Stochastic Modelling of Land Cover (dynamic) Elements to Assess Landslide Vulnerability

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by

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I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.
Signed …………………….

Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Dedicated

To

My beloved

Ma and Papa

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ABSTRACT

Growing population and the resultant pressure on environment has forced the occupation of dangerous and unstable mountainous areas. The Bhatwari area along the Bhagirathi river in between greater and middle Himalayas in Uttarakhand state of India is a typical example. It is part of a zone that is highly prone to landslides, where debris slides and rock slides are a major threat to people. In recent time land-use and land cover changes have taken place following various development activities that have changed the slope conditions and have resulted in a frequent occurrence of landslides. In the present study an attempt is made to assess the vulnerability to landslides in a stochastic way and to model the dynamic movement different vulnerable element with the help of remote sensing images and on the basis of field base data from the study area. The main focus is to assess the stochastic vulnerability to landslides in an area on the basis of a dynamic modelling of different elements at risk and to assess the vulnerability of dynamic elements at risk. Different scenarios of day-time, night-time vulnerability have been generated for the optimal assessment of landslide vulnerability. An effort has also been made to monitor dynamic land cover changes using satellite images from different dates to quantify the changes that occurred in the area and to analyze the effect of these changes on landslide vulnerability. For the present work, LISS-III and Ortho-rectified Cartosat-I images have been used along with ancillary information collected from the field. The study quantifies changes in land cover (forest, agricultural land, barren land, scrubs) in a historical prospective and analyzes their impact on vulnerability to landslides. A change detection technique is being used to identify changes from two different years from satellite data by monitoring the differences in the state of a land-cover object. Results showed that from 1998 to 2006 a large portion of barren land, scrub land and forest land has been converted into agriculture land. It was also observed that around one fourth area under agriculture has changed to barren land resulting in decreased land values. Accuracy assessment of both classified images was carried out and overall classification accuracies of 84% and 83% were obtained with kappa statistics equal to 0.79 and 0.785, respectively. To assess the vulnerability of such an object to landslides, both property vulnerability and population vulnerability are considered. Vulnerability of each object depends on its relative position with respect to a particular hazard or event in a given time. Vulnerability of a vehicle on the road is assessed by the expected number of vehicles at any time on a road section. A working methodology has been established by assuming 1 km of road length as unit road stretch and the average speed of vehicle as 35km/h. Results indicate that the vulnerability of vehicles to landslide events on road sections varies throughout the day, depending on the number of vehicles. Population vulnerability was assumed to depend upon population density. Results indicate that vulnerability of land-cover class has changed between 1998 and 2006. Vulnerability of these classes has increased at several places, whereas in other places it has decreased. Therefore the vulnerability of an element is very much dependent upon the spatial location of the exposed element at risk at a given time and varies greatly within the space and time.

Key words:- Landslide, Stochastic vulnerability, land-cover, elements at risk.

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1. Introduction

Since the beginning of the civilization natural hazards have threatened human lives and environmental ecosystem. Landslide is one type of hazard, accounting for large damage on properties in mountainous regions of the world in terms of both direct and indirect cost each year (Dai *et al.,* 2002). Landslides are defined as the movement of masses of rocks, debris or earth down a slope (Cruden, 1991). In India Garhwal Himalaya is well known for a frequent occurrence of landslide due to a fragile landscape. The large number of people living in these areas is thus under a continuous threat of landslides, leading to many deaths and property damage. For example on 11 and 19 August 1998 one landslide occurred in Ukhimath and affected an area of 20 km^2, taking the lives of 102 people (Naithani *et al.,* 2002). On 16 July 2001 a cloudburst rainfall induced a landslide in the Byung area of Rudraprayag district of Uttarakhand triggered more than 200 landslides that killed 27 people (Kumar *et al.,* 2003).

With the growing population density and industrial development in these areas the threat of landslide disaster has increased, Assessing vulnerability of an area has thus become a basis for information to recognize measure and predict risk for mitigation and prevention of an expected land slide disaster. Different scientific groups have different view on quantifying and assessing vulnerability. For disasters this is determined by exposure and susceptibility to harm (Taubenbock *et al.,* 2008). Exposure in turn is determined by the relative location to the hazard, whereas susceptibility is based on the socio-economic, environmental, and psychological variables that intervene in producing different impacts amongst people at a similar level of exposure (White *et al.,* 2005).

Vulnerability assessment of landslides however is complex and different from the other hazards such as flooding and earthquakes. The reason is that landslides occur at comparatively isolated locations leading to damage at point locations and not within large areas (Westen *et al.,* 2006).Modeling of landslide vulnerability is also complex as the spatial and temporal uncertainty of landslides is caused by different types of elements at the risk. In fact, movement of people and vehicles on roads is dynamic and changes over during the day, during a week, or during a season (Roberds, 2005).

Land-cover is an important factor in landslide studies. The seasonal dynamic nature of land-cover pattern can thus act as a potential triggering factor of landslides and can alter the vulnerability. For example, land cover changes in hill slopes affect the slope stability and can lead to land slide in hilly regions. These regions do not only become hazardous but also the changed land cover, such as crop land from forest, pastures from forest and settlement from barren land becomes vulnerable. Remote sensing data have the potential to detect such changes semi-automatically. The availability of temporal satellite image of different dates makes it possible to detect the land cover changes that have occurred in those areas, thereby indicating the vulnerability of such areas to landslides.

The aim of present study is to develop a stochastic methodology for assess the vulnerability of landslides. This methodology will be used to investigate the impact of land cover changes. The study focuses on a single road track in the Himalayan area. It investigates land cover changes that have taken place in this area during the last ten years. It is expected that the end result of this study will be helpful for the government and private agencies which is working on mitigation and management of landslide hazard related risk.

1.1. Problem definition

With the growing human population and the resultant pressure on the living environment, human population is forced to occupy comparatively dangerous and unstable mountainous areas of the world and there to lead their livelihoods. As a consequence, the risks associated with landslide hazard have drastically increased (Dai *et al.,* 2002). The selected area for this study is located within the high landslide prone zone, where debris slides and rock slides are a major threat for the population living in this area. Recently major land use and land cover change have taken place following establishment of various power plant and road cutting in these areas. Slope conditions have changed drastically and the net result of this is the frequent occurrence of landslide in this areas. It becomes essential to assess and quantify the vulnerability of people and building object against the landslide hazards, leading to a better management of landslide related disasters.

Modeling and assessing quantitatively the vulnerability for landslide is a complex task. The discrete nature of landslide occurrence and the dynamic movement of element at risk make it more complex than the other hazard (Westen, 2006). To model the uncertain and unpredictable movement of different vulnerable element in space and time it self already a challenging job. On top of that, it as to be studied how the elements at risk will change and where it will take place. Some vulnerable elements are changing more rapidly than other elements, like the presence of people at specific locations, and there number, the movement of vehicle on road and there frequency, whereas other change are less dynamic, like formation and extension of settlements and the change of land cover (Roberds, 2005). In the present study an attempt has been made to assess the vulnerability to landslide in a stochastic way and to model the dynamic movement different vulnerable element with the help of remote sensing images and on the basis of field base data from the study area. Different scenarios of day-time, night-time vulnerability have been generated for the optimal assessment of landslide vulnerability. An effort has also been made to monitor dynamic land cover changes using satellite images from different dates to quantify the changes that occurred in the area and to analyze the effect of these changes on landslide vulnerability.

1.2. Research objective

The main research objective of this research is to assess the stochastic vulnerability to landslides of an area on the basis of a dynamic modelling of different elements at risk.

1.2.1. Sub-objectives

- To analyze the different time period satellite images to assess the impact of land cover change on the Landslide vulnerability.
- To assess the vulnerability of dynamic elements at risk like people, vehicle & Land cover.

1.3. Main research questions

The research questions to be addressed are:

- What will be the best way to analyze temporal images to extract dynamic features contributing to landslide vulnerability?
- How can stochastic vulnerability can be assessed for element at risk?

1.4. Structure of the thesis

This thesis contains seven chapters.

- **Chapter 1** gives a general introduction about the vulnerability and why this study is important to carry out. This chapter also highlights the current problems in the vulnerability study as well as the various objectives and research questions that will be addressed in the present study.
- **Chapter 2** discusses the details of a literature review, the background of the research work and the general concepts of vulnerability in a stochastic framework.
- **Chapter 3** briefs the general idea about the study area its location, climate, rainfall, major land cover, general geology etc.
- **Chapter 4** discusses the various steps of methodology adopted during this research.
- **Chapter 5** presents with the results obtained during the research.
- **Chapter 6** briefs about discussion and future recommendations of the research.
- **Chapter 7** contains the conclusion and limitations of the research.

2. Literature review

2.1. Introduction

Vulnerability refers to the degree of loss that may occur to elements at risk due to a particular hazard. It is commonly accepted that vulnerability indicates the susceptibility and potential damage of any element at risk having some economic value (Ebert. A, 2006). Vulnerability can be a broad term, encompassing the effects like 'vulnerability as an internal risk factor' to 'multi-dimensional vulnerability encompassing physical, social, economic and environmental vulnerability. As vulnerability by all likelihood covers a broad area of interest and the consequence of hazards, it needs to be assessed quantitatively. Studies relating to vulnerability have gained importance in recent times in various fields. According to EM-DAT: Emergency events database; during 2008, natural hazards caused enormous damage globally. The record shows that as many as 3924 people were killed, 3828660 people affected and estimated damage up to 4.5 million, US dollars (EM-DAT, 2008) only with the mass movement related events. The risk management paradigm has been proposed as a useful framework for identifying robust decisions in the face of the inherent uncertainties associated with the uncertain events like landslides. Vulnerability though categorized into social, physical economic and environmental sub-types, they are highly inter-related and not static through time. As the elements at risk can be both static and dynamic so is the case for vulnerability. As a consequence of temporal variation in elements at risk, vulnerability changes through time. Thus it is imperative to address the stochastic/probabilistic aspect of vulnerability to have a comprehensive assessment of the hazard and risk associated with an event.

2.2. Landslide vulnerability: Definitions

Vulnerability assessment of landslide is an important component in the field of landslide risk assessment. Concept of vulnerability in context with landslide is still a sharply debated question among the various scientist groups working in this field. Background of literature indicates that there is not a single definition of vulnerability of landslide that is universally accepted. Different scientist group has different view and perception on vulnerability. The most acceptable and widely used definition of vulnerability is proposed by Varnes and his IAEG collaborators (1984), "landslide vulnerability is the degree of loss to a given element – or set of elements- at risk resulting from the occurrence of a given magnitude in an area". Liu, (2002) has defined vulnerability in terms of potential total maximum losses due to potential damaging phenomenon for a specified area and during a reference period and it is measured on a scale of 0 (no loss) to 1 (total loss). Alexander (2005) in Galli (2007) has defined vulnerability as the ability of an element at risk to withstand mass movement of a given dimension, subsequently. White *et al.,* (2005) have defined vulnerability in terms of susceptibility, exposure and copping capacity which can be expressed mathematically as

$$\text{Vulnerability} = \frac{Susceptibility \times Exposer}{copingcapasity} \qquad \text{(White } et\ al.\text{, 2005)}$$

Birkmann.J, (2007) proposed the concept of vulnerability in terms of different levels of vulnerability sphere, starting from 'vulnerability as an internal risk factor' to multidimensional vulnerability incorporating physical, economic, social, economic, environmental and institutional features.

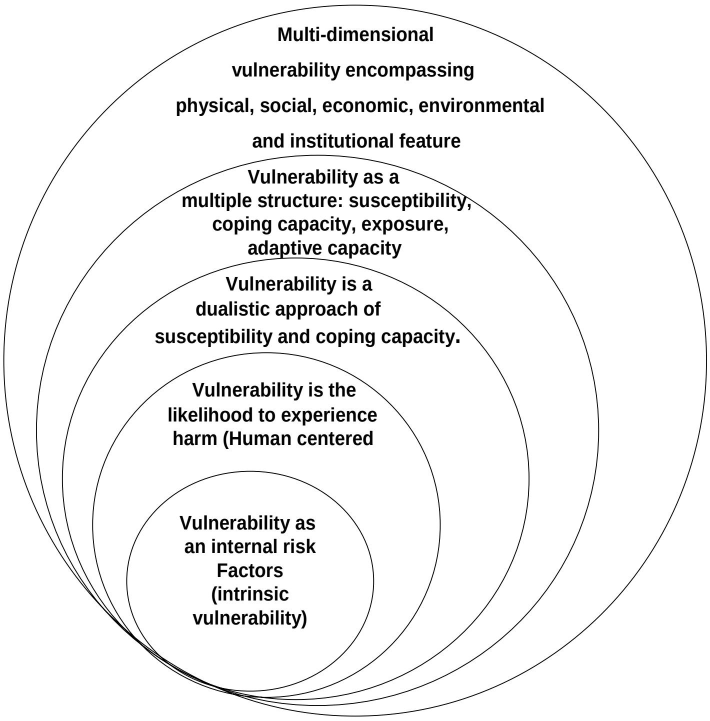

Figure 2-1: Conceptual spheres of vulnerability [Source: (Brikmann, 2007)]

2.2.1. Types of vulnerability

(United Nations development Program, 2004) had classified vulnerability into four major categories:

1. *Physical vulnerability* indicates losses due to the damage of physical infrastructure and buildings and a fixed asset value is required to quantify it (Liu *et al.*, 2002).

2. *Environmental Vulnerability* includes the loss due to damage of natural resource mainly water, land resource etc.

3. *Social vulnerability* deals the loss on population and the social structure due to any damaging event.

4. *Economic vulnerability* is the effect on the economic condition of the affected area and it is assessed on the basis of gross domestic product (GDP), the higher the GDP of an affected area the greater would be the vulnerability.

2.3. Elements at risk mapping and role of remote sensing

Elements at risk comprise those objects or elements that can be affected by any damaging events. It refers to buildings, population, infrastructure, economic activities. On the basis of spatial and temporal characteristics of these elements it can be grouped into two categories (Roberds, 2005; Westen *et al.*, 2008).

- Static elements at risk
- Dynamic elements at risk

Static elements at risk refers to those element which do not changes there location with time for example, buildings, civil engineering works and there vulnerability condition is supposed to be constant. Dynamic elements at risk indicate the object which changes there location with respect to time like population, vehicle movement on road, land use etc (Roberds, 2005).
Mapping and monitoring of these elements is a tedious work and it requires various level of details information depending on the nature of study (Westen *et al.*, 2008). Remote sensing images acquired from different sources optical, Lidar, InSar play a major role in the extraction and mapping in some of the elements. Taubenbock *et al.*, (2008) explore the capacity of high resolution IKONOS images in automatic extraction of buildings related information like height, roof types and age for the assessment of earthquake vulnerability.

2.4. Land cover change and its impact on landslide vulnerability

Land cover plays a major on the vulnerability to landslide. The process of land cover change is controlled either by the human intervention in the natural ecosystem or by the natural process. The dynamicity of land cover changes has been studied by various researchers recently to understand the process of landslide (Guthrie, 2002; Glade, 2003). Deforestation, excavation of slope for the construction of road and building in the mountainous terrain are major triggering factor for landslide occurrence (Dai *et al.*, 2002). As Land use and land cover change can be a potential triggering factor that makes area hazardous by changing the morphology and changed surface cover. Another important aspect that, the changed land cover/land use becomes vulnerable to landslide and intrinsically linked to hazard. People migrate to hill slope for cultivation and other purposes and this leads to large scale deforestation and increased chances of slope failure, as well as leading to more severe damage when natural buffer zones are destroyed increasing vulnerability of people and property (Kerle *et al.*, 2003). Land cover change and the vulnerability condition can be analyzed by image mining technique from multi source and multi temporal satellite images (Silva, 2004).

2.5. Research background

Most researchers have focused on risk and community vulnerability (Kohle *et al.*, 2007). Among them Dai *et al.*, (2002) in his study discussed that vulnerability assessment is somewhat subjective and mainly depends on the historical record. The vulnerability to landslide depends on several factors like run out distance, volume , velocity of sliding, nature, type of elements at risk and there proximity to the slide. The work highlighted that for a similar type of slide the vulnerability of property and lives will be different. He also mentioned in his study that there are two ways of assessing the vulnerability; one is expert judgment and the other is based on the statistical approach of detailed historic record.

Liu *et al.*, (2002) proposed an empirical model for the assessment of vulnerability, risk and hazard of debris flow prone area of Yunnan province, SW China. They have estimated the property and population vulnerability individually and sum model was applied to estimate the overall vulnerability. In there study property vulnerability has been assessed by total maximum loss in terms of money due to damage of property and infrastructure. Population density along with the age, education and wealth condition of the inhabitance area has been taken as the basic value to estimate the population vulnerability. The study also proposed an indirect method to transform the value of property and population with different measurement units to make them dimension less and stretched the value into 0 to 1 scale. Similar vulnerability model was applied by Liu.X, (2006) ; Liu.X and Lei.J, (2003) in different part of the Yunnan provinces of china to assess the vulnerability of debris flow.

Glade, (2003) assessed the vulnerability of landslide for Rheinhessen, in Germany and Bildudalur, Iceland and found that there is no unique and simple method available for the assessment of vulnerability within landslide risk analysis. In his study he mentioned that the vulnerability estimation is very much dependent on the availability of historical data for the region and recognized that with these known limitation, there are numerous advantages from detailed landslide risk analysis. He has also proposed a modified table of vulnerability value for different element at risk according to the type of damage through landslide.

In his study Roberds, (2005) has defined vulnerability as, uncertain damages associated with any particular ground movement and discussed that these uncertainty was mainly due to uncertainty in the factors that determine the vulnerability and hazard. It has been noticed that one of the major factor of these uncertainty in vulnerability and hazard is due to the temporal variability. The study mainly focused to understand the temporal aspect of vulnerability and an attempt has been made to model the dynamic elements at risk like people and vehicles which changes rapidly during the course of the day. Two case studies one is on Italy and the other is on Hong Kong has been presented in the study and conditional consequence model was being proposed to generate different scenarios of vehicles accident due to occurrence of Landslide event on the section of road.

Duzgun and Lacasse, (2005) have studied vulnerability in integrated risk assessment frame work. The study has highlighted the issues, why the quantitative modeling of landslide vulnerability is difficult and different from the other hazard like flood, earthquake and hurricanes. It has been found in the study that the vulnerability assessment in case of landslide depends on the variable nature of element at risk, the way of hazard computation and the scale of investigation. A 3-D conceptual frame in integrated risk frame work was proposed for the assessment of vulnerability.

Westen, (2006) in his study highlighted the issue, why vulnerability assessment in case of land slide is difficult. It was observed that the vulnerability to landslide is very much dependent on the spatial-temporal location and thematic characteristic of elements at risk. The study points out that determination of temporal vulnerability of element at risk is time consuming and might be difficult to model.

Galli and Guzzetti, (2007) have studied the vulnerability of landslide in Umbria province in central Italy. The study mainly focused to estimate the degree of loss on buildings and road by taking assumption that the elements at risk are permanent and fixed. Power law function was applied to establish the upper and lower threshold to generate the vulnerability curve. The study also explored the degree of damage caused by landslide on the elements at risk is the function of various factor like the rate of movement of landslides, type of the slide movement, relative location of the exposed elements at risk and there capacity to resist ground deformation etc.

Kohle *et al.*, (2007) studied the buildings and social vulnerability in GIS environment. The study highlighted that the vulnerability is dynamic and it should be assessed by taking its spatial and temporal aspect into consideration. Buildings type, age, height and its use has been taken as the basis to assess the degree of loss. Weight linear combination method as a multi criteria evaluation was applied to assign the weight for each factor by assuming that not all the factors are equally important for overall vulnerability. Human vulnerability was assessed on the basis of density of population and the vulnerability of building.

Fuchs.S, (2007) found a lack of knowledge in the field of vulnerability studies related with debris flow event. It was noticed that till now most of the models used for the assessment of vulnerability were qualitative and mainly based on the expert knowledge, historical records and on the conceptual approach. In the study, an attempt has been taken to establish a quantitative relation between the intensities of process and vulnerability value by using second order polynomial function.

Kaynia *et al.*, (2008) proposed a new methodology for the probabilistic estimation of landslide vulnerability in village of Lichtenstein, Germany. The methodology has been applied to estimate the susceptibility to structure and susceptibility of person in structure. In this study "first order second moment" (FOSM) approach has been proposed to assess the vulnerability. This approach allows integrating the potential influencing factors of landslide vulnerability as well as it also measure the uncertainty present in vulnerability estimation. In this study the author has defined vulnerability as a product of landslide intensity and susceptibility.

2.6. Stochastic concept and vulnerability assessment

In nature not all process are deterministic but some of them are stochastic (random) in which the sequence of outcomes are governed by a low of probability. By the definition, stochastic processes can be defined as the "phenomenon that unfolding in time according to a certain probabilities law" (Sharma, 2002).

In probability theory the concept of stochastic has been implemented to understand the experiment which involves observing some phenomenon over time (Sarkar *et al.*, 2002). Mathematical stochastic processes can be defined as "non-countable infinity of random variables, one for each time (t) and for a specific time, stochastic processes X(t) is an random variable with distribution" (Papoulis.A, 1985)

$$F(x,t) = P\{X(t) \le x\} \qquad \textbf{2-1}$$

The concept of stochastic process covers a wide area of study, in share market and exchange rate, medical sciences, physics (Brownian motion, voltage etc.), risk assessment, environmental science etc. Vulnerability assessment of elements at risk to any hazards is considered as stochastic, in the sense that the factors that determine vulnerability depend on numerous factors, the combination and out come of which is highly uncertain. Vulnerability of an elements to a given hazards is not always constant but it changes dramatically over time and the results are very much sensitive to the choice of time horizon (Elbers and Gunning, 2003). Various research groups (Glade, 2003 ; Roberds, 2005 ; Kohle, 2007) have noticed that an important causes of this uncertainty in vulnerability study is the dynamic behaviour of the various exposed elements at risk like the dynamic movement of population at different places with time, vehicle on road, land cover change etc.

Some studies have been carried out to model the vulnerability stochastically by various researcher groups. Among them Katz, (2002) proposed a random sum model to assess damage related with the Hurricane event. In his study he modelled event occurrence as a passion process and damage of an event as a lognormal distribution. Elbers and Gunning, (2003) studied the vulnerability in a stochastic dynamic model and proposed Ramsey model to assess the household vulnerability to unfavourable shocks.

3. Study Area

This chapter gives a general description about the study area and reasons for selecting the area for this study.

3.1. General Introduction of the study area

The Garhwal Himalaya in Uttarakhand state is well known for frequent occurrence of landslide hazards over the entire region. The selected study area comes under the Uttarkashi district of Uttarakhand state, (INDIA), the whole study area comes under the threat of landslide and landslides are very frequent, specially during the every monsoon Season. The name of the state Uttarakhand come into existence in year 1999 as a 27 state of Republic of India earlier this state was the part of Utter Pradesh. Uttarakhand surrounded by Tibet in north and Nepal in the east. The whole state is hilly terrain incorporating the Tethys, Higher, Lesser and sub Himalaya part along with the great Indo-Gangetic Plain falling in the Hardwar and Udham Singh Nagar Districts.

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3.1.1. Location of the study area

Selected study area is located between the latitude 30^0 48’ 02” N to 30^0 50’ 53” N and latitude 78^0 36’ 04” E to 78^0 48’ 05” E in Bhatwari river catchments in Garhwal Himalayas.

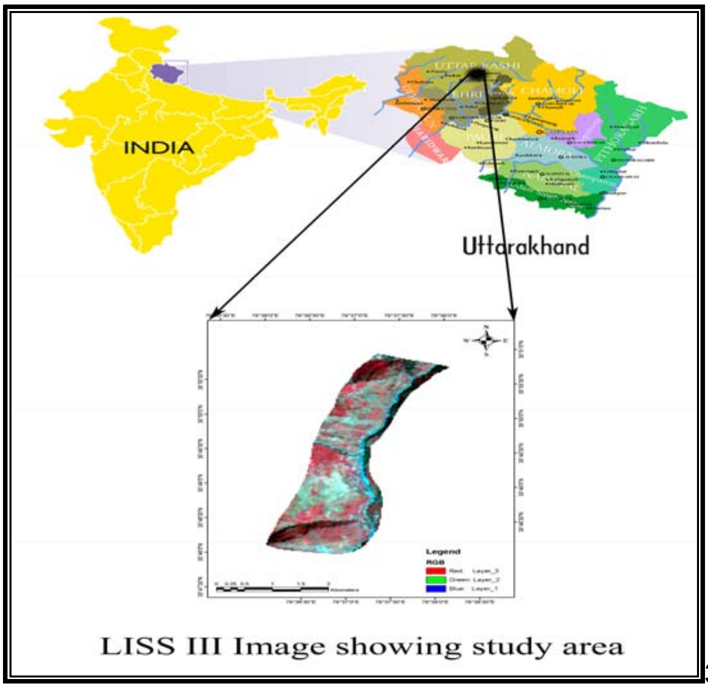

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Figure 3-1: Location and extent of study area.

3.1.2. Reasons of selecting study area

The selected study area comes under the threat of frequent landslide occurrence. The area is located near one of the well known holiest place Gangotri, because of this reason tourist concentration and vehicle movement in this area is very much fluctuating over year. Recently it has been noticed that that the area has faced a major land cover change due road, tunnel construction and by other anthropogenic activities and the probability of occurrence of landslide has increased.

3.1.3. Soil

The soil is generally shallow and moderate with less than 50 cm thickness on area steep slope area except in cultivated areas on moderate slope where the thickness of the soil relatively more and mainly comprise of fine soil (NRSA, 2001). The flat areas and inter-mountain valleys contain thicker soil cover. The piedmont zones in the area contain variable thickness of the soil types. It can be noticed in the entire study area that the characteristic of soil changes with changing altitude and geomorphic situations.

3.1.4. Land cover

The major land cover patterns in the study area are forest, scrubs, barren land and agriculture land. The agricultural land is mainly present in hill cut terraces and near the river terraces. The major settlements in the study area are along the national highway that runs close to Bhagirathi river. Some other isolated settlements also present in scattered form in the area.

3.1.5. Vegetation

It can be observed that in the entire study area with high altitude the dominant plants are Deodar, Pinus, Rhohododendrron, Betulautilus, Cesrus, Piceasp with beautiful pasture and grass land. In moderate and low altitude slope are generally used for step cultivation for growing vegetables and crops. The dominant natural vegetation over these slope are mainly Pinus, Dalbegia sisoo and Shores Robusta etc.

3.1.6. Weather and climate

As the study area is part of high altitude location, it experiences a subtropical temperature climate throughout the year. Maximum elevation of the study area with mean sea level is about 3543/m and minimum elevation is around 1159/m. The whole area receives heavy precipitation during summer monsoon between July and September and moderate rainfall during winter monsoon between January to march every year. On an average there are about 100 rainy days in a years and average annual rainfall in the area is approximately 1200mm. About 70 % of the total rainfall is received during the month of July to September in which maximum landslide occurs in the area.

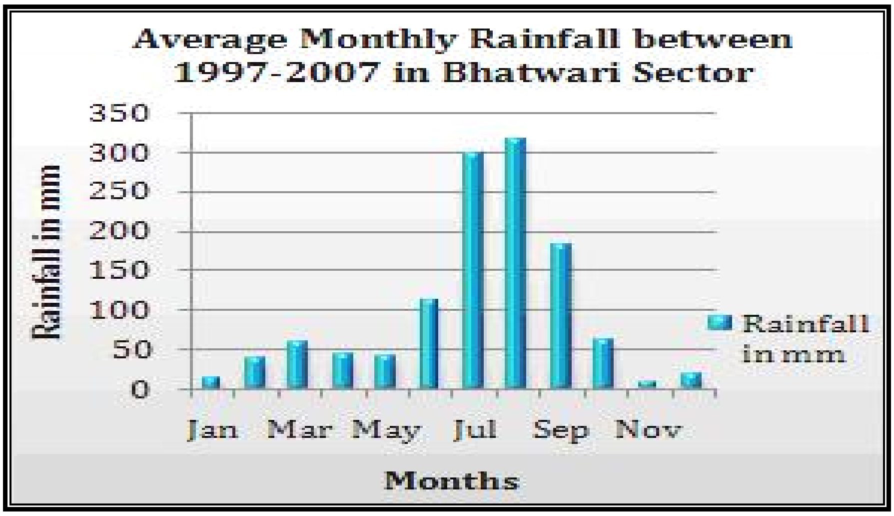


Figure 3-2: Graphs showing the distribution of average rainfall in the Bhatwari, Uttarakhand
Source: (BRO, 2007)

3.1.7. Drainage

The study area is drained by one of the holiest river Ganga which is known as Bhagirathi in the upper riches. It originates from the Gangotri Glacier in Tethys Himalaya and form a U- Shaped valley in the upper course near Jhala. It forms V-shaped gorges during the course of greater Himalaya and lesser Himalaya. The dendritic drainage pattern is predominant over the entire region of the study area. The parallel and sub-parallel pattern can also be observed along the hill slopes.

3.1.8. Geology and Geomorphology

The study area mainly consists of two geological stratigraphic units from south to north namely: Garhwal group and the central crystalline. The Chail thrust separates the Garhwal group from the Central crystalline (Islam. R and Thakur, 1988). The dominant rock types found in this the Garhwal group are mainly quartzite and metabasic with intercalation of phillite and chlorite schist, while the central crystalline group mainly consist of Sheared granite gneisses, porphyritic gneiss, talk schist, mica schist, mylonites and quartzo – feldspathic schist (Choubey and Ramola, 1997). The area is transversed by numerous transversed by numerous thrust and faults trending in east-west. Geomorphology of the area can be described as highly dissected structural hills of Pre-Cambrian metamorphic/metasedimentary rocks with active denudational processes leading to rugged topography. The major landforms in the area are glacial, fluvial, structural and denudational in origin. The general geomorphic features are cliffs, rocky slopes, waterfalls, major and minor ridges and quaternary deposits along the river valley and hill slope. The structural and litho-logical control on the development of landforms is evident in the area by the fact that the metamorphic rocks which are dominant in the area are more resistant to weathering process.

4. Material and methods

To carry out any research work various kinds of data required from different sources as purpose. This chapter gives a brief description about the data used as well as brief description about the methodology applied during the pre-processing of satellite data, field data collection as well as the technique used to find the dynamic land cover change from the different years of satellite data and technique applied to model stochastic vulnerability of landslide.

4.1. Satellite Data

To model landslide vulnerability stochastically, it is required to have the knowledge about the dynamic change of the vulnerable elements with respect to time. The dynamic nature of land covers also affect vulnerability scenario thus to model the change in land cover that has occurred within the past ten years, two different dates images of LISS-III were selected after looking the availability of data sets. Other satellite data used in present work is of high-resolution Cartosat-1 to extract the static element at risk (buildings and road).

4.1.1. Satellite Data Acquisition

To model the dynamic land cover change, it was necessary to acquired that all images acquired were from same season to avoid the seasonal change. In present study summer season images of LISS-III (March 1998 and 2006) of spatial resolution of 23.5 meter was acquired from the special request to the NDC (NRSC, Data Centre, Hyderabad). Ortho-rectified Cartosat-I image of high spatial resolution 2.5 meter was made available by Indian institute of remote sensing, Dehradun.

4.1.2. Sensor characteristics

LISS-III

Linear imaging self scanner on board of IRS- IC is a multi-spectral sensor of medium spatial resolution of 23.5 meters. It operated in four spectral bands, among them three are in visible and NIR and one is in SWIR region. The spectral characteristics of sensor is describe in the below table.

Table 4-1: Spectral characteristics of LISS-III

BAND	WAVELENGTH	SWATH WIDTH	SPATIAL-RESOLUTION	REVISIT TIME
1.(GREEN)	0.52-0.59	141 km	23.5 m	24days
2.(RED)	0.62-0.68	141 km	23.5m	24days
3.(NIR)	0.77-0.86	141 km	23.5m	24days
4.(SWIR)	1.55-1.70	148 km	70.5m	24days

Cartosat-1

Cartosat-1 is a high resolution Indian satellite, which provides stereo pair image of the earth.

Table 4-2: Spectral characteristic of Cartosat-1

BAND	BAND- WIDH	SWATH WIDH	SPATIAL_RESOLUTION	REVISIT TIME
1.(PAN)	500nm-850nm	30km	2.5m	5days

4.2. Flow Diagram

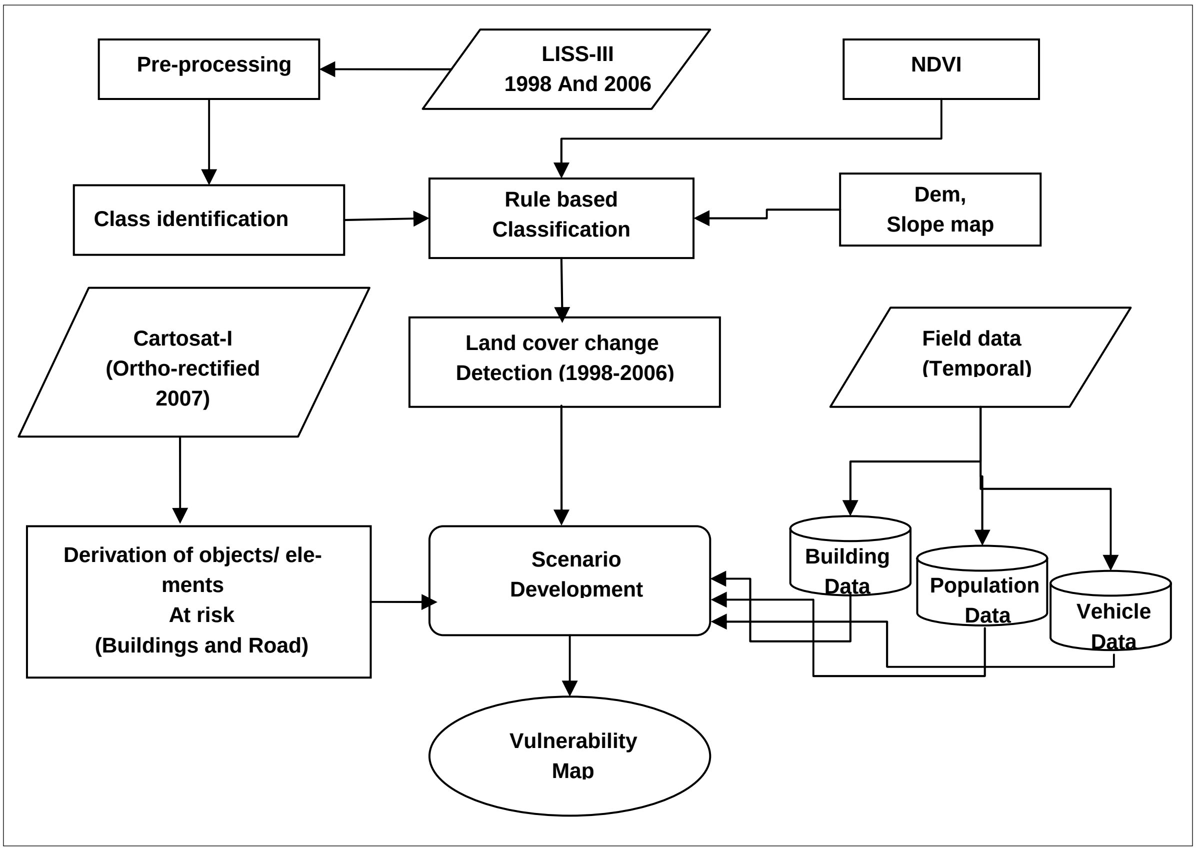


Figure 4-1: Flow diagram of methodology

4.3. Data pre-processing

Raw satellite data contains various types of geometric and radiometric errors with it, thus it is necessary to remove these errors before further use of data. Pre-processing of satellite data consist of image geometric correction, haze or cloud removal etc. In present study only the cloud free data were selected.

4.3.1. Image geometric correction

The raw satellite data contain geometric distortion and it is necessary to rectify them from the images in order to enable correct measurement of area, precise localization and multi-source data integration(Zhang.J and Zhang.Y, 2007). In case of land use change detection the proper geo-rectification is essential and the accuracy of geo-rectification should be within 1 to 2.5 Pixels (Zhang.J and Zhang.Y, 2007). Image to image rectification technique was applied because it minimizes the residual rectification error (Dai, 1998). Ortho-rectified CartoSat-1 provided by geo-science division, Indian Institute of Remote Sensing were taken as a base data to geometrically correct the LISS- III images. Total 37 well distributed permanent point like road crossing, reservoir, dams, bridge on both images were considered as a ground control (GCP) for the geo registration of LISS –III images in UTM projection with WGS 84-North spheroid and Zone 44. Polynomial model were applied for the geo- rectification of LISS-III images. The root mean square error (RMSE) during the geometric correction was 1.695 pixels due high elevation variation in the area.

4.4. Extraction of dynamic land Cover change

There are various factors that determine the vulnerability condition of an area prominent. Among them, land covers elements which changes comparatively less frequently but has greater impact on the vulnerability condition. In present study, one of the objective is to quantify the changes in land cover (forest, agricultural land, barren land, scrubs) in a historical prospective and to analyze there impact on vulnerability to landslide. Change detection technique can be a solution to identify the change element from two different years of satellite data as it help to monitor the difference in the state of an object by observing at different time (Singh, 1989 in Deng *et al.*, 2008). There are various techniques available for the identification of change. Image differencing, principal component analysis and post-classification are the most commonly used methods (Lu *et al.*, 2004). In present study post classification change detection technique was applied to extract the dynamic land cover element because it avoids the difficulties in change detection associated with analysis of images acquired at different time (Deng *et al.*, 2008).

4.5. Classification technique

The general idea of classification process is to classify all pixels in an image into land cover classes based on predefined classification model. In mountainous region with high topographic variation is more, traditional classification techniques are not very much helpful for mapping land cover and land use classes (Shrestha and Zinck, 2001). In traditional classification of multi-spectral data the supervised classification (Maximum likelihood classification) is considered to provide the best result because it also takes into account shape, size and orientation of cluster. The major draw back of this classification technique is that it assumes normally distributed training samples. In case of hilly or

complex terrain this ideal condition does not exist due to variation in sun illumination conditions (Shrestha and Zinck, 2001). To overcome these problems associated with conventional classification technique various studies has been carried out to improve the classification accuracy by using ancillary layer and experts' knowledge (Shrestha and Zinck, 2001; Stolz.R *et al.,* 2005).
The accuracy assessment of both supervised and unsupervised classification in the present area showed the accuracy of 68% and 76% respectively. Thus it was proposed to use knowledge based classification together with ancillary information and data layers to achieve better accuracy for the classification purpose of land cover classes. In order to classify the LISS-III image three different ancillary layers, namely digital elevation model (DEM) provided by Indian institute of remote sensing, Dehradun (INDIA), normalized difference vegetation index (NDVI) and slope map together with all bands of LISS-III (green, red, NIR,SWIR) were used. To generate decision rules for knowledge base See5 (data mining software) was applied.

4.5.1. Ancillary data preparation

Slope of an area represents the change in elevation with respect to a certain distance. To differentiate agriculture land from forest land hilly terrain slope can be considered as one of the criteria as agriculture land prevalent in gentle slope areas. Similarly differentiating scrubs lands from agriculture area, slope can be helpful input. Slope map was generated directly from the existing Cartosat-1 digital elevation model by applying following algorithms in ERDAS imagine software.

$$\text{Slope} = \sqrt{\frac{(\Delta X)^2 + (\Delta Y)^2}{2}} \qquad 4\text{-}1$$

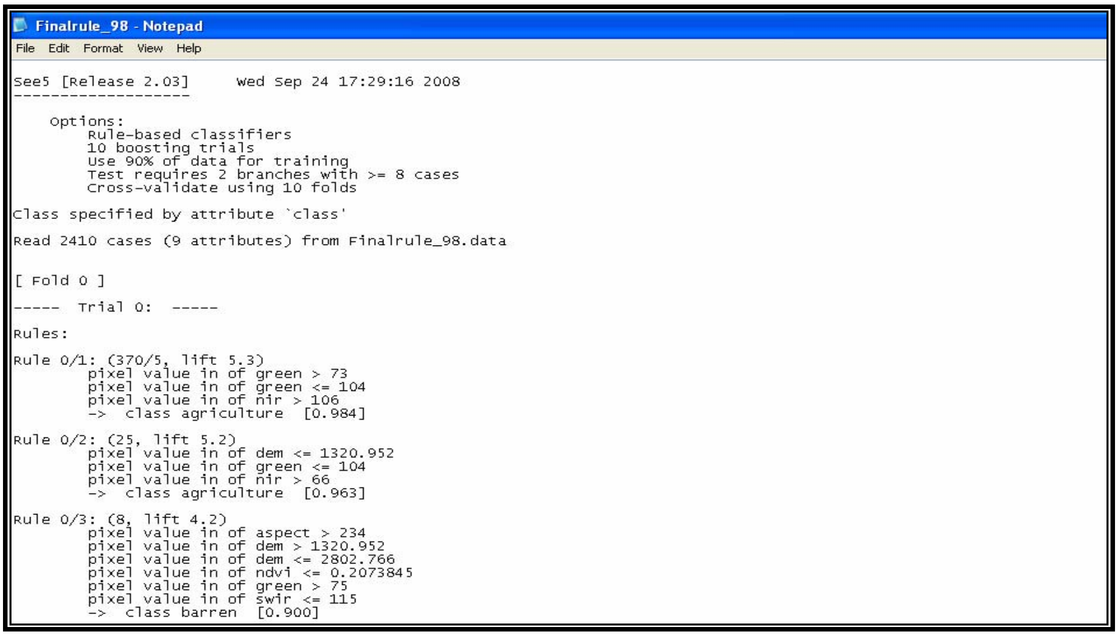
NDVI (Normalized differential vegetation index) was used as one of the ancillary layer for land cover classification because it is a good indicator of vegetation and helps to interpret the urban, rural or vegetation/forest contrast and seasonal change in vegetation (Emerson *et al.,* 1999 in Nayak, 2008). NDVI image was generated from the LISS-III images using ERDAS imagine model maker and mathematically it can be written as.

$$NDVI = (NIR - R)/(NIR + R) \qquad 4\text{-}2$$

Where "NIR" is satellite reflectance in near infra-red and "R" is reflectance in the red (Visible) region.

4.5.2. Generation of decision rules

Decision rules are pre-request for expert's classification. In present study to generate automatic decision rules data mining software See5 was used. All above mentioned ancillary layer together with four bands of LISS-III image were re-sampled on 10 meters pixel size in order to bring all the seven layers to a common spatial resolution. For the purpose of classification training data were collected from the LISS-III image by using stratified random sampling technique. For each class of 100 samples of pure pixels were taken and stored in a point shape files. Subsequently these points were used to extract the pixel value from all seven layers. All the extracted values from each ancillary layers were arranged in two different files. One is data file which contains all the information related with training set where as other is name file which serves as a metadata file and contain all the definition about attributes and land cover classes for the decision tree training data sets (See Appndix-1). These two files were used in See5 software to generate classification rules.



```
Finalrule_98 - Notepad
File  Edit  Format  View  Help

See5 [Release 2.03]     Wed Sep 24 17:29:16 2008
-------------------

    Options:
        Rule-based classifiers
        10 boosting trials
        Use 90% of data for training
        Test requires 2 branches with >= 8 cases
        Cross-validate using 10 folds

Class specified by attribute `class'

Read 2410 cases (9 attributes) from Finalrule_98.data

[ Fold 0 ]

-----  Trial 0:  -----

Rules:

Rule 0/1: (370/5, lift 5.3)
        pixel value in of green > 73
        pixel value in of green <= 104
        pixel value in of nir > 106
        ->  class agriculture  [0.984]

Rule 0/2: (25, lift 5.2)
        pixel value in of dem <= 1320.952
        pixel value in of green <= 104
        pixel value in of nir > 66
        ->  class agriculture  [0.963]

Rule 0/3: (8, lift 4.2)
        pixel value in of aspect > 234
        pixel value in of dem > 1320.952
        pixel value in of dem <= 2802.766
        pixel value in of ndvi <= 0.2073845
        pixel value in of green > 75
        pixel value in of swir <= 115
        ->  class barren  [0.900]
```

Figure 4-2 : Classification rules generated from See 5 Software

4.5.3. Classification on the basis of decision rules

Decision rules extracted from See5 serves as a knowledge base to classify the remote sensing images. On basis of these knowledge base both dates of LISS-III images were classified using knowledge engineer module in ERDAS imagine 9.1 Software.

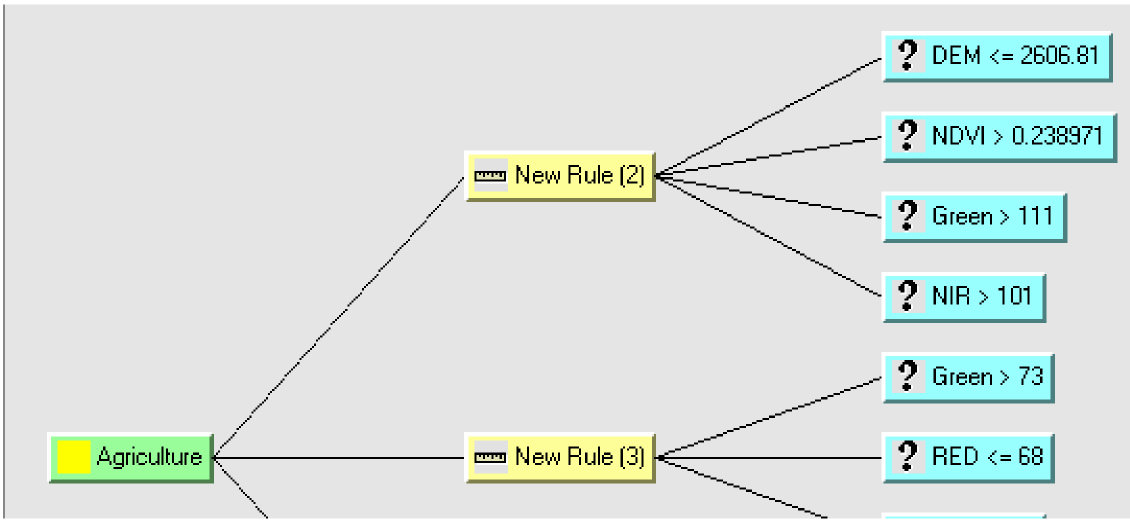


Figure 4-3: knowledge base classification using decision rules.

4.6. Accuracy assessment

For the purpose of the accuracy assessment stratified random sampling technique was applied to generate test sample on classified image. Total 100 samples were taken from all four classes. Original LISS-III data was taken as the reference image to check the classification accuracy. Testing sites selected from classified map were visually compared with the reference image and the accuracy report were generated using ERDAS imaging Software. The overall accuracy for the knowledge base classification was 84% for LISS-III (1998) and 83% for LISS-III (2006)

4.7. Change detection

Post classification change detection technique was applied to extract change in different land cover classes. The change detection matrix was calculated to find the proportion of each class which has undergone change during the last ten years.

4.8. Extraction of static element at risk

In present study buildings and roads are considered as a static element for the vulnerability assessment. CartoSat-1 image of resolution 2.5 meters was used to extract the buildings and road (national highway-108) from the study area. In total 281 buildings and one major road segment, seven kilometer in length was extract through visual interpretation.

4.9. Field data collection and data base generation

To assess vulnerability stochastically, large sets of field data is essential to collect. To gain knowledge and to collect literature about the study area on the first hand basis a field survey was conducted from 21 October to 27 October 2008. In which general pattern of population movement and variation in vehicle frequency at different time of the day were also considered. Two types of data were collected during the field work, primary data which was based on personal interview from the locals and secondary data form Government offices.

4.9.1. Primary data collection

The printed maps of the buildings foot print and road map were used in order to collect the building and road information. Primary data collection was based on the set of questionnaire answered by the locals. A total of 281 different buildings like residential houses, schools, government offices, hospitals were surveyed and their GPS locations were stored. To get information about the people occupancy in different types of buildings at different time of the day (morning, day, evening, night), several types of questionnaire were set and the interview was conducted from the related persons and the information was filled in the following format (Appendix-2).

Table 4-3: Field data format for Population information collection

Serial Number	Building use	Total population	Morning time population	Day time population	Evening time population.	Night time population.
1.	Residential house					
2.	Office					
3.	School					
4.	Hospital					

Information regarding the vehicle frequency on different section of the road was collected by personal observation of the vehicle movement. Hourly monitoring of the vehicle movement was carried out. For each vehicle passenger capacity was taken on the basis of number of seats in that vehicle. All the observed information was entered in the available format (Appendix-2).

Table 4-4: Field data format for vehicle information

Road section.	Time Duration (1 hour).	Number of vehicle.
1.	08-09	104
2	16-17	78

4.9.2. Secondary data collection

Secondary information related to the study was collected from various Government departments. The census data of the study area was obtained from the Block office and from the Junior Secondary School, Bhatwari. Per kilometer road construction coast in the area was collected from the Border Road Organization departments (INDIA). Average construction coast of building per-square feet in the region was obtained from the district civil construction department Uttarkashi. Total vehicle frequency per day and average allowed speed for vehicle were collected from the traffic control department Bhatwari.

Figure 4-4: Field data collection

4.10. Vulnerability assessment and scenario development

Vulnerability scenario for road, building, population and different land cover classes were assessed separately. In order to assess the vulnerability of an element to landslide both property vulnerability and population vulnerability was considered. Two hour time resolution was taken to generate the vulnerability scenario for population at different time of the day, except morning 8:00 to 10:00 hour and evening 16:00 to 18:00 hours where one hour resolution has been considered. This is because during these times there are more variation in population due to movement of people and children going to work and schools respectively. Similarly the vulnerability of road was assessed by considering each of the road section and the time scale that was used for population vulnerability calculation.

To assess the vulnerability of property and population in present study the concept was adopted from Liu, (2006).

$$V \alpha (V_1 + V_2) \qquad \textbf{4-3}$$

where,
V = vulnerability,
V_1 = Property Index (potential total maximum loss of property in terms of money due to landslide).
V_2 = Population Index (Potential maximum loss of life due to landslide event).

To transform the values between “0” to “1” and to makes the property and population value dimension less following empirical method was applied proposed by Liu, (2006).

$$FV_1 = 1/1 + \exp(-1.25 \log(V_1 - 2) \qquad \textbf{4-4}$$

where,
FV_1 = Transformed value for property index (0-1).
V_1 = Property Index (10000 Yuan equivalent to 1,047 EUR).

Equation 4-4 represents a sigmoid curve and assumes that the property accumulation fits a logarithmic increase.

$$FV_2 = 1 - \exp(-0.0035 v_2) \qquad \textbf{4-5}$$

where,
FV_2 = Transformed value for population Index (0-1)

V_2 = Population Index (500 people / km^2)

Equation 4-5 explains Poisson curve and assumes that the relationship between population increase and population vulnerability is positively nonlinear.

4.10.1. Vulnerability of vehicle on road

Vulnerability of any elements is dependent on its relative position with respect to particular hazard or event in a given time. To assess the vulnerability of the vehicle on the road it is important to know the expected number of vehicles at any time on the part of road section. A working methodology was established by assuming 1 km of road length as unit road stretch and the average speed of vehicles as 35km/h. To calculate the expected number of vehicles it is also assumed that the average vehicle speed limit is constant through out the road section. Following conceptual formula was applied to calculate the expected number of vehicles at any given time on the part of road section as suggested by Guzzetti, (2005).

$$Vehicle = \frac{Average\ daily\ traffic}{Average\ speed\ of\ vehicle} \times Travel\ time \qquad \textbf{4-6}$$

Where,

Vehicle = is the expected number of vehicles at any time on road section.

Travel time = Time taken by vehicles to travel unit distance on road.

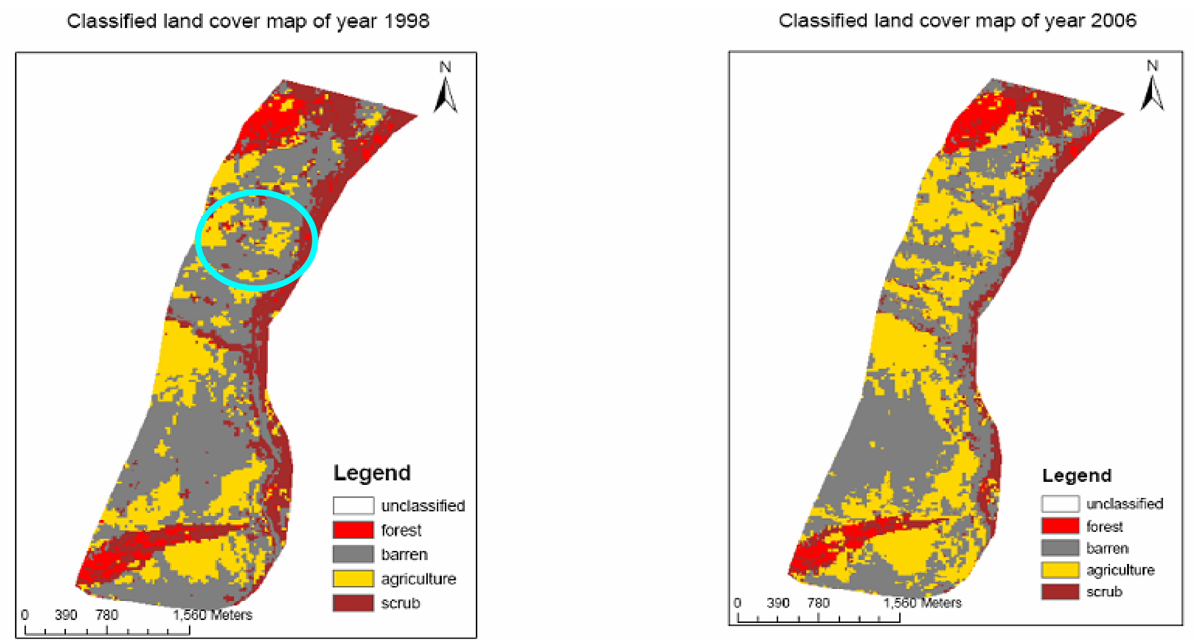
To calculate the expected number of vehicles on part of road track, in present study one hour time resolution was considered.

5. Results

This chapter deals with the experimental results of the objectives undertaken in the study. To assess the vulnerability in stochastic framework, it requires knowledge about the spatial and temporal variation in different elements at risk. Depending on the objectives of research, present study mainly focused on to explore the effect of temporal variation in land cover changes, population movement and vehicles frequency on road to generate vulnerability scenario.

5.1. Results of landcover classification

In order to analyse the effect of land cover change on vulnerability condition in time, two different years 1998 and 2006, LISS-III of IRS-1C images were classified into four different classes by using knowledge based classification technique (Figure 5.1a & 5.1b). Post classification change detection technique was applied to extract the changes that have occurred during these periods.



(a) (b)

Figure 5-1: Classified image of LISS-III (19-April 1998 & 30-April 2006).

5.1.1. Classification Accuracy

Accuracy assessment of both classified images was carried out to check the classification results obtained after using knowledge based classification as discussed in section 4.6. For each class, producer and user accuracy was calculated. Overall classification accuracy of 84% and 83% was obtained respectively with overall kappa statistics of 0.79 and 0.785. Detailed of accuracy assessment reports are shown in the table 5-1.

Table 5-1: Classification accuracy of LISS-III (1998)

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Forest	19	20	17	89.47%	85.00%
Barren land	23	21	19	82.60%	90.47%
Agriculture land	18	21	17	94.44%	80.95%
Scrub	22	20	16	72.72%	80%
Total	82	82	69		

Table 5-2: Classification accuracy of LISS-III (2006)

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Forest	15	20	15	100	75%
Barren land	26	21	19	73.07%	90.47%
Agriculture land	17	21	16	94.11%	76.19%
Scrub	24	20	18	75%	90%
Total	82	82	68		

5.1.2. Change Detection Result

Post classification change detection technique was applied to analyse the change in all land cover classes. Change detection matrix was calculated to quantify the percentage of change in area from one class to other class (Shown in table: 5-3).

Table 5-3: Change Detection matrix for different land cover classes

Class Name	**Forest (ha.) (1998)**	**Barren Land (ha.) (1998)**	**Agriculture Land (ha.) (1998)**	**Scrub Land (ha.) (1998)**	**Row Total (ha.) (1998)**	**Class Total (ha.) (1998)**
Forest (2006)	31.07	0.48	0.72	3.33	35.57	35.57
Barren Land (2006)	17.2	238.54	39.23	43.49	322.98	322.98
Agriculture Land (2006)	3.41	93.16	128.23	25.42	250.22	250.22
Scrub Land (2006)	2.67	7.55	2.18	84.43	96.83	96.83
Class Total	38.87	339.73	170.36	156.64		
Class Change	7.8	101.19	42.13	72.21		
Image Difference	-3.3	-16.75	79.86	-59.81		

Change detection results clearly indicate that there are major land cover changes taken place in the study region during 1998 to 2006. The agriculture land has increased by approximately 47% of its area where as forest class, barren land and scrubs has decreased by 8.5%, 5% and 38.20% of its area.

The change detection result also indicated that the 8.8%, 27.42% and 16.23% area of forest, barren land and scrub land has become converted into agriculture land where as 23% area of agriculture land has changed into barren land. Total forest area in 1998 was 38.87 hectare of which 4.42%, 6.86%, and 8.8% has become changed into barren land, scrub land and agriculture land respectively.

5.2. Vulnerability assessment of vehicles along road

To assess the vulnerability of vehicle on road it is required having knowledge about expected no of vehicle at any given time on the examined road section. In present study seven sections each of one kilometer, distance of road stretch were examined. To assess the vulnerability of vehicle on road section, two hour time resolution was taken except in morning (8:00 to 10:00hrs) and evening (16:00 to 18:00 hrs) where one hour resolution was taken as discussed in section 4.10.

Table 5-4: Showing the average vehicles density on different sections of road at different time of the day

Road section	6:00 – 8:00hrs	8:00 – 9:00hs	9:00-10:00hrs	10:00-12:00hrs	12:00-14:00hrs	14:00-16:00hrs	16:00-17:00hrs	17:00-18:00hrs	18:00-20hrs	20:00-08:00hrs
1.	58	119	123	137	124	135	128	119	113	00
2.	67	117	128	141	131	137	135	124	119	00
3.	72	114	124	138	128	135	132	121	116	00
4.	68	111	123	133	124	127	128	121	111	00
5.	59	97	103	116	102	109	95	104	89	00
6.	56	91	96	109	102	111	89	97	81	00
7.	59	94	93	111	107	114	92	102	83	00

Expected number of vehicle at any given time zone for each section of road was calculated by using the formula as discussed in section 4.10.1. Results obtained is summarised in figure 5-2 and in table 5-5.

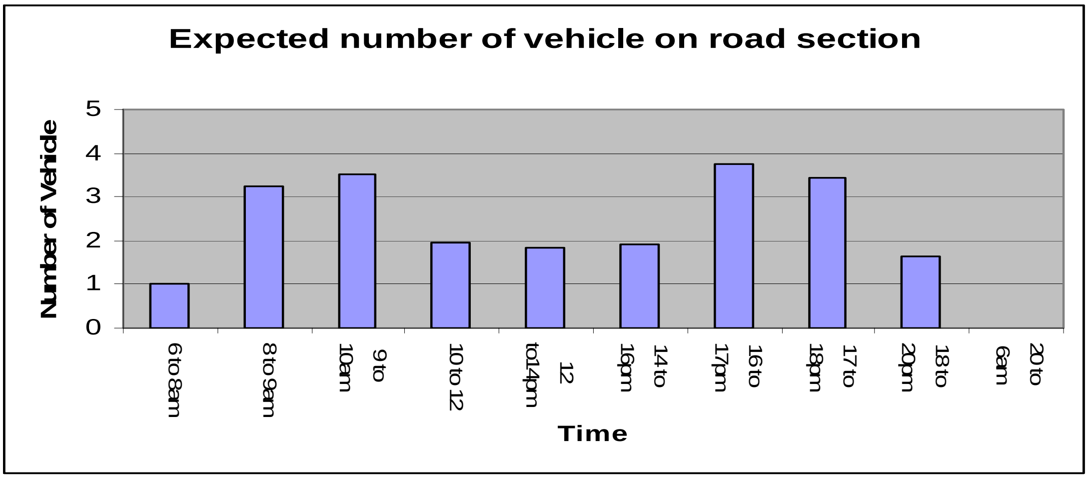


Figure 5-2: showing the expected number of vehicles during different time of the day

Above graph indicates that the number of vehicles at any time on road section varies greatly during different time of the day. The result also indicates that the maximum movement of vehicle on road section is at morning 8:00 to 10:00hrs and evening 16:00 to 18:00 hrs where as less than one vehicle can be expected at morning time 6:00 to 8:00hrs. Rest of the day the traffic density is respectively constant and on an average two vehicles are expected that will always be present during given time period. Night time vehicle movement is not allowed in the area thus the vulnerability of vehicle on road section is expected to be zero during night time (Results of the other sections has been summarised in Appendix -3).

Table 5-5 expected number of vehicle on road section at different time of the day.

Time	Road length	Travel time in minutes	Expected vehicle
6:00- 8:00hrs	1 km	1.71	1.02
8:00- 9:00hrs	1 km	1.71	3.25
9:00-10:00hrs	1 km	1.71	3.53
10:00- 12:00hrs	1 km	1.71	1.97
12:00-14:00hrs	1 km	1.71	1.82
14:00-15:00hrs	1 km	1.71	1.92
15:00-16:00hrs	1 km	1.71	3.76
16:00-17:00hrs	1 km	1.71	3.45
17:00-18:00hrs	1 km	1.71	1.65

From the above calculation it was found that the maximum expected vehicle loss will not exceed more than four in general traffic condition. Thus to assess the vehicle vulnerability on part of road track at different time of the day four vehicles was taken as a maximum threshold. In order to assess vehicle vulnerability similar concept proposed by Liu, (2006) to assess population vulnerability was applied.

$$FV_{vec} = 1 - \exp(-0.429 \times V_{vec}) \quad \textbf{5-1}$$

where,

FV_{vec} = Vulnerability value of vehicles.

V_{vec} = Expected vehicle value.

Poisson distribution curve as discussed in equation 5-1 was applied to calculate the vehicle vulnerability on different road section at different time of the day. Results obtained are shown below in table 5-6.

Table 5-6: Showing vulnerability of vehicles along different section of road at different time of the day.

Road section	06 to 08hrs.	08 to 09 hrs.	09 to 10 hrs.	10 to 12 hrs.	12 to 14 hrs.	14 to 16 hrs.	16 to 17 hrs.	17 to 18 hrs.	18 to 20 hrs.	20 to 06 hrs.
1.	0.30	0.77	0.78	0.56	0.52	0.56	0.79	0.77	0.50	0
2.	0.33	0.76	0.79	0.58	0.54	0.56	0.80	0.78	0.52	0
3.	0.35	0.75	0.78	0.58	0.54	0.56	0.80	0.77	0.50	0
4.	0.34	0.72	0.78	0.56	0.54	0.54	0.79	0.77	0.50	0
5.	0.30	0.70	0.72	0.50	0.45	0.47	0.69	0.71	0.40	0
6.	0.29	0.67	0.69	0.47	0.45	0.50	0.66	0.69	0.38	0
7.	0.30	0.69	0.67	0.50	0.47	0.50	0.67	0.71	0.40	0

Results obtained above clearly indicates that the vulnerability of vehicle to landslide events on road section varies through-out the day and it depends on the number of vehicle present at any moment of time on a given section of road. It was observed that in study region the vulnerability of vehicle is very high between morning 08:00 to 10:00hrs and evening 16:00 to 18:00 hrs due to high traffic density on road section. It was also noticed that the vulnerability of vehicle is constant between 10:00 to 16:00 hrs and at 18:00 to 20:00 hrs. In the study region the vulnerability of vehicle is comparatively less at morning time between 06:00 to 08:00 hrs. Different vulnerability scenarios were developed to assess the vulnerability of vehicle on different part of road sections as shown below in the figure 5-3.

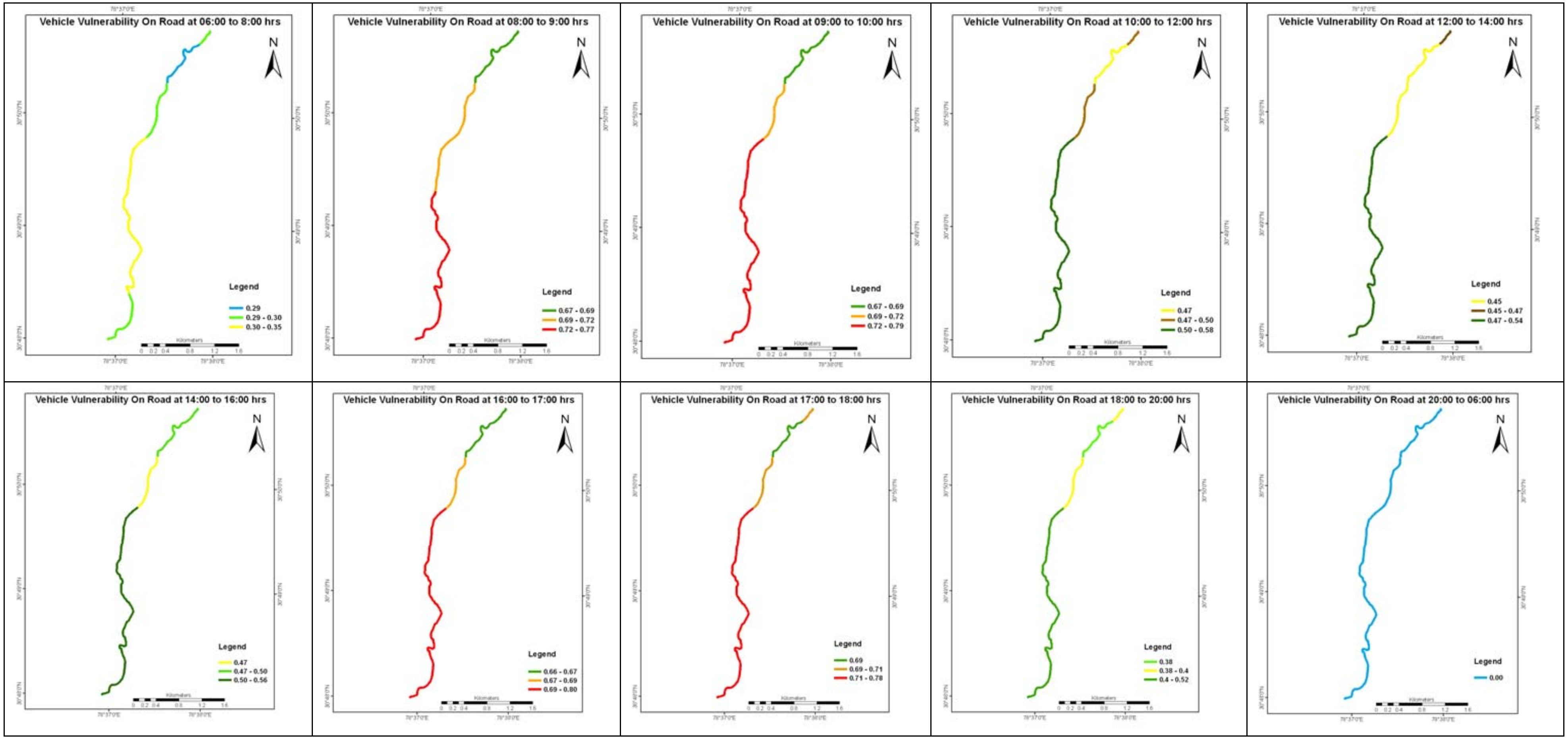


Figure 5-3: vulnerability of vehicle on different part of road section at different time of the day.

5.3. Vulnerability assessment of buildings

Vulnerability of building in the area was assessed on the basis of expected potential maximum loss. To assess vulnerability of buildings, 2000 Rupees (Indian currency) was considered as maximum threshold. This upper threshold was decided on the basis of 10000 meter^2 area, damage of buildings might not exceed 10000 × 2000 Rupees. In order to assess building vulnerability it was assumed that in 1000 meter^2 area landslide will destroy all buildings present in that area. It was also assumed that the mean construction cost for each building is same; as maximum buildings in the area are mostly single storied and construction material used in each building is also similar. To calculate the vulnerability whole area was divided into 100 meter × 100 meter cell size by taking assumption that the one single landslide event will not exceed more than 10000 square meters of area. Value of buildings in each cell was calculated after multiplying the area of buildings in each cell to its mean construction coast of the buildings. Mean construction cost per square meter was considered 1000 Rupees on the basis of secondary information obtained from the concerned departments. Vulnerability of buildings for each cell was assessed by applying the concept proposed by Liu, (2006) that the property vulnerability fits a logarithmic increase. Following sigmoid curve equation applied by Lie, 2006 was used to transform the value of building on 0 to 1 scale.

$$FV_1 = 1/[1 + \exp(-1.25 \log(V_1 - 2))] \qquad \textbf{5-2}$$

where,

FV_1 = Property vulnerability.

V_1 = Value of property.

The above formula was used to assess the vulnerability of building in settlement area. In doing so, the data for the building value was rescaled on a linear scale between (0 - 2000) in a similar way as applied by Liu, (2006). New co-efficient was derived by using regression analysis and by this modified transformed model; vulnerability of buildings at different cells was assessed.

$$FV_{Build} = 1/[1 + \exp(-1.463 \times \log(V_{Build}) + 2.26] \qquad \textbf{5-3}$$

Some of the obtained vulnerability values of buildings at different locations are summarized below in table (5-7).

Table 5-7: showing vulnerability value of buildings.

Locations	V_{build} Maximum loss of Property (buildings)	FV_{build} Vulnerability Value of V_{build}
1.	264.29	0.78
2.	647.14	0.86
3.	1092.93	0.90
4.	2000.00	0.93

Results obtained after using equation 5.3, indicates that property (buildings) vulnerability of an area follow logarithmic increase. Vulnerability value FV_{Build} will reach its maximum 1, when expected property (buildings) loss V_{Build} exceeds its maximum threshold 2000, where as vulnerability FV_{Build} is near about 0.6, if V_{Build} is 100. Obtained value of FV_{Build} was used to prepare building vulnerability map (shown in figure 5-4) to delineate the vulnerability condition of building at different locations in the study region.

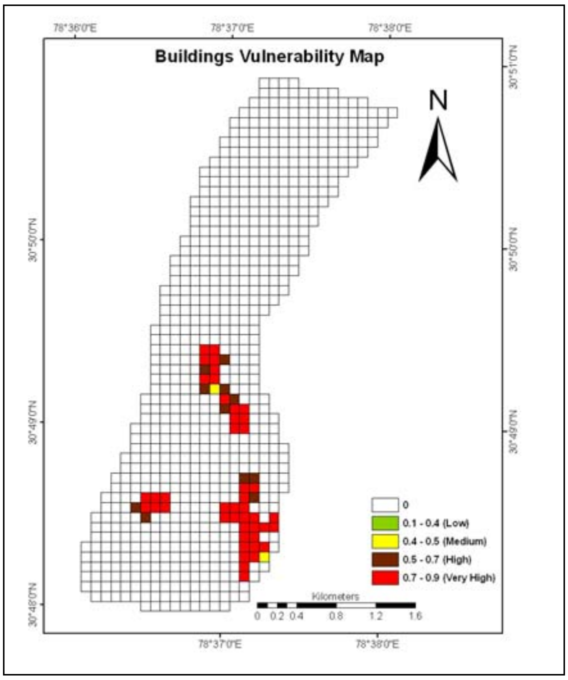


Figure 5-4: Vulnerability of buildings at different locations

Obtained results also indicate that the property (buildings) vulnerability of an area is very much dependent on the accumulation of property (buildings) in that area.

5.3.1. Vulnerability assessment of population in buildings

Vulnerability of population in different buildings structures at different time of the day was assessed. To quantify the population vulnerability, maximum threshold of 70 people was considered on the basis of field knowledge of the area. Poisson curve model as discussed in equation 4.5 was applied to calculate population vulnerability. In doing so, the formula applied by Liu, (2006) was modified according to the new threshold value by using similar approach as discussed in section 5.3.

$$FV_{Pop} = 1 - \exp(-0.025V_{Pop}) \quad \textbf{5-4}$$

Where,
FV_{Pop} = Population vulnerability value
V_{Pop} = Population value
By using the above mentioned transformation function vulnerability of population for each cell at different time of the day was assessed (Shown in table 5-8).

Table 5-8: Showing variation in the population vulnerability at different time of the day.

Location	V_{pop} (6:00-8:00)hrs	FV_{pop} (6:00-8:00)hrs	V_{pop} (12:00-14:00)hrs	FV_{pop} (12:00-14:00)hrs	V_{pop} (18:00-20:00)hrs	FV_{pop} (18:00-20:00)hrs
1.	11	0.24	5	0.12	9	0.20
2.	27	0.49	10	0.22	21	0.41
3.	39	0.62	25	0.46	34	0.57
4.	68	0.81	23	0.44	52	0.73

Result obtained after using equation 5.4 clearly indicates that the population vulnerability of an area is dependent on its population density. More the population density of an area greater would be the people's vulnerability in that area to landslide in comparison to low population density area. The study was carried out to assess the vulnerability of population to landslide hazard in a different period of time. It was observed that the vulnerability of population of an area is not constant always, but it varies greatly during the course of the day. In present study three different categories of buildings, residential, schools and offices were studied to quantify the population vulnerability at different time of the day. It was found that the population vulnerability in residential buildings is maximum at night time between 20:00 hrs to morning 8:00 hrs due to maximum accumulation of people in there houses. Results obtained also indicate that during this hour vulnerability value is generally constant because of less spatial variation in the population movement. It was noticed that the population vulnerability value fluctuate rapidly during morning time 8:00 to 10:00 hrs and at evening 16:00 to 18:00 hrs due more spatial variation in populations where as vulnerability of people in residential area between 10:00 to 16:00hrs is respectively constant and low. In case of population vulnerability in schools and offices, results showed that probability of loss of people is very low between evening 17:00 hrs to morning 09:00 hrs. This is because of very less presence of people during that time in these places. It was also observed that the vulnerability of population between morning 9:00hrs to evening 17:00hrs is very high due to high density of population at these locations. Eight different scenarios for population vulnerability maps were generated in order to quantify the vulnerability value of population at different buildings as shown below in figure 5-5.

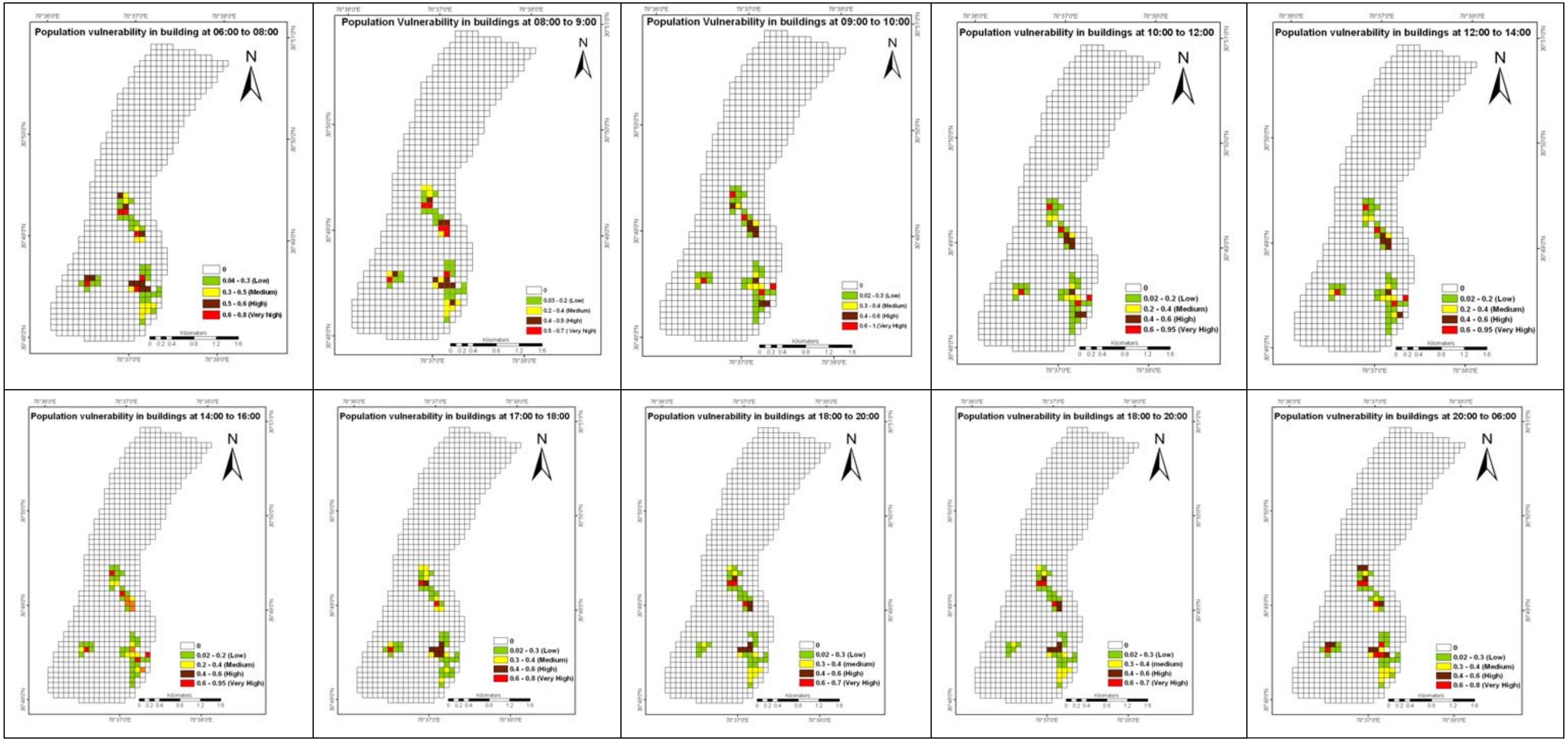


Figure 5-5: population vulnerability scenario in different locations at different time of the day.

5.3.2. Vulnerability assessment of Land cover

In present study land cover is also considered as one of the element at risk to landslide hazard which is stochastic in nature and changes in varying degree with change in time. Four different land cover class as discussed in section 4.4 was considered to analyse the vulnerability condition of these elements. Vulnerability of these elements was assessed on the basis of current land value in Indian currency. Maximum threshold 250 Rupees was taken to assess the vulnerability of various land cover classes. In doing so, barren land value and scrubs land value has been taken zero. This threshold was decided on the basis of current economic value of various land resource and it was assumed that in study area landslide event will not damage these property more than 10000×250 Rupees. Similar approach was applied as discussed in section 5.3 to obtained new coefficients for the property vulnerability model discussed by Liu, (2006).

$$FV_L = 1/[1 + \exp(-2.037(\log(V_L) + 2.15))] \qquad \textbf{5-5}$$

Where,

FV_L = Vulnerability value of land cover.

V_L = Value of land cover.

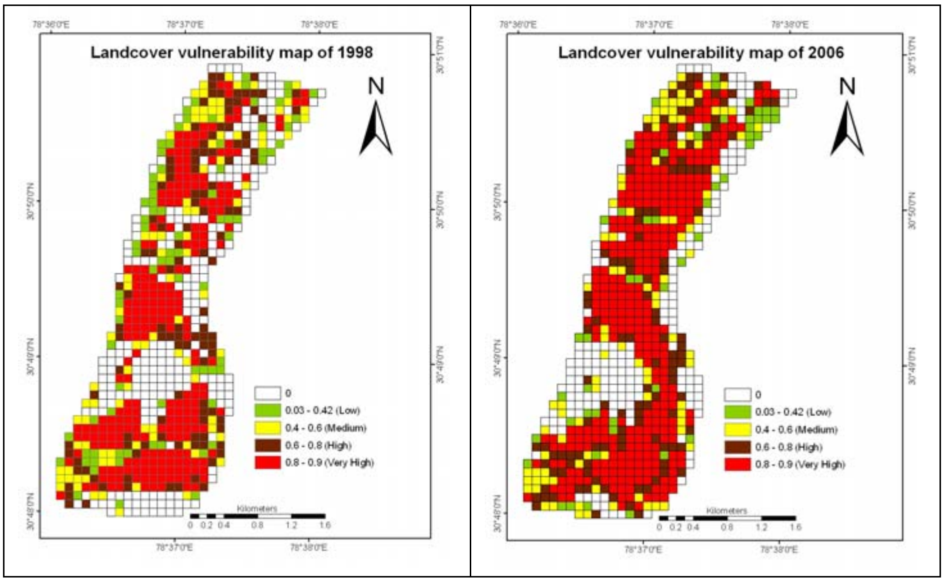


Figure 5-6: showing land cover vulnerability from 1998 to 2006

Results obtained above, indicate that the vulnerability of land cover class in the study area has changed from 1998 to 2006. It was observed that in some places the vulnerability of these classes has increased where as in some place it has decreased. Results showed that from 1998 to 2006 large portion of barren land (27.42%), scrub land (16.23%) and forest land (8.8%) area has been converted into agriculture land. Due to this, land value has increased on those areas where land value was comparatively less previously (Appendix-3). It was also observed that 23% area of agriculture land has been changed into barren land in the year 2006. This change indicates that the land value which was high in 1998 has decreased in 2006.

6. Disscussion and Recommendation

This study dealt with a stochastic approach to assess the vulnerability to landslide hazard. The study presented mainly focuses on addressing the vulnerability in the spatio-temporal domain. The dynamic nature of various elements at risk with time makes it a challenge to assess the vulnerability related with hazards like landslide. In this study a probabilistic approach was applied to model the vulnerability of these dynamic elements quantitatively. Not all the elements at risk change in similar way, some of these elements change more slowly, e.g. in months or years (land cover), whereas other elements change more frequently, e.g. in minutes, hours or days. In the present study both types of risk elements are considered when assessing vulnerability. The study proposes a post classification based change detection method, followed by a knowledge based classification of medium resolution satellite images to monitor land cover changes in a hilly terrain area in the Himalayan region. The objective was to extract land cover changes from temporal images and to gain information about which class has changed into another class and how vulnerability changed from one class to the other. Other elements at risk, such as population and vehicles on road were considered to assess vulnerability to landslides. A field based study was carried out to monitor the pattern of change of these elements at risk. Monetary values were used for property vulnerability, population density for population vulnerability and vehicle frequency for vehicle vulnerability, respectively. Empirical vulnerability models to assess property and population vulnerability as proposed by Liu, (2006) were applied to quantify the vulnerability of examined elements at risk for different time periods.

The obtained results indicate that the vulnerability of elements at risk to landslide varies greatly at different places and at different times of the day. This variation mainly was due to the dynamics of elements at risk. As an assumption we took in this study that the pattern of change in elements at risk will be similar throughout the years, although in reality such assumptions may not hold and uncertainty may arise due to environmental (change rainfall patterns) and social causes. In such a case the vulnerability result may lead to the wrong conclusions. To highlight the advantages and disadvantage of the present study a SWOT (Strong – Weak – Opportunity – Threat) analysis has been carried out.

6.1. SWOT analysis of the present study.

Every research work like the present research has its own advantages and disadvantages. To highlight the advantages and risks of the present study the SWOT analysis has been carried out.

Table 6-1: SWOT Analysis of the present study

INTERNAL FACTORS EXTERNAL FACTORS	**Strengths** 1. Provides a method for quantitative assessment of vulnerability. 2. Allows assessing vulnerability of the elements for any specific moment of time. 3.Considers spatio-temporal movement of elements at risk	**Weakness** 1. Subjective in nature and based on assumptions. 2. Requires a large set of real-time data (movements of elements at risk). 3. Does not consider the uncertainty due to environmental and social factors.
Opportunity 1. Probabilistic assessment of vulnerability is more reliable than the traditional qualitative approach. 2. Based on probabilistic theory the approach provides an integrated way to dealt with landslide vulnerability.	**SO strategies** 1. Based on long and profound theoretical background of probability theory this approach can be used to model the vulnerability more accurately. 2 Spatio-temporal analysis of the element at risk can help to predict the vulnerability at any future date.	**WO strategies** 1. The uncertainty in the element at risk can be modelled by taking advantages of probabilistic approach. 2. Other types of hazards can be considered
Threat 1. High uncertainty in the movement of elements at risk. 2. Lack of methods to validate the results.	**ST strategies** 1. Quantitative analysis of uncertainty can provide more comprehensive results.	**WT strategies** 1. It is very difficult to validate the vulnerability results. Long time observation can be helpful in this case. 2. Uncertain nature of vulnerability in absence of proper validation methods makes the even weaker.

6.2. Recommendations

The present study identified issues related to a detailed vulnerability assessment to landslide hazards. The study shows that vulnerability assessment of dynamic elements at risk can be satisfactorily approached by means of a stochastic approach. In this study some aspects related with stochastic vulnerability assessment has been un-touched due to time constraint and data constraint. Therefore the suggestions for future researcher are recommended below.

- Uncertainty in element at risk due to environmental and social factors should also be incorporated in the future vulnerability assessment study.

- Validation of results in case of landslide vulnerability is still an active area of research.

7. Conclusion

Chapter presents the conclusions arrived after the detailed study of stochastic vulnerability to landslide.

7.1. Conclusion

The main objective of the research was to "assess the stochastic vulnerability to landslides of an area on the basis of a dynamic modelling of different elements at risk". The study was undertaken over landslide prone area of Himalaya, India. Four different elements at risk *viz.*, population, vehicle on road, land cover, and building were considered. An important focus point was the spatial location of the element at risk to a particular hazard and time of the occurrence of events. The spatial and temporal uncertainty associated with the various elements at risk requires a stochastic analysis of vulnerability assessment. This leads to different vulnerability values for similar elements at risk at different times and different places. Another important aspect is that, vulnerability of an area is proportional to the property accumulation and population density in that area. A higher population density and property accumulation results in a higher vulnerability. Taking this into account, we assessed vulnerability of all the selected elements at risk to achieve the objectives of this research and to answer the proposed research questions accordingly.

What will be the best way to analyse the temporal images to extract dynamic feature contributing to landslide vulnerability?

Land cover class is also considered as one of the dynamic elements at risk to landslide which changes varying degree with time and play a major role in vulnerability study. Change in land cover class can be monitored from the temporal satellite images. Knowledge based classification with different ancillary information was applied to classify the satellite images. The reason is that traditional classification techniques are not very helpful in land cover categorisation in hilly and complex terrain conditions due to high variation in sun illumination conditions (Shrestha and Zinck, 2001). The classification accuracy was above 80%, which was sufficient to extract changes in land cover classes in hilly terrain conditions.

It was concluded from the result obtained after using knowledge based classification technique, in the hilly terrain condition due to high altitude variation and sun illumination condition Land cover identification is not only governed by its spectral signature. Thus the best way to incorporate expert's knowledge together with ancillary information to identify the classes which can help to improve the classification accuracy and further to identify the dynamic change in land cover classes from temporal images with the help of post classification technique.

How can stochastic vulnerability can be assessed?

To assess the vulnerability stochastically different dynamic element at risk (population, vehicle on road, buildings and land cover) were considered and there vulnerability was assessed. An important consideration in stochastic vulnerability assessment is that it requires a large amount of real-time data. In the present study, we used field knowledge and information extracted from satellite images and analyzed population accumulation at different times of the day at different locations, vehicle frequency on a part of a road track at different times and land cover change from one class to another class. The expected number of vehicles on the road and the population movement from one place to another at different times of the day were estimated by assuming that similar conditions apply throughout the year. We also assumed that all elements at risk present within the study area are equally vulnerable to landslide hazard and that every object and each person will be completely destroyed if the landslide will occur in the region. Criteria to assess the vulnerability were the monetary values for property loss, the average population density for population damage and the maximum number of expected vehicles on any moment of time on part of road track, respectively. On the basis of these criteria, threshold values for maximum damage were selected for each element at risk. The threshold value for elements at risk was transformed into a probability by using the sigmoid curve equation for property value and the Poisson curve equation for population density. With the help of these transformed values, vulnerability of all observed elements at risk was generated for different time zones.

Thus the stochastic vulnerability to landslide can be assessed through modelling the uncertainty in various dynamic elements at risk within the space and time.

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Appendix – 1

Showing the data file and name file generated during the process of rule based classification.

Data file

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22,2002.509277,0.27394828,79,49,86,109,agriculture
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Name file

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rules_set_06 - Notepad
File Edit Format View Help
class.                         |the target attribute

pixel value in of slope:  continuous.
pixel value in of dem:  continuous.
pixel value in of ndvi:  continuous.
pixel value in of green:  continuous.
pixel value in of red:  continuous.
pixel value in of nir:  continuous.
pixel value in of swir:  continuous.
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```

Appendix – 2

Field data 1: Information collected about population accumulation in different places at different time of the day from field survey.

	A	B	C	D	E	F	G	H	I	J	K
5	residential_house	5	3	2	2	2	2	3	3	4	5
1	Building_type	6am_to_8	8_to_9	9_to_10	10_to_12pr	12_to_14	14_to16	16_to_17	17_to_18	18_to_20	20_to_6am
2	residential_house	7	5	2	2	3	3	5	5	6	7
3	residential_house	3	2	1	1	1	1	2	2	2	3
4	residential_house	5	4	1	1	1	1	4	2	4	5
5	residential_house	5	3	2	2	2	2	3	3	4	5
6	residential_house	3	2	2	2	2	2	2	3	2	3
7	residential_house	4	3	1	1	1	1	3	2	3	4
8	hospital	7	16	19	21	11	9	7	7	7	7
9	school	1	1	56	56	56	56	1	1	0	1
10	school	2	2	194	194	194	194	2	2	2	2
11	office	1	1	19	19	19	19	19	1	1	1
12	office	1	12	12	12	12	12	12	1	1	1
13	office	2	17	17	17	17	17	17	2	2	2
14	office	2	2	19	19	19	19	19	2	2	2
15	residential_house	3	2	1	1	1	1	2	2	2	3
16	residential_house	5	4	2	2	2	2	4	3	4	5
17	guest_house	25	18	5	5	5	5	15	21	21	25

Field data 2: Information about vehicle movement on different examine road section collected during field survey.

	A	B	C	D	E	F	G	H	I	J	K
1	Road section					Observation Durations					
2	NH_108	at6_to_8	8_to_9	at9_to10	10_to12	12_to14	14_to16	16_to17	17_to18	18_to20	20_to6am
3	section1	58	119	123	137	124	137	128	119	113	0
4	section 2	67	117	128	141	131	137	135	124	119	0
5	section 3	72	114	124	138	128	135	132	121	116	0
6	section 4	68	111	123	133	124	127	128	121	111	0
7	section 5	59	97	103	116	102	109	95	104	84	0
8	section 6	56	91	96	109	102	111	89	97	81	0
9	section 7	59	94	93	111	107	114	92	102	83	0

Appendix-3

Expected number of vehicle calculated for different section of road for different time of the day.

Table 3.1: expected vehicle number of vehicle on road section 1.

Time	Road length	Travel time in minutes	Expected vehicle
6:00- 8:00hrs	1 km	1.71	0.83
8:00- 9:00hrs	1 km	1.71	3.39
9:00-10:00hrs	1 km	1.71	3.5
10:00- 12:00hrs	1 km	1.71	1.95
12:00-14:00hrs	1 km	1.71	1.76
14:00-15:00hrs	1 km	1.71	1.95
15:00-16:00hrs	1 km	1.71	3.65
16:00-17:00hrs	1 km	1.71	3.40
17:00-18:00hrs	1 km	1.71	1.61

Table 3.2 expected vehicle on road section 2.

Time	Road length	Travel time in minutes	Expected vehicle
6:00- 8:00hrs	1 km	1.71	0.95
8:00- 9:00hrs	1 km	1.71	3.34
9:00-10:00hrs	1 km	1.71	3.65
10:00- 12:00hrs	1 km	1.71	2.00
12:00-14:00hrs	1 km	1.71	1.86
14:00-15:00hrs	1 km	1.71	1.95
15:00-16:00hrs	1 km	1.71	3.84
16:00-17:00hrs	1 km	1.71	3.53
17:00-18:00hrs	1 km	1.71	1.69

Table 3.3: expected vehicle on road section 4.

Time	Road length	Travel time in minutes	Expected vehicle
6:00- 8:00hrs	1 km	1.71	0.97
8:00- 9:00hrs	1 km	1.71	3.16
9:00-10:00hrs	1 km	1.71	3.50
10:00- 12:00hrs	1 km	1.71	1.90
12:00-14:00hrs	1 km	1.71	1.76
14:00-15:00hrs	1 km	1.71	1.80
15:00-16:00hrs	1 km	1.71	3.64
16:00-17:00hrs	1 km	1.71	3.44
17:00-18:00hrs	1 km	1.71	1.58

Table 3.4 expected vehicle on road section 5.

Time	Road length	Travel time in minutes	Expected vehicle
6:00- 8:00hrs	1 km	1.71	0.84
8:00- 9:00hrs	1 km	1.71	2.76
9:00-10:00hrs	1 km	1.71	2.93
10:00- 12:00hrs	1 km	1.71	1.65
12:00-14:00hrs	1 km	1.71	1.45
14:00-15:00hrs	1 km	1.71	1.55
15:00-16:00hrs	1 km	1.71	2.70
16:00-17:00hrs	1 km	1.71	2.96
17:00-18:00hrs	1 km	1.71	1.19

Table 3.5: Expected number of vehicle on road section 6.

Time	Road length	Travel time in minutes	Expected vehicle
6:00- 8:00hrs	1 km	1.71	0.80
8:00- 9:00hrs	1 km	1.71	2.59
9:00-10:00hrs	1 km	1.71	2.73
10:00- 12:00hrs	1 km	1.71	1.55
12:00-14:00hrs	1 km	1.71	1.45
14:00-15:00hrs	1 km	1.71	1.58
15:00-16:00hrs	1 km	1.71	2.53
16:00-17:00hrs	1 km	1.71	2.76
17:00-18:00hrs	1 km	1.71	1.15

Table 3.6: Expected number of vehicle on road section 7.

Time	Road length	Travel time in minutes	Expected vehicle
6:00- 8:00hrs	1 km	1.71	0.84
8:00- 9:00hrs	1 km	1.71	2.68
9:00-10:00hrs	1 km	1.71	2.65
10:00- 12:00hrs	1 km	1.71	1.58
12:00-14:00hrs	1 km	1.71	1.52
14:00-15:00hrs	1 km	1.71	1.62
15:00-16:00hrs	1 km	1.71	2.62
16:00-17:00hrs	1 km	1.71	2.90
17:00-18:00hrs	1 km	1.71	1.18

Table blow showing the changes in land value from 1998 to 2006.

Table: 3-7. Result showing change in land value in different examined land cover classes from 1998 to 2006.

id_1	Area_C1	Area_C2	Area06_C3	Area06_C4	area98_C1	Area98_C2	Area98_C3	Area98_C4	cost98_grd	Cost06_grd
4	0	2101.05	0	1400	0	0	0	3500	0	0
5	500	3301.6499	800	2200	800	1900.38	1200	2900	32000	21250
6	1700	4502.25	2300	1500	2000	4600.9199	1200	2200	35000	61750
7	1300	2501.25	1100	5100	1400	400.07999	600	7600	18500	30750
8	0	100.05	0	9900	0	0	0	10000	0	0
9	200	1600.8	200	8000	200	1800.36	0	8000	500	5500
10	1200	1600.8	1200	4100	1200	700.14001	1200	5000	33000	33000
11	0	0	0	5500	0	0	0	5500	0	0
12	0	0	0	2800	0	0	0	2800	0	0
13	3300	0	200	1500	2700	0	400	1900	16750	13250
14	7600	0	1400	1000	7300	0	1300	1400	50750	54000
15	8900	0	1100	0	5200	0	4800	0	133000	49750
16	7100	0	2400	500	6400	0	3100	500	93500	77750
17	5500	0	0	4500	4500	0	0	5500	11250	13750
18	2300	200.10001	0	7500	2500	200.03999	0	7300	6250	5750