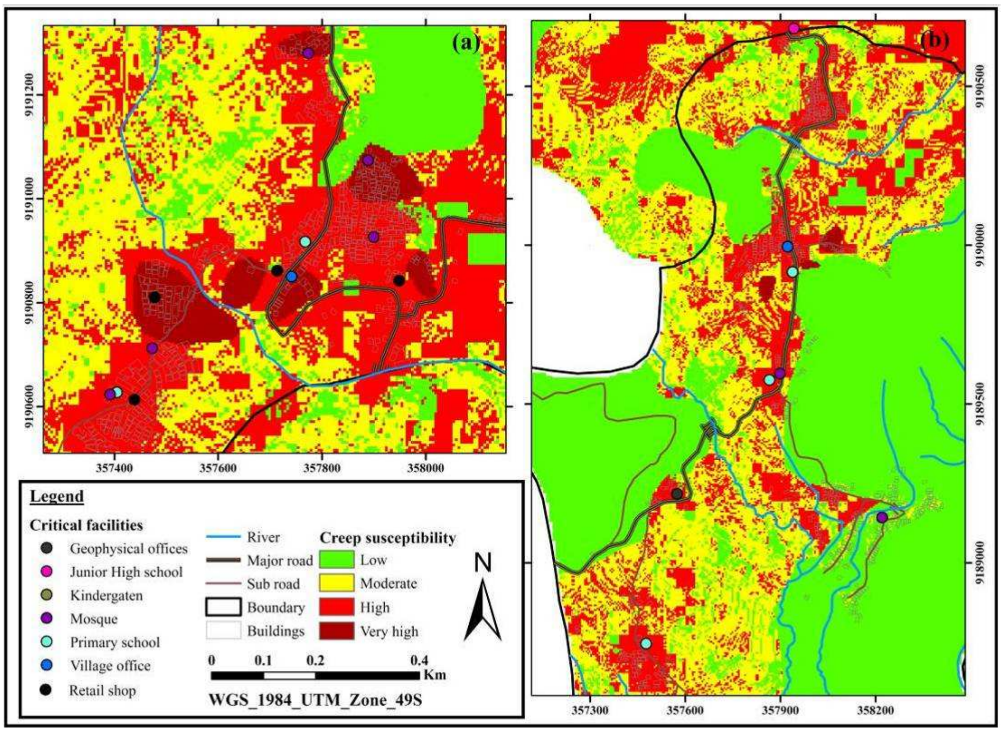


Figure 9-6: Spatial distribution of the critical facilities in (a) Sijeruk and (b) Kalilunjar with the creep phenomena susceptibility map as background

9.3.3. Building location

People's location when a hazard strikes influences their exposure (Glade, 2003). The day time – night time presence principal determines the degree of exposure. For example, the exposure of the employed group of people and school going children will be lower during the day if their home is located in a susceptible area but will be higher at night. Also physical location of a building matters though it's relative to the phenomena taking place. A house located on a ridge is regarded to be more vulnerable than one located along the slope. Likewise, a house located in the valley maybe more at risk since all material from upslope will inundate it. Using the latter situation, analysis was made on building locations in the study area. From table 9-5, most of the buildings in the study area are located along the slope (95.4%). Using the obtained susceptibility maps, it can be seen that majority of the buildings in the study area are located in both the moderate and high susceptibility zones. This alone makes them extremely vulnerable to the hazard.

Table 9-5: Topographic location of the houses

Topographic location	Measurements	Village		
		Kalilunjar	Sijeruk	Total
Along the slope	Count	61	42	103
	% of Total sample	56.5	38.9	**95.4**
At the mountain foot	Count	0	3	3
	% of Total sample	0	2.8	2.8
On the ridge	Count	1	1	2
	% of Total sample	0.9	0.9	1.9
Overall %		57.4	42.6	100

Source: Fieldwork 2009

9.4. Social – economic characteristics

Social – economic characteristics define the ability of an individual within a household to cope with the impact of a natural hazard (in this case landslide) when they happen in their localities given their socio-economic status (Armaş, 2008). These aspects are related to people's lives, economic activities, income levels, where they live; etc. An understanding of the people's action is obtained once these characteristics are analyzed. Some of the key characteristics collected during the survey are explained below.

9.4.1. Age of the respondents

This is usually used in respect to the young and elderly. But in this study, it was used to be able to determine if the respondents had any recollection of the past landslide events in the respective villages in the study area. The older one is, the higher the chances of having experienced or heard about a past event than one who is tender in age. It is assumed that age has a correlation with how individuals will conduct themselves when responding before, during and after a landslide event. Having lived through a similar hazardous event in the past can increase one's preparedness and improve the way they respond in case of an emergency (Hufschmidt, 2008). During the survey emphasis was placed on having respondents above twenty years of age since they are considered adults and are in position to best explain the situation of what is happening in their area. Table 9-6 below, shows the age distribution of the respondents with the dominant ages between 20 – 49 years for both villages.

Table 9-6: Cross table of gender and age of the respondents

Village	Gender	Age group (%)					
		20 - 29	30 - 39	40 - 49	50 - 59	> 60	Total
Kalilunjar	Male	11.3	8.1	12.9	8.1	8.1	48.4
	Female	19.4	16.1	9.7	3.2	3.2	51.6
	Total	30.6	24.2	22.6	11.3	11.3	100
Sijeruk	Male	13	10.9	23.9	8.7	8.7	65.2
	Female	4.3	10.9	13	6.5	0	34.8
	Total	17.4	21.7	37	15.2	8.7	100

Source: Fieldwork 2009

9.4.2. Length of stay

This was not only used to determine if the respondents had any recollection of the past landslide events, but it's also related to social networking and local support from which one can profit due to shared responsibilities and resources as well as emotional support in case of a disaster. Lack of a social network can be a limiting factor. Recent immigrants may lack connections to the larger community and may hesitate to seek assistance outside their family (Morrow, 1999). It is believed that the longer one stays in a particular area, the wider the social network. This means that such a person can get assistance from neighbours and this helps to minimize to an extent the impact of the landslide disaster. Table 9-7 shows the results from the analysis. Majority of the respondents 88% (51.9% for Kalilunjar and 36.1% for Sijeruk) had stayed in the respective villages for more than five years so depending on the frequency of the hazard, they must have an understanding of which are the safe places and possible evacuation routes. Plus who to run to for help. It was realised that the individuals who had stayed for less than one year were teachers who had been recently offered jobs in some schools in the study area.

Table 9-7: Duration of stay of the respondents

Village	**Duration (%)**			
	< 1 year	1-5 years	> 5 years	Total
Kalilunjar	1.9	3.7	51.9	57.4
Sijeruk	0	6.5	36.1	42.6
Total	1.9	10.2	**88**	100

Source: Fieldwork 2009

9.4.3. Income dependency ratio

The number of income generating members in relation to the number of dependants influences a family's economic status. Families with a higher ratio of dependants to income earners are generally under pressure to obtain a certain economic status which leads to a high demand when responsibilities for dependants exceeds the available financial resources (Morrow, 1999). In Indonesia, the central bureau of statistics defines an ordinary household as one with either one person or group of people living in a physical building and share common provision for food and other essentials. The dominant household family size in both villages is that between 4-6 members (63.9% for Kalilunjar and 57.8% for Sijeruk) (table 9-8).

Because the cost of living should be basically the same for every income group, households earning less and have many dependents are disadvantaged as they will have to bear the responsibility implications during and after a crisis. Therefore income dependency plays a role for the affordability of adaptive activities in vulnerability (Hufschmidt and Crozier, 2008).

Table 9-8: Cross table of the respondent's monthly income and the household size

Village	**Household size**	**Monthly income (Rp) (%)**					
		< 500,000	500,000 - 1,000,000	1,000,000 - 2,500,000	2,500,000 - 5,000,000	5,000,000 - 10,000,000	Total
Kalilunjar	0-3	4.9	8.2	8.2	6.6	0	27.9
	4-6	**13.1**	**26.2**	13.1	9.8	1.6	63.9
	>6	3.3	3.3	0	0	1.6	8.2
	Total	21.3	37.7	21.3	16.4	3.3	100
Sijeruk	0-3	6.7	20	2.2	2.2	0	31.1
	4-6	**6.7**	**26.7**	20	4.4	0	57.8
	>6	**2.2**	**4.4**	4.4	0	0	11.1
	Total	15.6	51.1	26.7	6.7	0	100

Source: Fieldwork (2009)

The bold numbers show percentages of the households that are having a high income dependency ratio and are likely to be affected most when disaster strikes. IDR is derived by dividing the monthly income by the total household size.

9.4.4. Education level

Illiteracy and poor education can reduce one's access to information and well paid jobs (Hufschmidt, 2008). Education is an important aspect with reference to the level of awareness of the hazard and the measures that need to be taken. Majority of the respondents in both villages had studied up to primary level (59.3%) as shown in table 9-9. Few had attained the university education (7.4%).

Higher education is related to better job opportunities. For example, in the study area, individuals that had a university education were gainfully employed unlike those with low or no education who have no option but to take on what life had to offer. It is assumed that such respondents with a good education have a better life in comparison to those with little or no education at all. One's level of education can help to influence their quality of life.

Table 9-9: Education level of the respondents

Village	**Education level (%)**				
	No formal education	Primary	Secondary	University	Total
Kalilunjar	2.8	35.2	13.9	5.6	57.4
Sijeruk	12	24.1	4.6	1.9	42.6
Total	14.8	59.3	18.5	7.4	100

Source: Fieldwork 2009

9.4.5. Occupation

Occupations such as farming that are tied to a natural resource are endangered directly if the resource sustains long term damage by a manifested natural hazard and there is no alternative source of employment (Hufschmidt, 2008). For example, a farmer will lose the basis of his livelihood in case a landslide struck his agricultural land and destroyed the crops while a teacher will easily relocate with his knowledge and skill to another area. The respondents were categorized into four groups (table 9-10): Skilled, formal, informal and unemployed.

Majority belonged to the formal group (53.2% for Kalilunjar and 71.7% for Sijeruk) which included civil servants, farmers, traders and tailors. The skilled group comprised of teachers who were regarded to be gainfully employed and are treated with a high social status and informal workers included miners, farm labourers, drivers and barbers. The unemployed group contains mainly housewives who stay home to cater for the well being of the family while their husbands bring in the income. Most of the farmers have salak as the main crop with rice, albacia, cardamom, coconut and cassava as subsidiary crops. All these are grown for both commercial and subsistence consumption. Some respondents indicated that they had two occupations so they are able to supplement the income from the first occupation.

Table 9-10: Cross table of first and second occupation of the respondents

		First occupation (%)				
Village	**Second occupation (%)**	Skilled workers	Formal workers	Informal workers	Unemployed	Total
Kalilunjar	Not applicable	1.6	35.5	1.6	35.5	74.2
	Applicable	4.8	17.7	3.2	0	25.8
	Total	6.5	53.2	4.8	35.5	100
Sijeruk	Not applicable	4.3	58.7	6.5	17.4	87
	Applicable	0	13	0	0	13
	Total	4.3	71.7	6.5	17.4	100

Source: Fieldwork 2009

9.4.6. Monthly income

Majority of the respondents in both villages where categorized into the low income group as shown in table 9-11 (14,000Rp = 1Euro during the time of fieldwork). From the monthly income, one can deduce that high income earners are less vulnerable since they can affect the degree to which protection can be built e.g. constructing preventive measures, building strong homes, etc while the low or medium income earners cannot afford to protect themselves to the same degree. Majority of the women interviewed were housewives who depended on their husbands' monthly income though some supplemented this income by setting up small retail shops in their houses (figure 9-7).

Table 9-11: Income levels of the respondents

	Income levels (Rp) (%)			
Village	Low Income (> 5,000,000)	Medium Income (1,000,000 - 5,000,000)	High Income (< 1,000,000)	Total
Kalilunjar	33.3	21.3	2.8	57.4
Sijeruk	27.8	14.8	0	42.6
Total	**61.1**	36.1	2.8	100

Source: Fieldwork 2009

Figure 9-7: Example of an in house retail shop

A correlation was made between the income and education levels of the respondents. This was to assess whether one's income level correlated with their education level. The results are presented in table 9-12. It can be seen that majority of the respondents with low and medium income have primary and secondary level education. Also some of those who claimed to have a university education fell in the low income category. This shows that to an extent the level of education does not affect the income levels in this case though we can't rule out the fact that some of the respondents could have given a wrong income amount in fear of being looked at as small earners. Nevertheless, people with a high income are believed to be less vulnerable than the medium and low income earners since they can use their means to cope up to a certain level with the disaster.

Table 9-12: Cross table of the education and income levels of the respondents

		Education level (%)				
Village	**Income levels (%)**	No formal education	Primary	Secondary	University	Total
Kalilunjar	Low Income	1.6	38.7	14.5	3.2	58.1
	Medium Income	3.2	19.4	9.7	4.8	37.1
	High Income	0	3.2	0	1.6	4.8
	Total	4.8	61.3	24.2	9.7	100
Sijeruk	Low Income	26.1	30.4	6.5	2.2	65.2
	Medium Income	2.2	26.1	4.3	2.2	34.8
	Total	28.3	56.5	10.9	4.3	100

Source: Fieldwork 2009

9.5. Spatial multi-criteria evaluation for vulnerability assessment

Spatial multi-criteria evaluation is a process that consists of procedures that involve the utilization of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules that result in an aggregation of multi-dimensional information into a single parameter output (Sharifi and Retsios, 2004).
ILWIS-SMCE was used as a basis to calculate a vulnerability index that integrates the factors discussed in sections above. The process was implemented using the steps in figure 9-8.

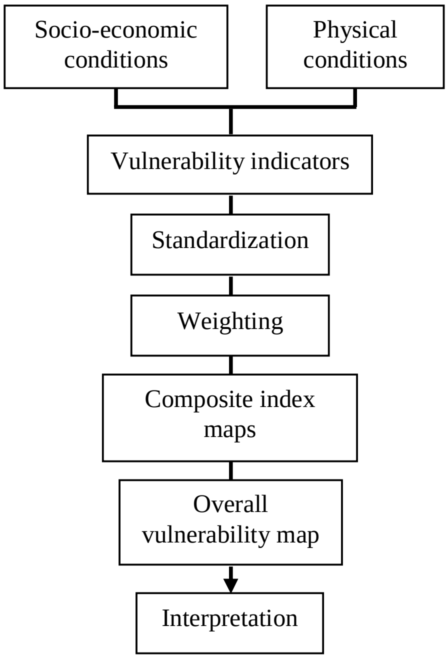


Figure 9-8: Flow chart for SMCE phase which results in a final vulnerability map

The inputs are a set of maps or tables that are a spatial representation of the criteria. They are grouped, standardized and weighted in a criteria tree with the output as one or more composite maps (Abella and Van Westen, 2007). Standardization is from the original value to a value range of 0 – 1. This is done because the indicators have different measurement scales and their cartographic representations are also different. Standardizing a “value” map with numerical and measurable values is different from a “class” map with categories or classes. Weighting is carried out to identify the relative importance of each indicator and is done using a number of techniques such as direct, pair wise comparison and rank-ordering that allow elicitation of weights in a user-friendly fashion at any level and for every group in the criteria tree (Abella and Van Westen, 2007; Sharifi and Retsios, 2004). In this work, pair wise comparison of the indicators was used.

SMCE allows the assessment of several alternatives in order to help understand their impacts, pros, and cons, their related trade-offs and the overall attractiveness of each option or alternative. An example of a criteria evaluation tree is showed in figure 9-9 while figure 9-10 shows standardizing and weighting respectively.

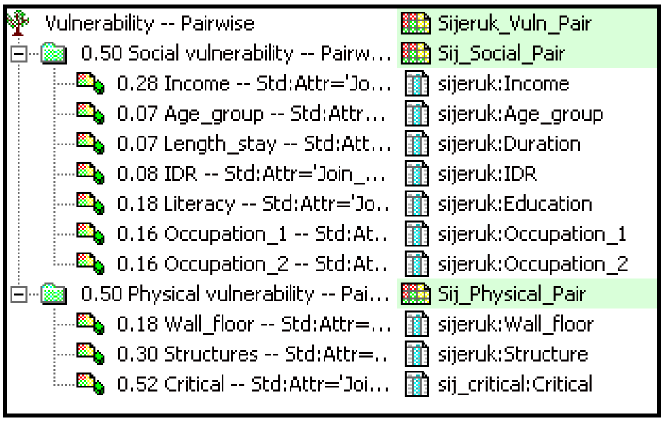


Figure 9-9: Multi-criteria tree for assessing vulnerability in Sijeruk village

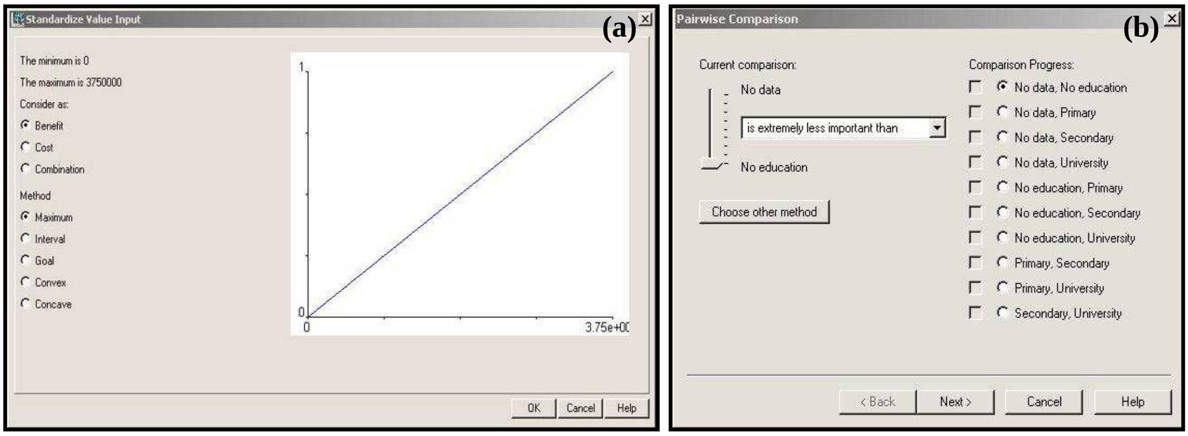


Figure 9-10: Example of (a) standardizing a value vulnerability indicator and (b) weighting using the pairwise function

9.6. Vulnerability analysis

The final representative vulnerability map for the study area with values ranging from 0 (low vulnerability) to 1 (high vulnerability) was developed using SMCE as indicated above. How the indicators were used in the SMCE for social vulnerability are explanied below.

9.6.1. Livelihood

In this category, the first and second occupation were considered. Dealing with this category is rather relative. On one hand, respondents with two occupations can be considered to be less vulnerable than those with one occupation yet on other hand there might be an individual with one occupation but an enormous amount of income that is more than that of another individual with two occupations. For this work, the former was considered where individuals with two jobs are better than those with one. This is because obtaining the income information from some of the respondents was not easy.

9.6.2. Awareness

Literacy and duration where used in this category. The higher the education level attainment, the less vulnerable an individual would be since they can be able to apply their knowledge to what is happening around them. Incase of duration, it was considered interms of social networking. The longer one stays in an area, the larger the social network than one who has stayed there for just a few years.

9.6.3. Income related

In this category, the respondents income and the income dependency ratio (IDR) were used. IDR was derived by dividing the income by the total number of people in the household. Individuals with a higher income and very few dependants have a higher IDR than those with a low income but with many dependents.

9.6.4. Household composition

Age and total household size were considered in this category. Dealing with age is also relative. On one hand, children below 15years and adults above 65years of age are considered vulnerable while on the other hand, adults above 65years of age can be considered less vulnerable due to the fact that they will have experienced an event in that area and are better equipped with knowledge of where and how often the events occur. The latter was considered since time did not allow collecting sufficient data.

9.6.5. Type of structure

This was considered in terms of whether the structure is permanent or semi-permanent. The Permanent structures as explained earlier are those made completely of brick and concrete while semi-permanent structures are those that have a brick-concrete shell but are partitioned with wood inside. A structure made completely of brick-concrete is seen to be stronger than one with only a brick-concrete shell. If force is exerted from the outside, the inner walls should be able to resist this force. But if they are made of wood, they will just crumble and the whole house will collapse.

The factors discussed in 9.6.1 to 9.6.5 were all summed up to obtain an overall vulnerability for the respondents within the study area. It is observed that most of the respondents lay within the moderate vulnerability class and the rest are distributed between the low and high vulnerability classes as shown in figures 9-11 (a) and (b). This pie chart distribution of the respondent vulnerability classes in both Kalilunjar and Sijeruk was made to compare their vulnerability levels. In figure 9-11 (a) and (b) it can be seen that most respondents are within the moderate class of vulnerability with 52% in Kalilunjar and 54% in Sijeruk. The low and high classes in both villages are relatively distributed among themselves with slight differences. Figures 9-12 and 9-13 show the distribution of the vulnerability classes in some areas of the study area.

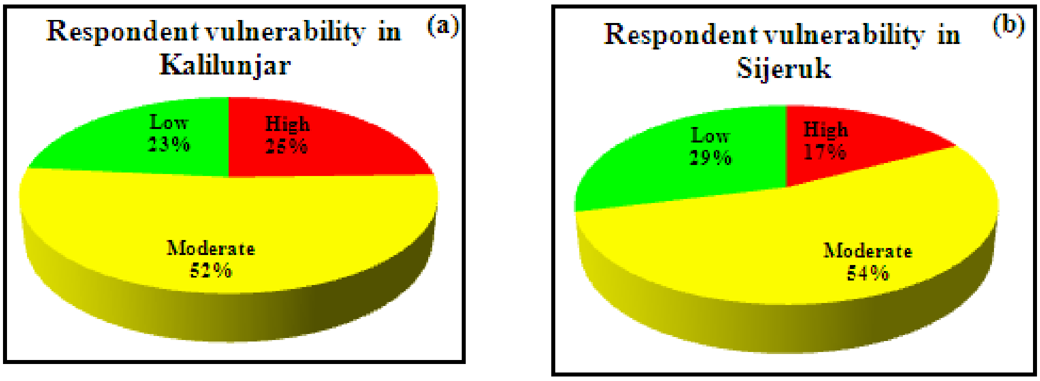


Figure 9-11: Percentage of each vulnerability class

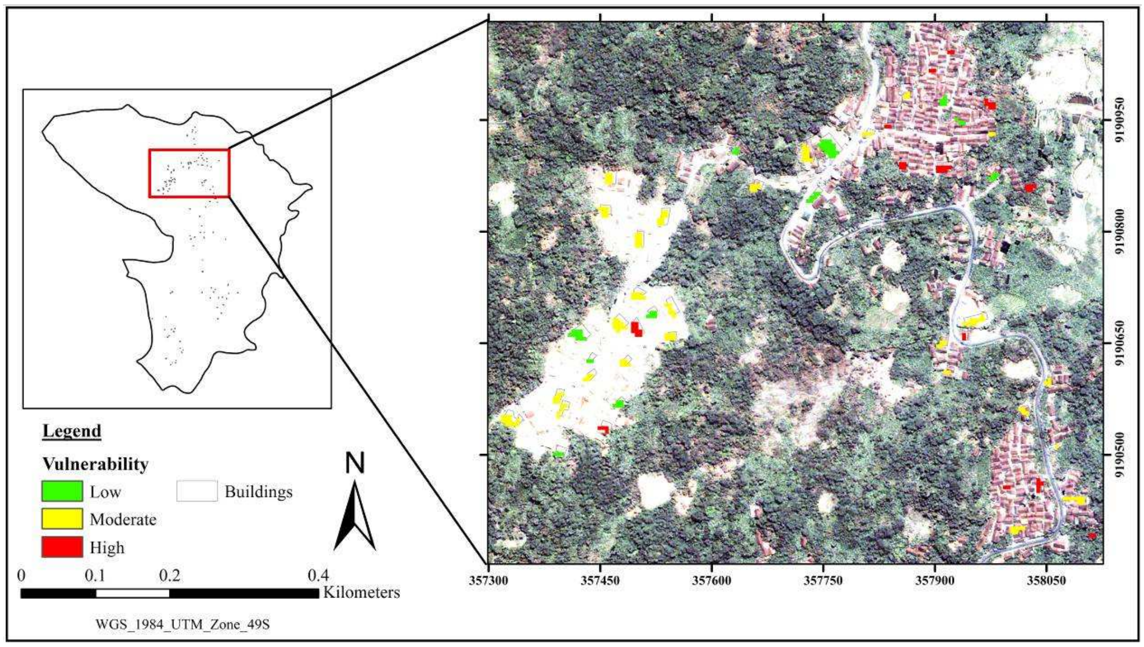


Figure 9-12: Overall vulnerability of some of the respondents from Sijeruk Village

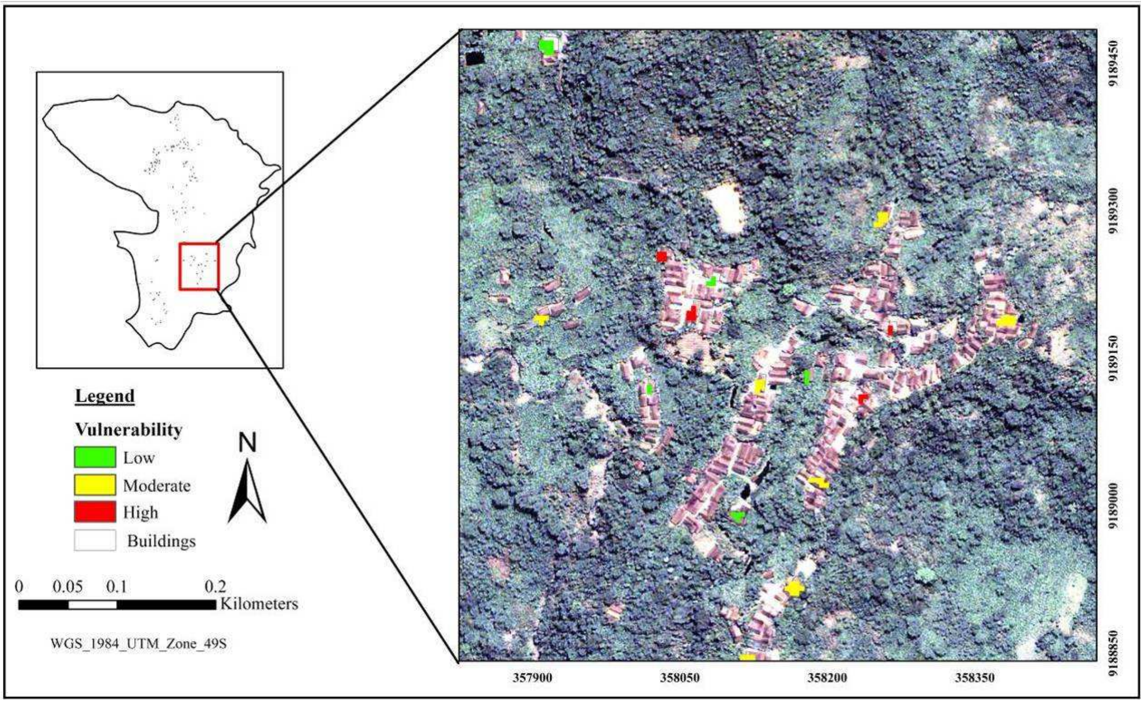


Figure 9-13: Overall vulnerability of some respondents in Kalilunjar village

The above analysis represents an important source of information for not only the local authorities but also those involved in disaster mitigation and prevention. More indicators need to be analysed inorder to obtain a more comprehesive final vulnerability map.

10. Risk analysis

According to Guzzetti (2005), risk is an attribute of an element and not of an area where the element is located. When establishing risk, the focus is on the assets such as the elements at risk that may suffer damage from the harmful consequences of the hazard. To estimate the risk, information on the type, distribution, vulnerability and value of the assets in the study area is required. Also the zonation of the area into susceptibility classes is a requirement when establishing the risk of an element (Guzzetti, 2005).
According to Cascini et al.(2005), risk cannot be readily determined because of the difficulty in assessing the elements at risk and their vulnerability. Concerning landslide risk, there is almost no indication of what is acceptable, tolerable and unacceptable risk (Cascini et al., 2005).
Risk assessment comprises of three parts including risk analysis, risk evaluation and risk management (Bell and Glade, 2004) as shown in figure 10.1.

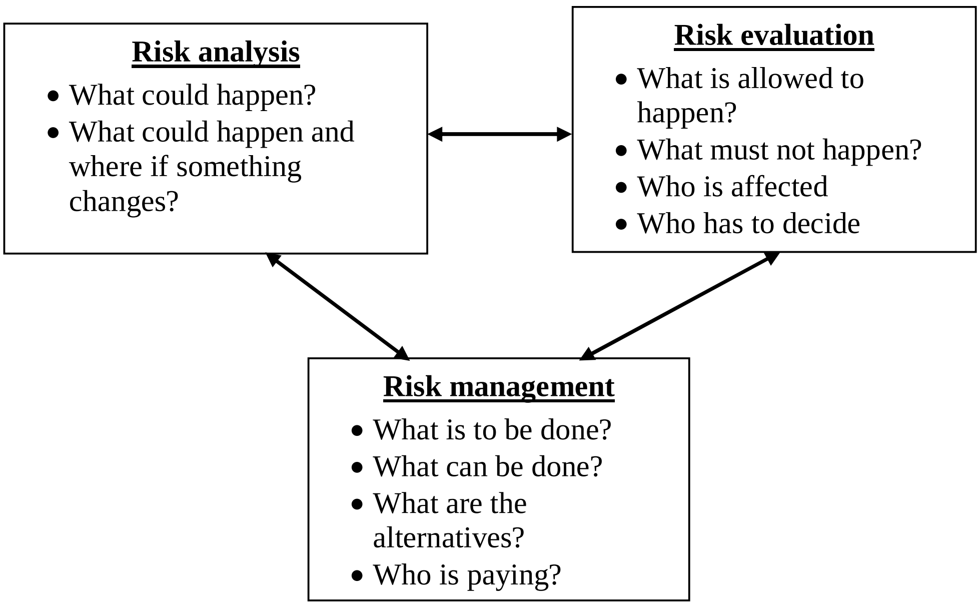


Figure 10-1: Risk assessment concept (adopted from Bell and Glade 2004)

For this research, risk analysis is considered. Risk to life caused by fast landslides and creep in this research was analyzed using equation 10.1. Landslide risk is commonly expressed as the product of the landslide hazard and vulnerability to landslides. A schematic representation of the input maps for the risk analysis is shown in figure 10-2.

Risk = Hazard x Vulnerability...10.1

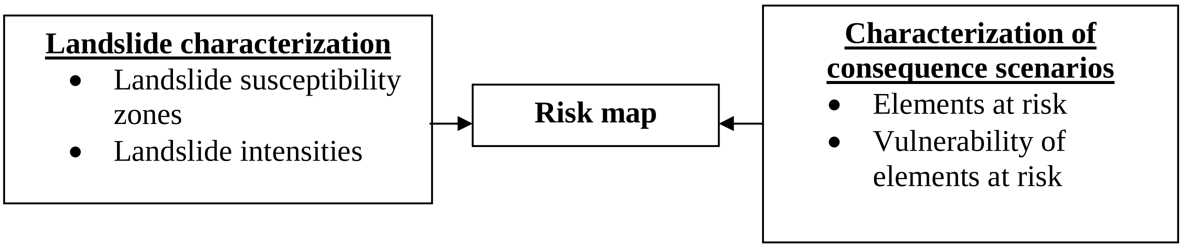


Figure 10-2: Schematic representation of the input maps for risk zoning. (Modified from Cascini et al, 2005)

The landslide characterization map which is the danger map includes the susceptible areas, landslide intensities and other datasets while the characterization of consequence scenarios includes the elements at risk and their vulnerability. Combining the two maps gives a risk map. According to Cascini et al. (2005), risk maps have different objectives of which the main one is to provide a global view of expected damage due to potential landslide hazard by identifying the most vulnerable elements that are threatened.

Using the obtained hazard susceptibility and vulnerability maps in the above chapters, a matrix was developed to calculate representative risk for both landslide types as shown in table 10-1.

Table 10-1: Risk assessment matrix

Hazard susceptibility / Vulnerability classes	Low	Moderate	High	Very high
Low				
Moderate				
High				

In this matrix, a given area may have many elements present but each with a different type of vulnerability. For example, if an individual is found to be in a high hazard class and at the same time he / she has a high vulnerability class tag, then the risk of such a person is considered high. However if an individual with in the same high hazard area has a low vulnerability class tag, then they can be assigned a moderate risk because they can withstand to an extent the impact of small events unlike the big ones. Below is an explanation of the matrix colours.

Red: People are at risk of injury both inside and outside of buildings. There is a possibility of a high destruction of buildings.

Yellow: If construction of the buildings has been adapted to the present conditions, damage can be expected but not destruction.

Green: In this zone, it can be said that people are at low risk of injury with slight damage to buildings.

To obtain the risk levels of the respondents, the hazard susceptibility map was crossed with the final vulnerability map using *ILWIS* software. The results of the calculation are presented in figure 10-3 below.

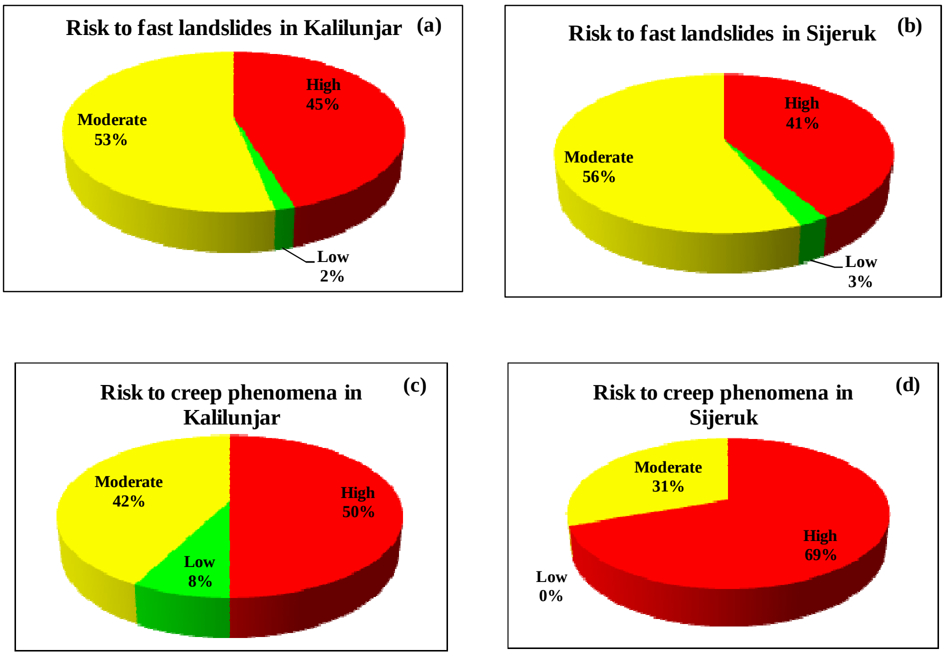


Figure 10-3: (a) and (b) - Fast landslides risk and (c) and (d) - creep phenomena risk in Kalilunjar and Sijeruk villages respectively

Using figure 10-3 (a) and (b) it can be concluded that the risk to fast landslides is almost the same in both villages. The moderate risk class has the highest percentage in both villages followed by the high class and finally the low class.

Considering the creep phenomena (figure 10-3 (c) and (d)), the risk is seen to be higher in Sijeruk village than in Kalilunjar. The high risk class has the highest percentage in both villages, followed by the moderate risk class and finally the low risk class which is only in Kalilunjar village and not in Sijeruk. It can be concluded that the highest risk to respondents in both villages is caused by the creep phenomena than the fast landslides.

The results from the risk analysis also show regions in relation to the respective processes and the elements at risk. Figures 10-4 and 10-5 show examples of risk from the fast landslides and creep phenomena respectively in selected places of the study area. They highlight to an extent the distribution of the different levels of risk of the respondents due to the difference in vulnerability and hazard susceptibility classes.

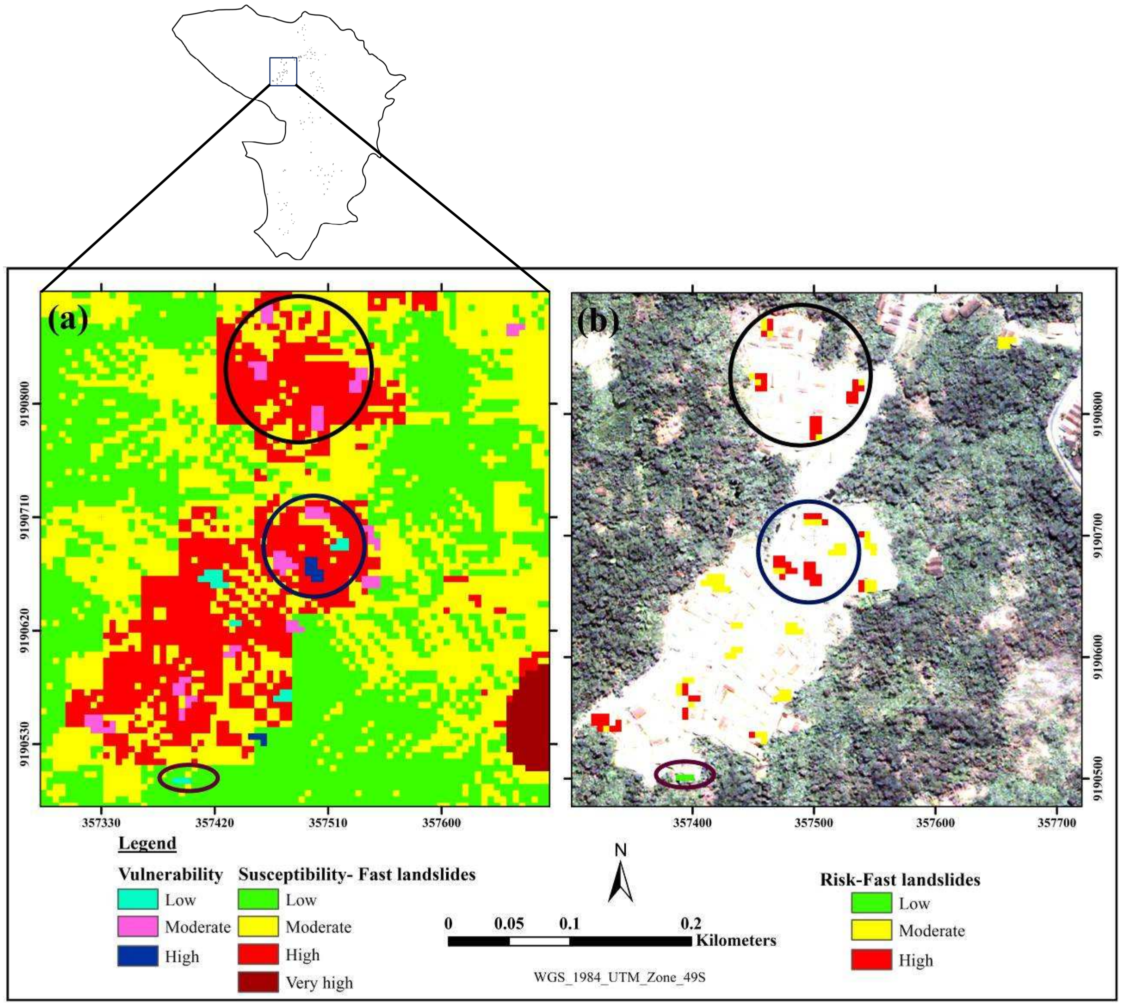


Figure 10-4: Fast landslides risk - (a) Susceptibility and vulnerability maps (b) Risk Map

In figure 10-4 (a), the black circle shows respondents with moderate overall vulnerability but residing in an area with moderate to high fast landslides susceptibility. The corresponding black circle in figure 10-4 (b) shows the levels of risk of these individuals. Referring to table 10-1, we can say that the risk of these individuals is high.

Again in figure 10-4 (a), the blue circle shows respondents with all the three classes of vulnerability residing in a high susceptibility area. Their respective risk level is also showed in figure 10-4 (b). The person with low vulnerability is seen to have moderate risk while those with moderate and high vulnerability have high risk. This still concurs with the matrix in table 10-1. Finally the brown oval in figure 10-4 (a) shows a respondent with both low vulnerability and low susceptibility with the corresponding risk in figure 10-4 (b) also low.

The assessment applied to figure 10-4 was also applied to figure 10-5. The black circle in figure 10-5 (a) shows respondents residing in an area that has very high creep susceptibility. The corresponding risk in figure 10-5 (b) shows their risk as high. The options that these individuals have are to either construct their houses with a deep foundation or they should relocate to a safe / better location.

The blue oval shows respondents with all the three classes of vulnerability residing in a high creep susceptibility area. Again figure 10-5 (b) shows their corresponding risk levels. The individual with low vulnerability is seen to have moderate risk while those with moderate and high vulnerability have a high level of risk. In case of creep taking place, the two respondents with high risk will have more damage than the moderate risk person.

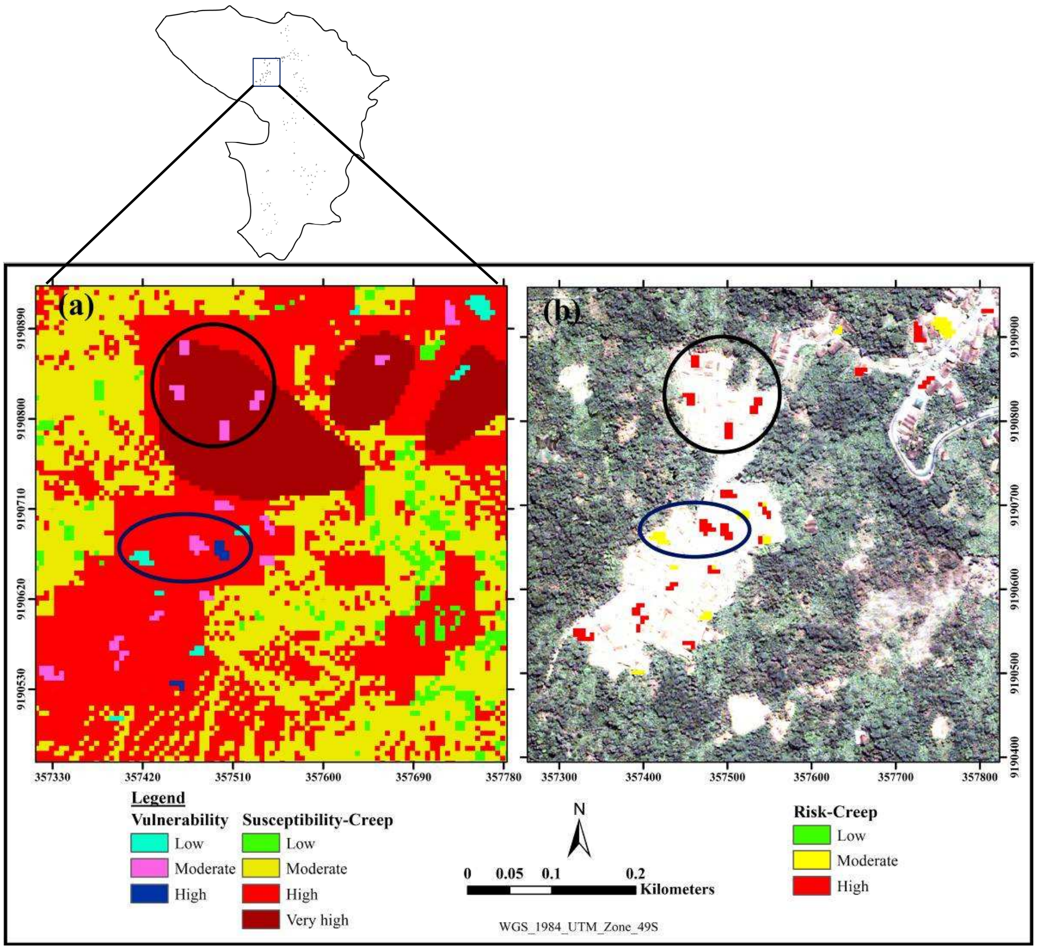


Figure 10-5: Creep phenomena risk - (a) Susceptibility and vulnerability maps (b) Risk Map

The risk assessment discussed above provides estimates for individual risk levels but does not provide insight on the geographical distribution of the landslide risk to the population in the study area. Also the constructed risk index matrix is not a final result per se. The ultimate objectives can only be fulfilled when proper risk reduction measures are implemented, leading to an observed decrease of casualties (Hy and Peduzzi, 2004). The above information can be used by the authorities to develop mitigation strategies and policies to minimize population risk. Despite the data limitations, the results obtained confirm that mass movements in the study area represent both societal and economic problems that should not be overlooked.

11. Conclusions, recommendations and study limitations

11.1. Conclusions

The study was carried out in Sijeruk and Kalilunjar villages located in Banjarmangu sub district Central Java province. It involved addressing the following objectives:

1. **Developing a hazard analysis based on the past landslide events experienced by the communities in the study area**

a) Reconstruction of the 2006 landslide event and rainfall analysis

The landslide processes taking place in the study area belong to two categories: (1) the fast movement types with a recent massive event in 2006 and the persistent slope creep that cracks building walls, road surfaces, etc. The research has revealed that the factors influencing these two processes are slope gradient and land use respectively. This is not surprising when compared to the perception results in section 6.2 and chapter 7 where the respondents have full knowledge of what the landslides are and also what causes them due to their interaction with the physical environment.

Whether the 2006 event was a reactivation of an older landslide or not could not be established during this research as the landslide records were scanty especially in this location of the study area. Apparently, within the study area under similar conditions, the fast landslide types do occur though they are site specific and are affecting individuals not the community at large. To the communities, as far as they are concerned, tangible landslide hazards are those due to the on going creep phenomena and occasional fast landslides.

During this research, there was insufficient data to fully understand the mechanism of the 2006 event. So no adequate answers could be provided to whether there is a probability if the remaining part of the mountain would mobilize into a similar a pattern or not.

An attempt was made to establish the relationship between the fast landslide slope failure and rainfall amounts. The analysis was done based on the daily and antecedent rainfall for different time intervals that included 3, 10, 15 and 20 days before the event. The minimum probable thresholds for the known landslide events were obtained and analysis of the graphs in figures 5-6 and 5-7 suggests that slope failure usually occurs immediately when the threshold exceeds the lower boundary.

These thresholds have been analyzed based on a small duration of landslide activity; implying that the approach is workable and can be used for a larger period to get better and valid results. The results can also be improved further by distinguishing between slope failures due to human activities such as road construction and those whose failure resulted from rainfall.

The use of the Gumbel extreme value method to analyze rainfall data yielded good results though the return period cannot be relied upon since very few landslide events are known with respect to the maximum daily rainfall value that was used. Nevertheless, it can be noted that the Gumbel distribution gives a range within which the return period of a particular rainfall amount is expected. Together with the rainfall thresholds, they help to anticipate what's going to happen and get prepared but does not result in the altering of the course of human actions.

b) Landslide hazard mapping and susceptibility analysis

A landslide inventory is a mandatory step for effective landslide investigations to determine the level of risk (Guzzetti, 2006). It is essential to keep records of historical landslide events in an area as they provide useful information such as determining societal and individual risk levels. They also help to ascertain the most common damage caused by the failures. An ideal historical landslide record should contain information on all aspects of the phenomena to enable a comprehensive analysis to be carried out.

The use of factors such as lithology, slope gradient, slope aspect and land use is important in landslide susceptibility analysis especially when using the weights of evidence modelling since they are easily mapped and they provide a quick and easy way to analyze the landslides. The short coming of this method as earlier indicated is that assumptions are made that all landslides occur under the same combination of factors yet each type of landslide has its own causal factors and should be treated differently. The quality of the landslide and thematic information is very important as it will affect the output of the model results.

Reliable landslide susceptibility/hazard maps are of significant value in establishing risk-reduction programs. Slopes that have moved in the past have a high risk of future movement as previous landslide activity is often a strong indicator for areas of future slope instability. So the inventory of landslides presented in this research establishes a framework from which to evaluate where slope stability problem areas exist or may develop in future. Furthermore, this inventory can be expanded upon with updated information to improve the presented susceptibility maps.

The sensitivity analysis performed on the conditioning factors used in the susceptibility analysis helped to identify which factors had more influence on the occurrence of the two landslide phenomena analyzed in the research. Slope gradient and land use were identified as the most significant factors for fast landslides and creep phenomena respectively. It can be concluded that areas prone to fast landslides in the study area are those with a high elevation such as mountain slopes while areas most prone to creep are the paddy rice fields and settlement. Again this is not so surprising when related to the respondents’ perception where they highly rated steep slopes as the most danger prone areas and also attributed improper waste water disposal as the cause of the creeping taking place.

Most of the failures that occurred in the agricultural land were the result of water movement from terrace to terrace but they were small with limited labour cost implications. In addition, they were only affecting few individuals.

On the whole, it can be said that Sijeruk village is more prone than Kalilunjar to both landslide phenomena analysed in this research as shown in figure 6-12.

2. Exploring the possibility of representing risk perception spatially

Analysing peoples’ perception is important as it facilitates the identification of the root causes of the problems affecting them so that the situation is addressed in an effective way. A social survey was carried out to ascertain the traditional knowledge in explaining landslides in terms of the causes, occurrences and locations plus the awareness. Gender perception towards landslide occurrences was also investigated. The study has showed that there was no distinction in terms of levels of awareness to the landslide hazard between men and women. This can also be attributed as earlier mentioned to experience and constant interaction with the physical environment. The responses were analyzed using SPSS software package and the results were subsequently represented in chapter 7.

Based on the results, it can be concluded that the January 4th 2006 landslide event substantially influenced the outcome of the perception results. Most respondents had identical perceptions regarding the landslide hazard in the two villages in the study area. Even for personal threat, no significant differences existed among the responses.

It can also be concluded that most respondents were fully aware of the locations where landslides have occurred and also where they might occur in future. The knowledge was not distinct in terms of gender as both female and male respondents had comparable knowledge on the causes and contributing factors though no differentiation between the two was made as it would confuse the respondents.

It’s suggested from the results, that the inhabitants of the study area would benefit from an in-depth knowledge of how human activities aggravate / exacerbate the landslide hazard. It would specifically be beneficial to know the role of cutting down trees (a common practice in the study area) which causes the soil to lose cohesion especially when it rains.

Some of the respondents' perception overlapped well with the classes in the susceptibility maps. This shows that taking into consideration people's perception helps in the identification of various characteristics of particular problems and also highlights the need to capture such information so that knowledge divide between local indigenous people and experts disappears.

Whether the populations in the study area accurately perceive the landslide problem or not, they may not be induced to act to prevent it from happening. On the other hand, they may understand that the problem is aggravated by their actions, but the alternatives may be too costly relative to the perceived near term benefits.

3. Identifying and evaluating coping capacities.

The research further demonstrated how the communities deal/cope with landslides. The strategies being used were grouped into before, during and after activities as indicated in table 8-1.

The research also revealed that the local people are aware of what needs to be done though they lack the resources to carry out any implementation activities singularly. Most of the management measures that have been implemented in the study area were done at community level so that they can benefit everyone and not just individuals.

The existence of an organised traditional early warning system – ketongan is a positive element within the study area. This shows that based on their knowledge and perceptions, the people are aware of the unusual signs associated with the occurrence of the hazard so they are alert. The disadvantage of this system is associated with false alarms which can not be differentiated from the real warnings.

It can be concluded that the following mechanisms have influenced / enhanced the adaptive capacities of the communities in the study area:

- Some families have more than one source of income which makes them less vulnerable than those with only one source of income. Similarly those who are dependent on agriculture as a source of income are more vulnerable than non agricultural job holders who can get employed elsewhere.
- From the questionnaire survey, most of the respondents believe that planting trees and the gabion embankment are the best solution given the current economic situation. Concerning the gabions and embankments, the communities are ready to provide labour for their construction if only they are provided with the necessary materials by the authorities.

4. Vulnerability analysis based on socio-economic and structural parameters related to landslide events

Some indicators were used to analyse the vulnerability level of the respondents. They included age, occupation, education level, length of stay, income levels and many others. These indicators could have been used interchangeably due to their relativity but because of insufficient data, such relative comparison was not done. For such indicators, only one option was considered for which data was available. Nevertheless, the obtained results can be built upon towards a holistic approach. Also the results can be used in the preliminary stages of the disaster management cycle.

The study has showed that majority of the respondents are semi-literate and have an awareness of what is happening around them in terms of environmental problems through their interactions with the environment. Analysis of the indicators showed some inconsistencies in the responses as highlighted in tables 8-2 and 8-6. To address such inconsistencies, a second survey to the same respondents is proposed.

Vulnerability of the communities to landslides maybe attributed to a low income dependency ratio that is a function of income and the total number of dependants, the education level and the type of houses among others. Also the location of the houses in the danger prone areas increases their vulnerability to failure.

The research also revealed that one’s education level did not affect their income levels which are a major contributor to vulnerability since a high income affects the degree to which one can build protection.

Vulnerability of structures was also considered in terms of quality and location. Most buildings were constructed with brick-concrete material though other building materials also had a share in the distribution. This could also be related to one’s income where the more you have, the more possible it is for you to construct a strong structure.

The overall vulnerability obtained from the research showed that both villages had comparable vulnerability classes with majority of the respondents with in the moderate class. As earlier indicated, a more holistic approach that incorporates most of the indicators including those not used in this research is recommended.

5. Evaluate the associated risk using the available hazard susceptibility and vulnerability information

As earlier indicated, constructing a risk index matrix is not a final result per se. The ultimate objectives can only be fulfilled when proper risk reduction measures are implemented, leading to an observed decrease of casualties. Authorities can use the above information to develop mitigation strategies and policies to minimize population risk.

From this research, it can be concluded that Sijeruk village has a relatively larger landslide problem than Kalilunjar. The magnitude and frequency of the events in Sijeruk are high and wide spread than those in Kalilunjar which are few and generally localized. This makes the cost of mitigation measures in Sijeruk to be higher as they require heavy retaining piles to resist the sliding material which is mainly in creep form.

Despite the data limitations, the results obtained confirm that mass movements in the study area represent both societal and economic problems that should not be overlooked. All in all, the outputs generated in this research can be seen as valuable tools for different end users. It underlines the usefulness of continuing the improvement of data collection in all disciplines for better identification of vulnerable populations at risk.

11.2. Research contributions

- The vulnerability assessment carried out is valuable information for the local authorities and relevant stakeholders when designing policies related to landslide risk reduction.
- The information obtained from the peoples' perception can be incorporated into the decision making processes to help solve the problems at a minimum cost with sustainability.
- By understanding the effectiveness of the coping strategies being currently employed, the local authorities together with the community at large can learn lessons from which they can improve and lessen their vulnerability and risk.
- The rainfall thresholds obtained can be used as an early warning method in addition to the already existing systems.
- The obtained susceptibility maps are useful information for not only the local authority but individuals too in terms of land use planning.

11.3. Recommendations

All stakeholders including the inhabitants of the two communities should endeavour to participate / get involved in risk and vulnerability programs within their areas / community. Participation of the communities helps them to get a sense of ownership to what is taking place within their society and at the same time makes the project sustainable since the community can take care of it in the long run.

Dissemination of the research findings to the concerned communities is essential in helping them understand the hazard more and also learn how to better deal with it.

11.3.1. Further research

- The study recommends that a detailed study of the geological and hydrological characteristics in the study area be carried out to obtain a detailed and better understanding of the ground motion phenomena in form of creep that is taking place.
- It has been showed that the landslides mainly occurred during the rainy season; so there is a need to carry out more critical rainfall threshold analysis in relation to the initiation of landslides since the results can be used as an early warning system. Also the relation of cumulative antecedent rainfall with the soil / geology of the area should be explored in detail.
- More landslide influencing factors such as the soil depth should be incorporated in to the susceptibility map to get holistic results for the area.
- Assessment and mapping of the landslide run out for hazard and risk analysis. Inundation from above is a very important factor relating to landslides.
- Since this type of research can be replicated, conducting it in other communities with differing conditions of the hazard can help in better understanding both the application and theory behind it.

It's hoped that the communities will one day be at peace carrying out their daily activities without being vulnerable to landslides. It's also hoped that the communities will one day be able to manage landslide risk by reducing their vulnerability.

11.4. Limitations of the study

The limitations of this research include:

Data availability

- Very limited secondary data was available to compliment the primary data. For example, records on past landslide events were scanty and also the rainfall data was not complete to enable the calculation of intensity-duration thresholds for landslide initiations.

Field survey

- Direct communication with the respondents' was not possible so the need to use interpreters was inevitable. This lead to loss of some information during translation.
- The time frame within which the fieldwork had to be completed was limited yet the field survey is time consuming depending on the size of the area under investigation plus the size of the questionnaire. In order to collect reliable and concrete information a lot of time is required to first bond with the communities to win their trust.
- Some of the data needed such as the financial situation of households was protected in such a way that some individuals did not feel comfortable talking about it.

Inventory and susceptibility mapping

- Although efforts were made to identify as many landslides as possible within the study area, omissions undoubtedly occurred as it is assumed that there has been continued land clearing and development over time and with the lack of enough aerial photographs to show the trend, not a lot could be done.
- Also a further limitation in the inventory mapping was in the spatial accuracy of the GIS polygons which is a function of errors produced during digitization of the features using the aerial photo and IKONOS image.

The weights of evidence method used to produce the susceptibility maps was constrained by the availability of data especially the landslide database.

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13. Appendices

13.1. Appendix 1: Household survey questionnaire

Survey questionnaire

My names are Geraldine Paula Babirye a student at ITC in the Netherlands. I am carrying out a research to assess vulnerability to landslides in your area as part of my MSc degree program. This is to request for your cooperation in providing information as accurately as possible. All responses will be strictly anonymous.

Identification

Interviewer ID:	Date:	Serial no (Include on image too):
GPS reading: Easting: ……………………….. Northing: ………………………. Elevation: ……………… (Coordinates should be taken at respondent's home)		

a. Demographic and socio-economic information:

1. Gender of respondent: ☐ Male ☐ Female	Age:
2. Since when have you lived here?	2(a). Where did you come from?
3. Total household no: Adults: Male……. Female…… Children: Boys…….. Girls………	
4. Education level: ☐No formal education ☐Primary ☐ Secondary ☐ University (Tertiary) ☐ Other (specify):	
Occupation: 1st Occupation: 2nd Occupation: Other (Specify):	
5. Yearly income: ☐500,000 - 1,000,000 ☐1,000,000 - 2,500,000 ☐ 2,500,000 - 5,000,000 ☐ 5,000,000 - 10,000,000 ☐ > 10,000, 000 ☐Other (specify):	
6. Properties owned: ☐Cultivable land ☐Livestock ☐Building (Estimate the size of the land and livestock) Other (specify):	
7. Residence: ☐Owned ☐Rented	
8. What type of structure is the house? (The interviewer to determine this) ☐ Permanent ☐Semi-permanent ☐ Temporary	
9. What type of material is the roof material? (The interviewer to determine this) ☐ Brick-concrete ☐Wood ☐Bamboo ☐Concrete-wood Other (Specify)	
10. What type of material is the wall material? (The interviewer to determine this) ☐Brick-concrete ☐Wood ☐Bamboo ☐Concrete-wood Other (Specify)	
11. What type of material is the floor material? (The interviewer to determine this) ☐ Brick-concrete ☐ Wood ☐Bamboo ☐ Concrete-wood Other (Specify)	

12. What is the topographic location of the house? (The interviewer to determine this according to printout)
☐ Along the slope ☐ At the mountain or hill foot ☐ Along the valley ☐ Along the ridge

13. If occupation is "farmer", who owns the land and what are the land and water rights? Please indicate location on map.

Ownership		Rights	
State	☐	Open access (Unorganized)	☐
Village / community	☐	Community (Organized)	☐
Group	☐	Leased	☐
Individual	☐	Individual	☐

14. If owned, how did you acquire it?

☐ Inherited ☐ Bought

15. How is land cultivation performed?

Manual labour ☐
Animal traction ☐
Mechanized ☐

What is the type of cropping system and major crops?

		List main crops in order of importance	
Annual	☐	Irish Potatoes	☐
Perennial	☐	Cabbages	☐
Subsistence	☐	Rice	☐
Other (specify)		Other (Specify)	

16. How significant is off-farm income for the land users in this area? (Off farm income is income from other sectors such as industry, manufacturing, trade etc). Give reasons

☐ Less than 10% of all income ☐ 10 – 50 % ☐ > 50% Specify

17. What is the market orientation of the production system?

Subsistence (self supply) ☐
Mixed (subsistence and commercial) ☐
Commercial / market ☐
Other (specify)

18. What type of water supply is available for the crops?

Rain-fed ☐
Mixed rain-fed and irrigated ☐
Full irrigation ☐
Post flooding ☐
Other (Specify)

b. Hazard knowledge

19. What type of land degradation is taking place? Rank accordingly

Loss of top soil / surface erosion ☐

Gully erosion / Ravine (>5m deep) ☐

Mass movements / landslides / Mudslides ☐

20. What are the natural causes of land degradation?

21. Are you concerned about the risk of land degradation?

☐Hardly ☐Not very ☐Don't know ☐ Quite ☐ Very

22. Please rank the land degradation risk in relation to other hazards

Hazard \ class	Slight	moderate	Severe	extreme
Landslides				
Surface erosion				
Gully erosion				
Earthquakes				

Please give reasons:

23. Please rank the landslide processes against each other

Hazard \ class	Slight	Moderate	Severe	Extreme	Does not happen
Rockfall					
Topple					
Rotational slide					
Translational slide					
Block slide					
Creep					
Lateral spread					
Debris flow					
Earth flow					

Landslide knowldege

24. Has your house been struck by a landslide? Yes ☐ No ☐

25. If yes, how was the damage?

☐None ☐ Little ☐ Much ☐Disastrous ☐ Other (Specify)

Please explain?

26. How many landslide events have you experienced in your house in this area? (Numbers in years)

☐ None ☐Once ☐ Twice ☐> three times

How big was the impact of the last event? ☐High ☐Medium ☐Low

Please explain (Indicate on image)

27. If farmer, have your agricultural fields been struck by a landslide? ☐ Yes ☐ No

28. How many landslide events have you experienced in your agricultural fields in this area? (Numbers in years)

☐None ☐ Once ☐Twice ☐> three times

How big was the impact of the last event? ☐High ☐ Medium ☐ Low

29. Within which type of terrain did the landslide occur?

☐ Steep slopes ☐Gentle slopes ☐Valley bottoms ☐Plains

☐ Terraced slopes (Back slope or flat part) ☐ Several terraces fail

30. What was the type of movement? **(tick one)**

☐ Fall ☐ Topple ☐ Slide ☐ Spread ☐ Flow

31. What was the size of the last landslide event in meters?

32. What was the extent of the impact? ☐ Site-specific (<Ha) ☐ Local (1Ha – 1Km^2) ☐ Regional (>1km^2)

33. What loss did you experience? ☐Death of a family member ☐Complete house damage ☐ Partial house damage ☐ Land destruction ☐ Loss of crops ☐ Loss of livestock Other (Specify):

If no loss has been experienced, please explain why?

34. Are the landslides affecting your land productivity? ☐Yes ☐No If yes, by how much?

c. Hazard Perceptions

35. What do you think are the causes of landslides in this area? Please explain. More than one answer is possible.

☐ Heavy Rainfall ☐ Deforestation ☐ Seismic activity ☐Excavation of the base ☐Climate change ☐ Construction of roads ☐Construction of houses ☐Farming activities

36. During which time of the year (season) do the landslides occur most?

37. After which characteristic rainfalls do the landslides occur?

☐ Low intensity rainfall for short periods ☐Low intensity rainfall for long periods

☐ Heavy rains for short periods ☐Heavy rains for long periods

38. What are the danger prone areas? ☐ Deforested land ☐ Steep slopes ☐Cultivated marginal lands ☐Other(Specify)
39. Do you think the rate of occurrence of the hazard has increased than before?
40. How likely is it that your house / property will experience a devastating landslide event in the next 10 years? ☐ Very unlikely ☐ Quite unlikely ☐ Don't know ☐ Quite likely ☐Very likely
41. How likely is it that the community will experience a devastating landslide event in the next 10 years? ☐ Very unlikely ☐ Quite unlikely ☐Don't know ☐Quite likely ☐Very likely
42. Are the landslides also occurring in adjacent / neighboring villages or only in this one?

d. Coping Mechanisms

43. What is your reason for living in this area? ☐ Cheap ☐Ancestral property ☐Own property ☐Access ☐Work ☐No option ☐Other (Specify):
44. How do you deal with landslides in your agricultural land?
45. Are there any landslide management or defence measures implemented in your area? ☐Yes ☐No ☐Don't know
46. If yes, which are the major implementing bodies / organizations?
47. What is being done to combat landslide occurrences? Afforestration ☐ Terracing ☐ Wire mesh blankets ☐ Draining out of the water ☐ Diversification of land use ☐ Reduction in slope angle and slope length ☐
48. What are the production and socio-economic benefits of the methods you are using? Reduced risk of mass movements ☐ Increased land for cultivation ☐ Collection of surface run off ☐ Increased crop yield ☐ Diversification of income resources ☐ Other (specify)
49. What are the production and socio-economic disadvantages of the methods you are using? ☐ Increased risk of mass movement ☐ Increased demand for irrigation water ☐ Loss of land ☐ Decreased farm income ☐ Increased risk of crop failure ☐ Increased labour constraints ☐

Reduced production diversification Other (specify)
50. What specific stakeholders / target groups are involved in the implementation of the management measures? Rank accordingly Individual land users ☐ Community land users ☐ Government leaders ☐ Others (specify)
51. Is the approach involving socially and economically disadvantaged groups? ☐No ☐ Yes, little ☐ Yes, moderate ☐ Yes, great If yes, specify group and how?
52. Are the land users being motivated in the implementation of the above approaches? Yes ☐ No ☐
53. If yes, what was the motivation? Rank accordingly Rules and regulations ☐ Subsidies ☐ Social pressure ☐ Well being and livelihood improvement ☐ Increased profit ☐
54. If subsidies have been used, are they likely to have a long-term impact?
55. Are you willing to be resettled elsewhere? ☐Yes ☐No ☐ Don't know If the answer is no, please give reasons.
56. Is there a policy in relation to landslide hazard management? ☐ Yes ☐ No. If yes, is it being utilized to the fullest?
57. After a disastrous event, how long did it take for Government to provide assistance if there was any? ☐ A few hours ☐ One day ☐ One week Other (Specify): 57 (a) What assistance did they provide? ☐Food distribution ☐Medical care ☐Tents ☐ Other(Specify):
58. After a disastrous event, how long did it take for NGO's to provide assistance if there was any? ☐ A few hours ☐ One day ☐ One week Other (Specify): 58 (a) What assistance did they provide? ☐ Food distribution ☐ Medical care ☐ Tents ☐ Other(Specify):
59. What do you think the Government should do to address the problem? ☐ Provide afforestration seedlings ☐ Conduct awareness campaigns on the dangers and causes ☐Others (Specify):
60. What do you think the NGO's should do to address the problem? ☐ Provide afforestration seedlings ☐ Conduct awareness campaigns on the dangers and causes ☐Build stabilizing walls Others (Specify):

Personal activities

Before	**During**	**After**

In case you know of anything relevant to this study but it's not included in the questionnaire please write it in the space below.

Thank you

13.2. Appendix 2: Scripts for the weights of evidence modeling

1. Script for weights

```
// make cross table
del %1_%2*.*  -force
Del W%1*.* -force
Del %1_%2.tbt -force
Del %1.tbt -force
// crtbl %1_%2.tbt
%1_%2.tbt= TableCross(%1,%2,IgnoreUndefs)
calc %1_%2.tbt
//calculation in cross table
tabcalc %1_%2.tbt npixact:=iff(%2=1,npix,0)
tabcalc %1_%2 nclass := ColumnAggregateSum(NPix,%1,1)
tabcalc %1_%2 nslclass := ColumnAggregateSum(npixact,%1,1)
tabcalc %1_%2 nmap := ColumnAggregateSum(NPix,,1)
tabcalc %1_%2 nslide := ColumnAggregateSum(npixact,,1)
//calculate Npix1 to Npix 4
Tabcalc %1_%2 Npix1 := iff(nslclass=0,1,nslclass)
Tabcalc %1_%2  Npix2 = iff((nslide - nslclass)=0,1,nslide-nslclass)
Tabcalc %1_%2  Npix3 = nclass - nslclass
Tabcalc %1_%2  Npix4 = nmap - nslide - nclass + nslclass
// calculate weights
Tabcalc %1_%2 Wplus=ln((npix1*(npix3+npix4))/((npix1+npix2)*npix3))
Tabcalc %1_%2 Wmin=ln((npix2*(npix3+npix4))/((npix1+npix2)*npix4))
Tabcalc %1_%2 wmintotal = ColumnAggregateSum(Wmin,,1)
Tabcalc %1_%2  Wfinal:=Wplus+Wmintotal-Wmin
// create table %1 with the correct domain
crtbl %1.tbt %1.dom
//copy attribute WFinal back to table %1
tabcalc %1 Wfinal = ColumnJoinAvg(%1_%2.tbt,Wfinal,%1,1)
//create the attribute map
W%1.mpr = MapAttribute(%1,%1.tbt.Wfinal)
Show W%1.mpr -noask
rem ILWIS Script
```

2. Script weight for the input maps

```
run weights Slope Scarp_active
run weights Geology Scarp_active
run weights Geomorph Scarp_active
run weights Landuse Scarp_active
```

```
run weights Rivers Scarp_active
run weights Aspect Scarp_active
run weights Accumulation Scarp_active
//The total weight map is calculated
wfinal {dom=value.dom ; vr = -10:10:0.001=wSlope+wGeology+wGeomorph+wLanduse+wRivers+wAspect+wAccumulation
calc wfinal.mpr
open wfinal.mpr –noask
```

3. Success rate script

```
// Cross Wfinal with Map: active
del success.tbt -force
success.tbt = TableCross(wfinal,active,IgnoreUndefs)
calc success.tbt
//In the cross table, calculate
tabcalc success npixact:=iff(active=1,npix,0)
tabcalc success Npcumactive = ColumnCumulative(npixact)
//determine the maximum value with landslide pixels.
tabcalc success Maxlandslide = ColumnAggregateMax(Npcumactive,,1)
//calculate percentage of landslides
tabcalc success percentage:=100*(Npcumactive /maxlandslide)
tabcalc success Percentlandslide:=100-percentage
tabcalc success Npixcum:=cum(NPix)
tabcalc success NpixCumMax := ColumnAggregateMax(Npixcum,,1)
tabcalc success reverse := NpixCumMax-npixcum
tabcalc success percentmap := 100*(reverse/NpixCumMax)
//calc success.tbt
open success.tbt
//graph
```

13.3. Appendix 3: Tables

Table 13-1: Likelihood for a 10 year devastating landslide event in Sijeruk village

Sijeruk				
Survey Points	**Creep - Susceptibility class**	**Fast landslides- Susceptibility class**	**House damage**	**Community damage**
1	High	High	Very likely	Very likely
2	High	High	Quite likely	Quite likely
3	Moderate	Low	Quite likely	Quite likely
4	High	High	Very unlikely	Very unlikely
5	High	High	Don't know	Don't know
6	High	High	Don't know	Don't know
7	Very High	High	Very likely	Very unlikely
8	Very High	High	Quite likely	Quite likely
9	High	Low	Don't know	Don't know
10	Very High	Moderate	Quite likely	Quite likely
11	High	Low	Quite unlikely	Quite unlikely
12	Very High	Moderate	Don't know	Don't know
13	High	High	Very likely	Very likely
14	High	High	Quite unlikely	Quite likely
15	Very High	Very High	Very likely	Very likely
16	High	High	Don't know	Don't know
17	High	Moderate	Don't know	Don't know
18	High	Moderate	Very likely	Very likely
19	Moderate	High	Don't know	Quite unlikely
20	High	Moderate	Quite likely	Quite likely
21	High	Moderate	Very likely	Don't know
22	Very High	High	Very likely	Quite likely
23	Low	High	Don't know	Quite likely
24	High	Moderate	Quite likely	Don't know
25	High	High	Very likely	Very likely
26	High	Moderate	Quite unlikely	Very unlikely
27	Very High	High	Don't know	Quite unlikely
28	High	High	Don't know	Quite likely
29	High	Moderate	Quite likely	Quite likely
30	High	Moderate	Very likely	Very likely
31	High	High	Quite likely	Quite likely
32	High	Moderate	Quite unlikely	Quite likely
33	High	High	Don't know	Don't know
34	High	Moderate	Quite likely	Quite likely
35	High	Moderate	Quite unlikely	Quite likely
36	High	Moderate	Quite unlikely	Quite likely
37	High	High	Quite likely	Quite likely
38	Moderate	Moderate	Very likely	Very likely
39	High	High	Quite unlikely	Quite unlikely
40	High	High	Don't know	Don't know
41	High	Low	Don't know	Don't know
42	High	High	Quite likely	Quite likely
43	High	Moderate	Very likely	Very likely
44	Very High	High	Very likely	Very likely
45	Very High	High	Very likely	Very likely

46	Moderate	Moderate	Quite likely	Quite likely

Table 13-2: Likelihood for a 10 year devastating landslide event in Kalilunjar village

Kalilunjar				
Survey points	**Creep - Susceptibility class**	**Fast landslides - Susceptibility class**	**House damage**	**Community damage**
1	Moderate	High	Quite likely	Quite likely
2	High	Moderate	Don't know	Don't know
3	Very High	Moderate	Very likely	Quite likely
4	Low	High	Very likely	Very likely
5	High	Moderate	Quite unlikely	Very likely
6	High	Moderate	Quite unlikely	Don't know
7	Low	High	Quite unlikely	Very likely
8	High	High	Very likely	Quite likely
9	Moderate	High	Don't know	Quite likely
10	High	Moderate	Quite unlikely	Very likely
11	Moderate	High	Very likely	Very likely
12	High	High	Very likely	Very likely
13	Moderate	Low	Quite unlikely	Quite unlikely
14	Moderate	Moderate	Very likely	Very likely
15	High	Moderate	Quite unlikely	Quite likely
16	High	Moderate	Quite likely	Quite likely
17	High	Moderate	Quite unlikely	Quite unlikely
18	High	High	Quite likely	Quite likely
19	High	Moderate	Very unlikely	Very unlikely
20	High	Moderate	Very unlikely	Very unlikely
21	High	Moderate	Very likely	Quite unlikely
22	High	Moderate	Quite unlikely	Quite unlikely
23	High	Moderate	Quite unlikely	Quite unlikely
24	Moderate	Moderate	Quite unlikely	Quite unlikely
25	Moderate	Low	Quite unlikely	Quite unlikely
26	Moderate	Low	Quite unlikely	Quite unlikely
27	High	Moderate	Don't know	Don't know
28	High	Moderate	Quite unlikely	Quite unlikely
29	High	Low	Quite likely	Quite likely
30	High	Moderate	Quite likely	Quite likely
31	High	Moderate	Quite likely	Quite unlikely
32	Moderate	Low	Quite unlikely	Quite unlikely
33	High	High	Don't know	Very likely
34	High	Moderate	Don't know	Quite likely
35	High	Moderate	Quite unlikely	Quite unlikely
36	Low	Moderate	Don't know	Very likely
37	Low	Moderate	Don't know	Quite likely
38	High	High	Don't know	Quite likely
39	Low	High	Very likely	Very likely
40	Low	High	Very unlikely	Very unlikely
41	High	High	Don't know	Don't know
42	Low	High	Don't know	Don't know
43	Low	High	Quite likely	Quite likely
44	Low	High	Quite likely	Quite likely
45	Low	High	Very likely	Very likely

46	Moderate	High	Quite unlikely	Quite unlikely
47	Moderate	High	Quite likely	Quite likely
48	High	Moderate	Don’t know	Don’t know
49	Low	Moderate	Don’t know	Don’t know
50	Low	High	Don’t know	Don’t know
51	High	High	Very likely	Very likely
52	High	High	Very likely	Don’t know
53	High	High	Quite likely	Quite likely
54	High	Moderate	Very unlikely	Very unlikely
55	High	High	Quite unlikely	Quite likely
56	High	Moderate	Quite unlikely	Quite unlikely
57	High	High	Quite unlikely	Quite unlikely
58	High	Moderate	Quite likely	Quite likely
59	Low	Moderate	Don’t know	Quite likely
60	High	Moderate	Don’t know	Don’t know
61	High	Moderate	Quite likely	Quite likely
62	High	Low	Quite likely	Quite likely

Table 13-3: Location of the critical facilities in the study area

Sijeruk			
Survey points	**Fast landslides susceptibility class**	**Creep susceptibility class**	**Use – Critical facility**
1	High	High	Primary School
2	Moderate	Very high	Mosque
3	Moderate	High	Shop
4	High	High	Mosque
5	High	High	Mosque
6	Moderate	High	Shop
7	High	High	Shop
8	High	Very high	Shop
9	Moderate	Very high	Village Office
10	Very high	Very high	Mosque
11	Moderate	High	Primary School
12	High	High	Mosque
Kalilunjar			
Survey points	**Fast landslides susceptibility class**	**Creep susceptibility class**	**Use**
1	Moderate	High	Primary school
2	Moderate	High	Primary school
3	High	High	Village office
4	Moderate	High	Junior High school
5	Moderate	High	Geophysical offices
6	High	Low	Kindergarten
7	Moderate	High	Primary school
8	Moderate	High	Mosque
9	High	Low	Mosque