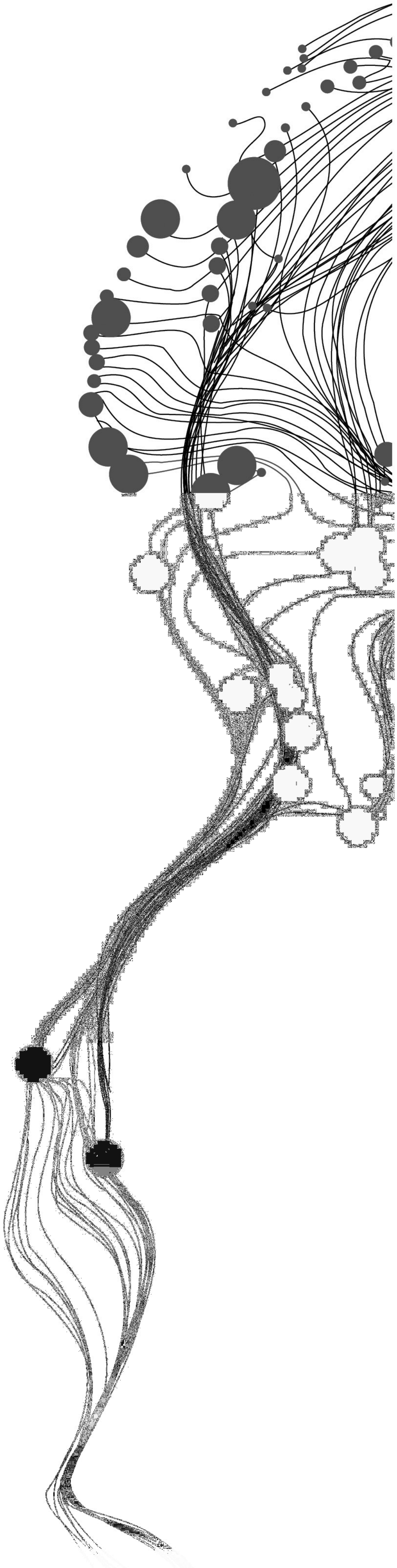
ENVIRONMENTAL VULNERABILITY ASSESSMENT OF ECO-DEVELOPMENT ZONE OF GREAT HIMALAYAN NATIONAL PARK, HIMACHAL PRADESH, INDIA

CHITTARANJAN SINGH
MARCH, 2012

SUPERVISORS:
Drs. N. C. Kingma
Dr. K.K. Das
Dr. S. Nandi



ENVIRONMENTAL VULNERABILITY ASSESSMENT OF ECO-DEVELOPMENT ZONE OF GREAT HIMALAYAN NATIONAL PARK, HIMACHAL PRADESH, INDIA

CHITTARANJAN SINGH
Enschede, The Netherlands, MARCH, 2012

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Hazards and Disaster Risk Management

SUPERVISORS:
Drs. N. C. Kingma
Dr. K.K. Das
Dr. S. Nandi

THESIS ASSESSMENT BOARD:
Dr. Ir. Alfred Stein (Chair)
Dr. D. N. Pant (External Examiner)

ABSTRACT

The Great Himalayan National Park (GHNP), located in Western Himalayan region, is a key mountainous ecosystem prone to environmental vulnerability due to anthropogenic stress and natural disasters such as landslide and forest fire. The environmental vulnerability of GHNP has been assessed using remote sensing (RS) and geographical information system (GIS) technologies. In order to quantify the environmental vulnerability, a numerical model using spatial principle component analysis (SPCA) is developed. This model considered five factors including landslide, forest fire, forest density, population density and landuse landcover change. The environmental vulnerability integrated index (EVSI) of the study area is calculated for 1990, 2000 and 2010 having values 2.44, 2.61, 2.88 respectively. The results showed an increasing trend of environmental vulnerability in the region. Based on the numerical outputs, the vulnerability of the region is categorized into five classes: potential, slight, light, medial and heavy by using cluster principle. The primary factor responsible for an increasing vulnerability is landuse landcover change in the study area due to human social economic activities like upcoming hydro power projects.

The outcome of the study shows that integration of remote sensing, GIS and SPCA can be effectively used to quantify and assess environmental vulnerability of the region. The future challenge lies in considering more number of relevant factors of change like climatic and socio – economic conditions thus providing more informed insights into the state of environmental vulnerability and related dynamics.

Keywords: *GHNP, environmental vulnerability, RS, GIS, SPCA, EVSI*

ACKNOWLEDGEMENTS

My thesis could not have come through without the help, inspiration and support of many people during all the stages of my research.

First and foremost I would like to thank my M Sc. supervisor Dr K.K. Das. He has always supported me with his good suggestions and discussion.

I feel highly indebted to my MSc. Co-supervisor Dr. S. Nandi for his inspiration and timely support.
Words are not enough to express my sincere gratitude to my ITC supervisor Drs. N. C. Kingma.
Critical analysis of research component and scientific writing carried by her, were instrumental in achieving the ultimate objective. The valuable feedback guidance and support have immensely helped me in successful completion of this research.

I am extremely grateful to program coordinator (IIRS) Dr. P.K.champati Ray for his constant support and encouragement Drs Michiel Damen program coordinator from (ITC) is also remember here for his love and care.

I acknowledge with thanks to all the persons who gave me help during my project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Environment, development and sustainability are the most significant issues of concern worldwide. Due to ever ending demand of resources and development, the environment of earth is in danger. Pressure on the environment is increasing due to exponential population growth and development. Hence protected areas are becoming more crucial for biodiversity conservation and ecosystem services. Anthropogenic activities are making protected areas susceptible to loss and degradation.

The Himalayas are one of the top ecologically fragile and economically underdeveloped part of the world (Tiwari, 2000).The ecosystem is highly stressed due to increasing population and agricultural expansion and developmental pressure is adding more. Therefore Great Himalayan National Park (GHNP) becomes one of the most important conservation areas in India. The people around the area are historically dependant on GHNP resources for their livelihood. The economy of these people depends on agriculture, livestock and forest products and agriculture and livestock economy is deeply linked with forests (Nagia and Kumar, 2001).The forests, grasslands and scrub vegetation around the habitat area of people, though degraded, meet a considerable proportion of biomass demand per year. Furthermore, the development activities like construction of hydro projects and transport network have imposed devastating impact on the local ecosystem. Moreover the conflicts over natural resources, increasing population pressure, lack of implementation and efficient planning are the major causes of depletion of natural environmental quality in GHNP. Once the local ecosystem is denuded and degraded, it will take a long time to recover.

This research is on assessing the environmental vulnerability, effect of stress factors on the local environment and the response and intensity of vulnerability on local environmental system. Environmental vulnerability assessment is an important tool to know how natural and anthropogenic stresses are affecting the local environment. For this first we need to find the indicators having negative impacts on the local environment in the region. After that their effect can be quantified, aggregated and ranked according to their impact. The environmental vulnerability assessment is used for comprehensive evaluation of the resource system affected by natural condition and intervened by human activities (Fan et al., 2009). Moreover it is an important way to find out potential causes of environmental vulnerability, diagnosing them with practical solution and developing capacity and future forecast of threats to environment and reduction of risk.

The present study aims at assessing the environmental vulnerability of Eco-development zone of Great Himalayan National Park (GHNP), Kullu, Himachal Pradesh over three time period (1990, 2000 and 2010), to analysis the trend of environmental vulnerability in the region and suggest remedial measures to overcome the problem. And this assessment of environmental vulnerability can be of great value to the park official and policy makers for further conservation process and sustainability of the study area. The figure 1-1 shows the photographs taken during field work.

(a)

(b)

(c)

(d)

(e)

(f)

Figure 1-1: (a) and (b) Landslides (c) and (d) Agricultural expansion and Forest fire (e) and (f) Destructions due to construction of hydro projects

1.1. Research Problem

The environmental degradation due to aggravated impacts of rapidly increasing population pressure and developmental activities pose great menace to ecosystem and biodiversity of GHNP. The human population living both inside and outside the GHNP region claim traditional rights to use GHNP resources (Pandey and Wells, 1997) the lack of information and active participation of local peoples is another hurdle in the efficient implementation of conservation efforts. The conflict between conservation and livelihoods has become integral part of all conservation planning of environment (Sabbwrwal and Chhatre, 2003). On other hand larger interest of development has edged out the lager interest of conservation. The GHNP management is doing strenuous work for conservation since park has established in 1984 and Government wants to utilize of water resources for generation of electricity as renewable sources of energy within and vicinity of GHNP. Through a peculiar sequence of events in 1999, a patch of 10 • • ? of the Park area was carved out to make way for the Parvati hydro-electric power station (Sabbwrwal and Chhatre, 2003) this dichotomy further made the conservation efforts in GHNP region difficult and National Park is losing its function of protection and conservation. The environment has become highly vulnerable as it will be higher in future, since no vulnerability assessment has yet been conducted. Besides the study on integrating vulnerability and regional planning is quite limited and rare (Metzger et al., 2006). An evaluation of the environmental response is needed to comprehensively determine the effects of developmental activities in the study area and this can be achieved through the present study.

1.2. Research objective

To assess the environmental vulnerability in the eco-development zone of Great Himalayan National Park and to analyse the change in the trend of environmental vulnerability in the study area.

1.2.1. Specific objectives

- To identify the factors which are responsible environmental vulnerability in the study area
- To evaluate the applicability of Spatial Principal Component Analysis for assessing the environmental vulnerability during three time periods.
- To analyse the spatial change trend distribution of environmental vulnerability in the study area.
- To recommend alternatives for GHNP authority in order to improve the effectiveness of conservation efforts.

1.2.2. Research Questions

- What are the factors responsible for environmental vulnerability in the study area?
- What is the change pattern of the environmental vulnerability in the study area?
- What are the alternative measures available for decreasing the environmental vulnerability in the study area?

2. LITERATURE REVIEW

2.1. Vulnerability definition and concept

Multiple definitions and different conceptual frameworks of vulnerability exist as several different schools of thought exist on vulnerability. According to UN-ISDR terminology, vulnerability is "The condition determined by physical, social, economic and environmental factors or process which increases the susceptibility of a community to the impact of hazards" (Anon 2009b). Vulnerability can also be defined as "The degree of loss to a given element at risk or set of element at risk resulting from the occurrence of a natural phenomenon of a given magnitude" (Anon, n.d.).Although vulnerability have multiple elements in its definition but it is most simply defined as the probability that future condition will be in negative direction (Bradley and Smith , 2004). Chambers, (1989) expressed two sides of vulnerability viz. external and internal, related to exposure to external shocks and stresses and the capacity to cope with them respectively. Vulnerability can also be expressed as external impacts caused by environmental changes (Kvaerner et al. 2006).In literature, ecological vulnerability reflects the degree of sensitivity of habitats, community and species to environmental changes (Nilsson and Grelsson, 1995).

The vulnerability is a function of the character, magnitude and rate of eco-environment change and variation to which a system is exposed, its sensitivity and its adaptive capacity (Boori and Amaro, 2010) According to Tixier et al., (2004) the environmental vulnerability accounts for three main factors viz. Natural environment, people around and the built-up environment by human. The environmental vulnerability is related with risk of damage to the natural environment, and entities at risk include ecosystem, population and physical and biological processes and these can be affected by anthropogenic activities (Kaly et al., 2002).Hence in a nutshell, the concept of vulnerability can be precisely expressed in terms of the exposure, sensitivity and adaptive capacity of the system.

In context of environment, a state may be defined as environmentally vulnerable if its ecosystem, species and process are susceptible to damaging anthropogenic and natural pressures and these pressures are high (Kaly et al., 1999).The environment vulnerability is concerned with the damage to the natural environment due to the various stress factors in a particular region. In the case of the present study, the vulnerability is expressed as threat or negative impact to protected area and its resources.

2.1.1. Environmental vulnerability assessment

The issue of environmental vulnerability to external and internal stress factor has been subject of active research and several methods have been reported to analyze vulnerability. Some study used mathematical modelling (Wilson et al., 2005), and others used Analytical Hierarchal Process (Wang et al., 2008), Fuzzy Evaluation Method (Enea and Salemi 2001), Artificial Neural Network (Dzeroski 2001), comprehensive evaluation met (Goda and Mastuoka, 1986), grey evaluation method (Hao and Zhou, 2002) Spatial Multi-criteria evaluation (SMCE) is also used for environmental vulnerability assessment (Enete et al., 2010). These methods are used for quantitative analysis of vulnerability. The variables used in above models are not easy to acquired and operated. Some of these methods are based on Analytical Hierarchy Process which depends on user evaluation for weight age of the factors and this dependency can directly affect the final results. Main disadvantage of AHP is that if the scale is changed, the numbers at the end will also change (Geoff., 2004).

Environmental vulnerability analysis is innately multidimensional. It is necessary to determine the interrelationship of all factors of vulnerability in order to assess over all environmental vulnerability. PCA or factor analysis is a robust statistical analysis technique to reduce the dimensionality of data and extract the innate relationship by developing composite variables. However PCA is not linked spatially. On the other hand, GIS is able to map several variables and their distributions, but often find it difficult to relationship among different factors. The integration of GIS and PCA hereafter referred as spatial principal component analysis (SPCA) can provide an insight on the spatial tendencies of the factors.(Anon n.d.). SPCA have been applied in a wide array of studies in environmental studies for revealing the relationships among different indicators (Calais et al., 1996; Yu et al 1998). Zhi et al. (2009) used spatial principal component for determine effects of land use change on environment quality. The spatial principal component analysis has been found as a good method for environmental vulnerability assessment (Li et al., 2006) which is the modification of the Principal component analysis (PCA). In this method environmental vulnerability index is calculated on the basis of coefficients of linear correlation and uses coefficients of linear correlation which offers the possibility to weigh a contribution of factor (Parinet et al., 2004) which is totally dependent on mathematical calculation and does not have any user dependency. Hence for accuracy of results in present study, SPCA has been used for environmental vulnerability assessment.

2.1.2. Application of Remote Sensing and GIS in Environmental vulnerability assessment

Vulnerability has been associated with spatio-temporal dimensions. Remote Sensing and GIS played a great role on extraction and preparation of the environmental vulnerability attributes (Hyandye et al., 2008). Numerous studies of vulnerability assessment have been carried out using RS and GIS tools (Wang et al., 2008); Anthony and Li, 1998) states that integration of RS and GIS provides an excellent framework for data capture, storage synthesis, measurement, and analysis, all which are essential to eco-environment analysis. These methods have also been used in determining priority location for conservation (Pressey and Taffs, 2001). Some researchers used GIS to analyze vulnerability from development pattern (Mehaffey et al., 2008). Remote sensing ,GIS and numerical modelling has been developed as a powerful tool for ecological environment assessment (Kristov., 2004).

2.1.3. A review of Local environmental Research

On the basis of qualitative analysis and existing knowledge, factors are chosen for environmental vulnerability assessment. The selection of evaluation criteria is critical for the precise evaluation of environmental vulnerability. The Factors chosen are Land Use Land cover change, Forest canopy Density, Population Density, Forest Fire and Landslides. These are the main factors which responsible for major contribution in imposing negative impact on local environment. In the Study area, the landscape transformations have accelerated due to various human activities and there have been increase in habitation/agriculture/orchard and other land use with a corresponding decline in land cover and with increasing population pressure and agricultural expansion and developmental activities aggravates it further. The following table show the List of Hydro projects planned for 11th five year plan.

Table 1:List of hydro projects project planned for commissioning during 11th five year (2007-12) around the study area. (Source: *Department of Environment, science and Technology Government of Himachal Pradesh*)

Sr. No.	Name of project	Name of Basin	Installed Capacity(MW)
1	Sainj	Beas	100.00
2	Parvati-1	-do-	750.00
3	Parvati-2	-do-	800.00
4	Pravati-3	-do-	501.00
5	Largi	-do-	123.00
6	Thrithan	-do-	18.00

Constructions of these hydro projects have damaging impact on natural environment of area. Besides this, unscientific & illegal dumping along river banks and forest area have deteriorated and destroyed the ecosystem and biodiversity of the region (Anon., 2009a).These facts proved that the natural forest covers are removed considerably and replaced by human managed systems. The land cover land use mapping is done by visual interpretation, due the terrain complexity in Western Himalaya the spectral signature is influenced by many factors viz. slope, aspect and elevation which can lead to showing same reflectance to different object and different reflectance for same objects.

Forest fire is also a major factor for environmental degradation. The forest fire poses a threat not only to the forest wealth but also disturbing the ecology and environment of study area. For quantifying the fire hazard, fire risk zonation has been done. Fire risk zonation maps are obtained by integrating different variable with the help fire model supported by Analytical Hierarchal Process. The number of studies on spatial modelling for fire risk zonation has been done (Jain et al., 1996; Porwal et al., 1997; Roy & Porwal, 2004).

Landslide activity are intimately associated with the tectonically active Himalayan mountains (Sarkar et al., 1995). During the monsoons, heavy rain cause large scale landslides and huge damage, affecting normal life adversely. Study area is also facing various activities related to development such as construction of hydropower projects, tourism and transport network. The landslide hazard maps are obtained by Index Overlay Method. This method is based upon expert evaluation of the main influencing factors which are supported by the site recognitions in the area (Fattahi, 2011).

3. STUDY AREA

Eco-Development Zone of Great Himalayan National Park (GHNP), Kullu, Himachal Pradesh, India. The area is situated between 31°30`N to 31°55`N & 77°20`E to 77°35`E. The eco-development zone is important unit of GHNP acts as a buffer zone between core zone and non protected area. The eco-zone has an area of 265.6 km^{2}, which is about 22 percent of the GHNP. The location of the study area is shown in figure: 3-1.

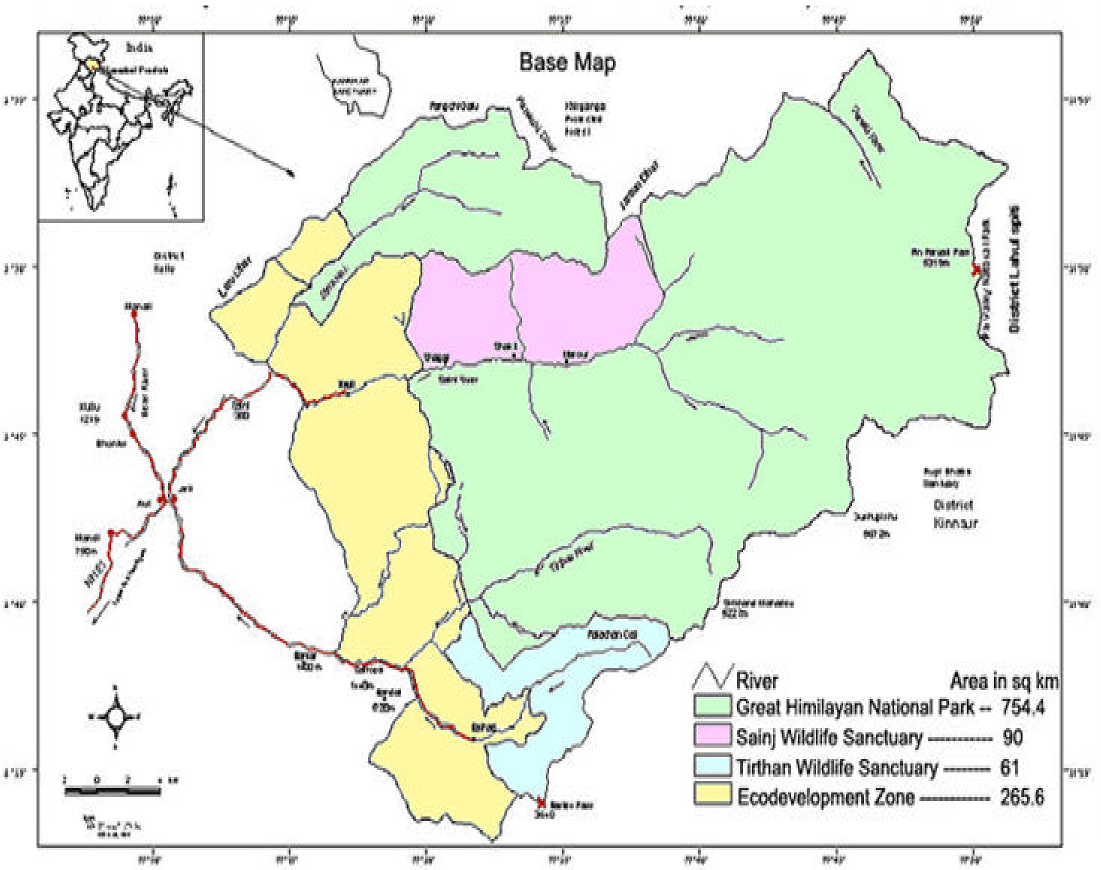


Figure 3-1: Location of Study area in India (Source- www.ghnpkullu.com)

3.1. Geology

Geologically underlying rocks found in the study area are quartzite, schist, phyllites, dolomite, limestone, shale's, slates gneisses and granite, which are responsible for variety of coniferous and broad leaved broad leaved vegetation (Jaiswal., 1987) Area is broadly divided in to glacial and permanent snow field, rocky/barren slopes, valley slopes ridges, main valley floor and influenced by both glacial and fluvial processes (Shah and Mazri, 2007). There are majors thrust along with the several local faults/lineaments and these thrusts are still active and play a major role in neotectonoics of the area (Choubay et al., 2007).

3.2. Soil

The soil of area has been formed *in situ* and belongs to podosolic group, mainly acidic in nature and covered with thick layer of humus (Jaiswal., 1987). The general soil pH is 6.05 with highest 8.22 and lowest 4.16. In the temperate climate under the broad leaved vegetation brown soils are formed. The area also comprises sandy soils which are sandy, sandy loam soils and alluvial soils are also formed due erosion process.

3.3. Population and Social structure

There are numerous settlements around study area. About 102 small villages are there (Nagia et al., 1999). Use of forest and its products is important dimension of villager's subsistence they have traditional right to use forest for grazing and collect firewood apart from this they collect variety of medicine herbs and wild mushrooms seasonally. Tucker, (1997) studied the social structure in detailed and according to him villagers in the eco-development zone are key to preserving the biodiversity since their use of natural recourses and their response largely determine the human impact. These people are not only dependent on forests but their culture religion and polity have evolved from these hills of Himalayas. Therefore these are deeply linked with natural environment and it plays important role in their lifestyle.

3.4. Climate

The climate of the study area is typical of western Himalayan ranges. It varies from temperate to alpine and there are prominent four seasons viz. October to Mid March, spring mid March to Mid April, summer from mid April to June and From July to September rainy season. Rains are confined to monsoon season and there is prominent snowfall during winters. The climate vary according to altitude the valleys are more hot than higher reaches. The mean annual precipitation in the region is between 1000-2000 mm and major part falls during monsoon (Gaston et al, 1981).

3.5. Ecological Importance

The western Himalaya are considered an endemic bird area by Birdlife International, supporting many restricted-range species, as well as a conservation international hotspot (Bibby et al., 1992).This region is a home of many threatened and endangered floral and faunal species. The study area is a part of one of the two National Parks in the world to support a population of endangered western Tragopan (*Tragopan melanocephhalus*) and a large number of rare species (Gaston and Grason, 1993). According to (Anon, 2011a), a team of international wildlife experts will visit Himachal Pradesh next year to evaluate the flora and fauna of Great Himalayan National park and the National park will be in the list of UNESCO's World Heritage sites.

3.6. Biodiversity

The study area is well known for its rich biodiversity. A total of 832 species belonging to 128 families and 427 genera of higher plants were recorded in the area and vegetation comprises of the following physiognomic types: Temperate broadleaf forest, Temperate broadleaf forest, Temperate Oak-conifer forest, Temperate secondary scrub, Temperate grassy slope, Subalpine Fir Spurse, Birch-Rhododendron, Alpine scrub, Alpine meadows (Singh and Rawat, 1998) And in addition area provides shelter to various faunal species many scheduled and endangered species which are 31 mammals (Vinod et al., 1997) ,300 species of birds (Ramesh et al., 1998) and more than 125 species of invertebrates (Unayal and Mathur, 1998).

4. MATERIALS AND METHODS

4.1. Data

4.1.1. Remote Sensing Data

The following remote sensing data has been used for present study.

Table 2: satellite data

Satellite	Spatial Resolution(M)	Swath(KM)	Acquisition date
Landast TM (30M) multispectral digital data	30	185	25 march 2010
Landast TM (30M) multispectral digital data	30	185	29 March 2000
Landast TM (30M) multispectral digital data	30	185	27 march1990
Aster DEM	30	185	29 June 2009

4.1.2. Ancillary Data Used

- Topographic Maps of 1:50,000 scale. June 1990
- Population data 1990, 2000 and 2011. From Block development office Banjar, Kullu District, Himachal Pradesh, India.

4.1.3. Software Used

The following Software's were used for research:

I. **Image Processing**
Erdas Imagine 9.3

II. **Geospatial analysis**
Arc GIS 10

III. **Instrument use**
- Global Positioning system (GPS)-Garmin 12 Channel
- Silva Rogers Compass

IV. **Others**
Microsoft Word (Thesis preparation) and Excel (Statistical analysis).
Google earth image (Delineation of road maps).

4.2. Methodology

The outline of methodology is given in figure 4-1.Two main data set are used namely remote sensing data and census data. From these data sources the factors defining environmental vulnerability were assessed. These factors are specifically related to the forest component of the environmental vulnerability. The factors are Land use land use cover, Forest density, forest fire risk zonation, population density and Landslide risk zonation. Initially all the factors maps are prepared and modified after field work. The entire inputs map are projected into WGS 84 projection system and standardized in to same. After standardisation maps are graded and converted in to standard grid of 100 ×100 m. than input maps are evaluate by means of spatial principal component and environmental vulnerability index computed. From environmental vulnerability index final maps are achieved and change trend is analysed.

The methodology is categorised in to three Stages

- Pre Field stage
- Field stages
- Post field stage

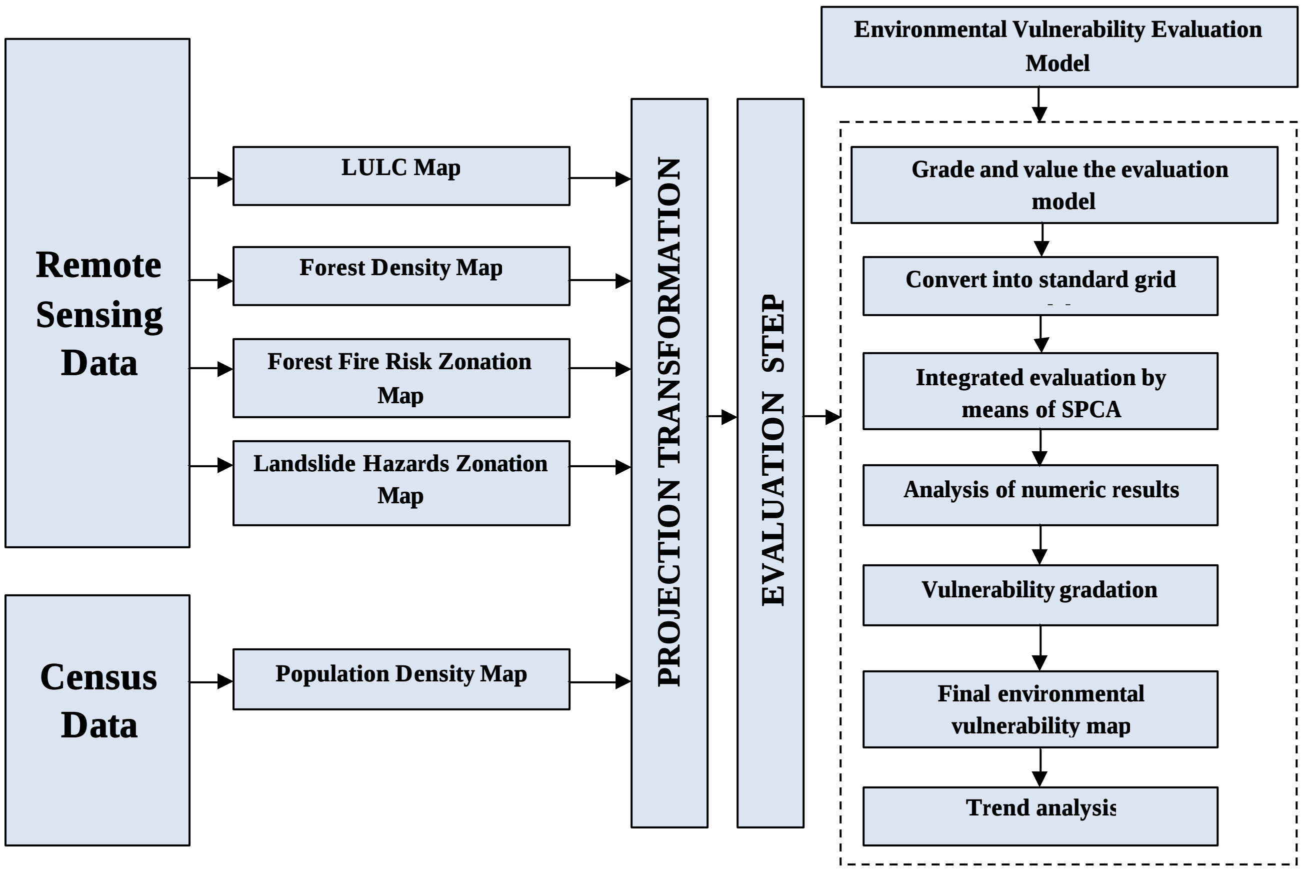


Figure 4-1: Paradigm of the study

4.2.1. Pre field stage

- Acquisition of multispectral of satellite data and Digital Elevation Model
- Collection of survey of India Top sheets.
- Geo-referencing of the toposheets.
- Preparing Base maps viz. Slope, Aspect, Elevation and Drainage
- Visual interpretation of satellite data and prepared maps viz. Land use land cover, Forest density, Fire risk zonation and land slide risk zonation.
- Planning for field work.

4.2.2. Field stage

During field work below mention task has been completed.

- Verification of image interpretation on ground and located them with GPS instrument.
- Collection of Population data.
- Collection of information about various development activities in study area.
- Discussion with GHNP official regarding project and its practical value.

4.2.3. Post Field Stage

Following work has been done after field visit.

- Modification of primarily maps and correction was made on the basis of field data and observation.
- Weighting of various maps for GIS integration and application of Analytical Hierarchal Model for Fire risk zonation and Index Overlay method for land slide risk zonation.
- Grade and evaluation of all input maps and conversion in to standard grid data.
- Evaluation by means of spatial principal component and environmental vulnerability gradation.
- Change trend analysis of environmental vulnerability in the study area.

4.2.4. Land cover Land Use (LULC) Mapping

The above mention satellite images were downloaded from Global Land Cover Facility (GLCF) site (htpp://glcf.umd.edu)and used for land cover Land use mapping. Initially the boundary of the study area has been generated and subset of the satellite data was done. On-screen visual interpretation was carried out to generate land use land cover maps. Various land cover and land use classes were interpreted and classified. Modification was done in LULC map after field work where ever necessary and consequentially vector layers were displayed over satellite data respectively for three times interval viz. 2010, 2000 and 1990.

4.2.5. Forest canopy density mapping

Forest canopy density map was generated by using on-screen visual interpretation of satellite data .The LULC map has been used to delineate of forest canopy density, initially non forest area is masked out from LULC map. After masking out non forest areas Normalised Differerence Vegetation index (NDVI) transformation of masked images is done. On the basis of visual interpretation and NDVI images forest cover is classified and modification on the generated map was done after field work.

4.2.6. Field work

After this, field verification was carried to correlate feature by effectively utilizing intensive ground truth information to different forest types and land use classes. The different classes were marked out on satellite image during ground truth collection and coordinates were recorded for marked locations throughout the study area by using Global positioning system (GPS). Location points are taken randomly in the study area.

4.2.7. Forest Fire Risk Zonation

The spatial Fire risk zonation is done using Analytical Hierarchical Process developed (AHP) by(Satty 1980).Fire Risk Index map is developed based on seven geospatial layers, viz. LULC map, forest density map, slope map, aspect map, habitation map, road map and elevation Map. Forest fire history data was also obtained during field visit from the GHNP authority.

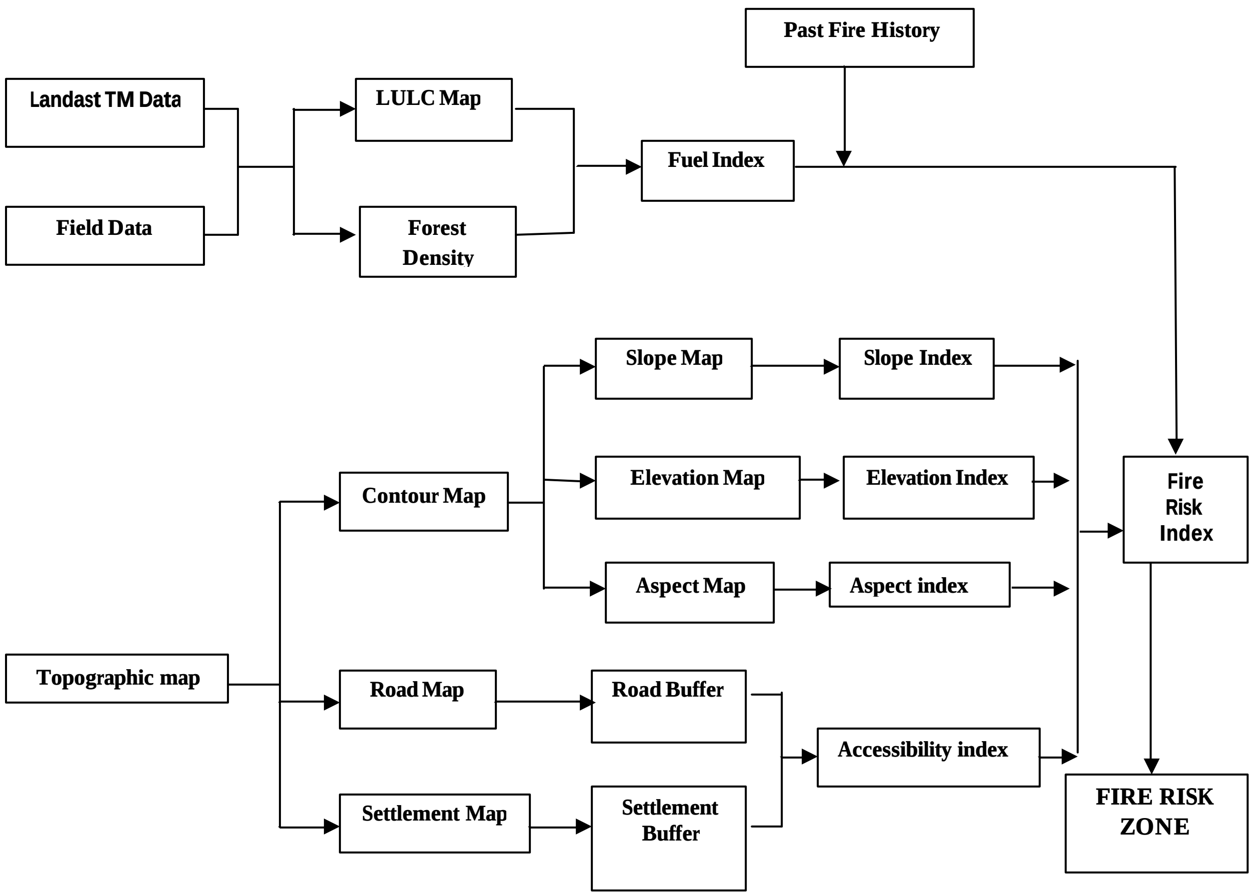


Figure 4-2: Fire Risk Model for Study

AHP is a decision making process developed by (Satty 1980).This process depends on the principal of decomposition, comparative judgement and synthesis of priority. According to (Satty 1980) following steps are followed to give weight age in the present work of fire risk zonation. The problem of forest fire is defined and goal is determined and the hierarchy from the top based on personal decision making through intermediate level to lowest level was constructed and a pair wise comparison matrix (size n × n) was prepared for each level with in each matrices and pair wise comparison accomplished. Then synthesis process was done to eigenvectors by the sum of each criteria and sum is taken over the all weighted eigenvectors corresponding to next lower level.

Slope, elevation and aspect maps were derived from DEM. Settlement location and Roads network have been delineated form of topographic maps and Google earth image in GIS environment. The Euclidean distance around roads and settlement location was calculated. The population density map was generated from the collected population data. Kriging interpolation technique was used to convert the data into geospatial layer.

Table 3: Pair-wise comparison scale for AHP preferences (Satty 1980)

Numerical Rating	Judgments of Preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very Strongly preferred
6	Strongly to Very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

After getting all the comparisons consistency was determine by using eigenvalue as follows.

$$??? \frac{??_{???}???}{?????} \quad (4\text{-}1)$$

Where CI is the Consistency ratio, n is the matrix size and $?_{???}$ represents the Eigenvalue.

Table 4: Average random consistency (RI) (Satty 1980)

Size of Table	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

It is assumed that each individual layer has its own significance and effect on the fire risk. Above mentioned seven geospatial layers are converted in to raster grids and interrelate in GIS environment in allusive order. Primitively each individual geospatial layer is reclassified in to five classes viz. Very high, High, Medium, Low and Very low according to impact on fire risk and then weights were subsequently assigned to each layer a with the application of (AHP).

4.2.8. Land slide Hazard zonation Mapping

Land hazard zonation mapping has been done with the help of Index Overlay Method (IOM). Initially all the factor maps was generated and. The seven factor maps were taken for Landslide hazard zonation viz. Geological map, LULC map, Slope map, Aspect map, Drainage map, lineament map and road density.

4.2.8.1. Index Overlay method (IOM)

The index overlay method is the knowledge driven method and depends on the observation of the decision maker. The map classes each input map are assigned different score and each map also given score as well according to their contribution towards the final output. Following steps has been followed for achieving final output map.

- Preparation of factor maps
- Conversion of each input map in to Grid format.
- Assigned score to each in put map class followed by assigning score to all input maps.
- Integration and analysis.

Following equation has been used for integration of factor maps

$$? \; ? \; \frac{s ? ? ?? ?}{s ? ? ?} \qquad (4\text{-}2)$$

Here ? ? in equation: (4-2) is the weight of ith factor map. ? ?? is the ith spatial class weight of jth factor map and ? is the spatial unit value in output map.

The geological map has been taken from GHNP authority. Lineaments are linear or curvilinear feature on the earth surface which significance in geological studies. By using satellite imagery the lineament are drawn and compared with the geological map. Using GIS application the Lineament density map has been developed. The LULC, aspect and slope maps were reclassified as according to their importance for Landslide risk zonation. Drainage density map has been derived from DEM.Drainage density expressed as channels per unit area and shows the closeness of spacing of channels in the total area. The drainage map has been prepared with application of Arc GIS by using arc hydro tool. Initially flow direction has been prepared and then flow accumulation and flow length, drainage and than from drainage map the drainage map was calculated. The road density based on the euclidian distance concept was calculated around roads.

The LULC, Forest density map, Fire risk zonation map, landslide hazard zonation map and population density maps were generated for 1990, 2000 and 2010 for SPCA evaluation.

4.2.9. Spatial principal component analysis (SPCA)

After creation of the all factors maps they were quantified qualitatively based on their contributing ratio on local environment with expert's inputs further followed by standardization. It is difficult to apply the selected criterion directly because they lack comparability due to different scales among variables, although according to their practical values their effect on environment can be worked out. Therefore to solve incomparable problem the factors must be treated qualitatively by applying a standard method (Li et al. 2006). Hence, evaluation criterion is to be standardized and graded from low to high so as to reflect the state of environment. The equation to be used for standardization of criteria is as follows:

? ? ???? ?? / ???? ???? ? ? (4-3)

Here ? is the standard value of i grade, ?? is the value of grade i and ???? is practical maximum value and ???? is the practical minimum value. After standardization of evaluating factors, they become a group of values reflecting their property features within the range 1to 5.

4.2.10. Conversion to Grid Data

Every evaluation factor has to be converted to grid data. The grid processing provides spatial data storage and powerful analytical model for analyzing spatial features. The grid structure have rapid processing, mathematical computation is simple and easy to put in practice. The vector evaluation factors are converted to the grids of various sizes as precision in computation is dependent on the grid pixel.

4.2.11. Integrated evaluation on the basis of SPCA

- The standardized disposal of primary data was done to overcome the disagreement among various parameter criterion measurement and to change data accordingly.
- Establishment of relevant coefficient matrix R of each variable.
- Computation of eigenvalue of matrix R and its correspondent unit eigenvectors.
- Linear grouping of eigenvectors and put out the principal components

This application converts the relevant multi-variable spatial data into a few irrelevant synthetic criterions with suitable software environment the data is transformed into stack from input multivariate attribute space to new multi-vitiate attribute space whose axes are rotated with respect to the original space. The axes in new space are uncorrelated. According to changed main factors, the number of factors is affirmed. The impact of each primary criterion on evaluation was graded .This method put weight on each factors contribution ratio compared with relative influence by expert's subjective opinions.

? ? ???? ? ???? ? ? ? ???? (4-4)

In the Arc GIS Software environment the function 'Princomp' is used for data stacking from input multivariate attributes space to new multivariate attribute space. According to commutative contribution of principal components, the number of components was confirmed five.

4.2.12. Vulnerability Gradation

The result computed will be a continuous value. It should be classified in to different levels standing for different eco-environmental vulnerability. The computed results were graded in to five levels defined as Low vulnerability, Slight vulnerability, Moderate vulnerability, High vulnerability and severe vulnerability.

4.2.13. Change Trend Analysis

Based on the gradation of vulnerability for different levels, the change in trend form 1990 to 2000 and from 2000 to 2010 was analyzed based on Environmental vulnerability integrated index (EVSI) index proposed in (Li et al. 2006), given by the formula.

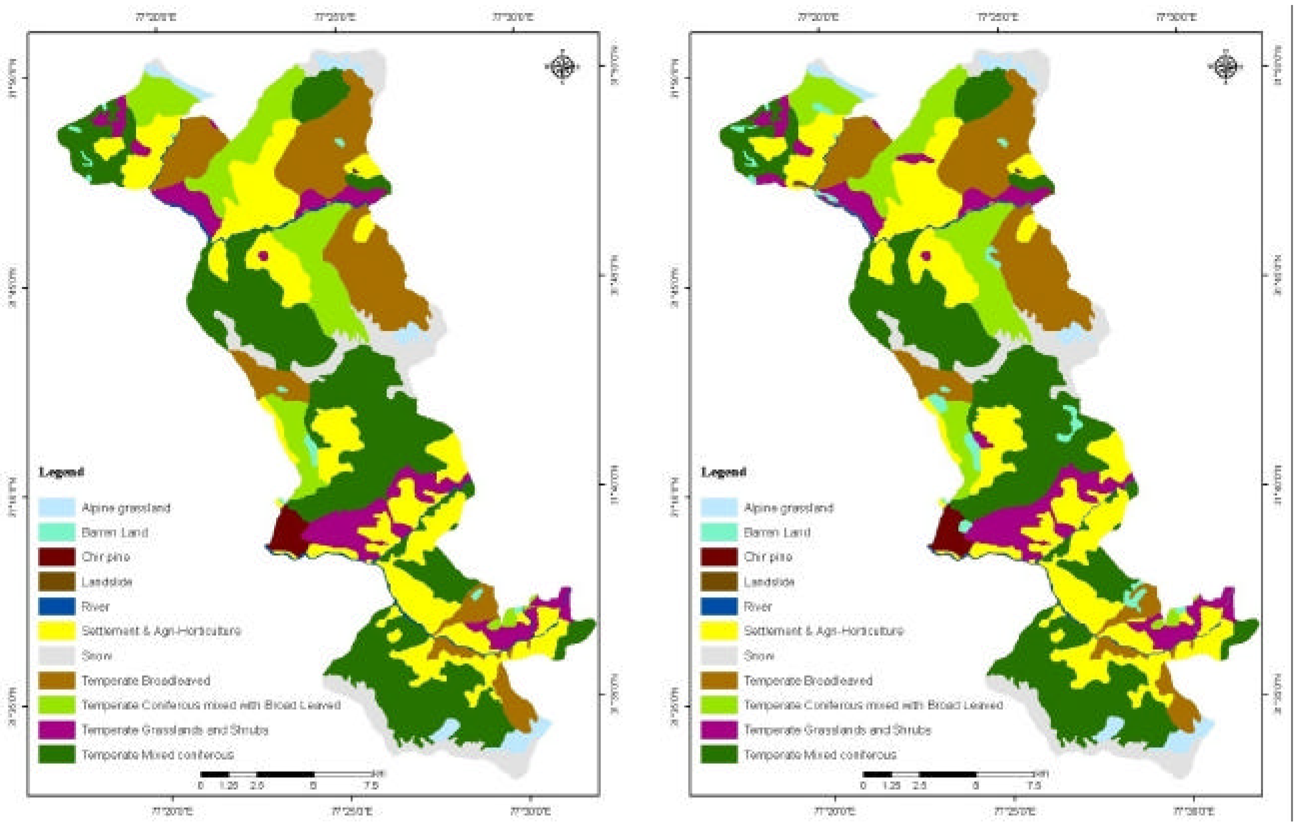
????? ? s ?? ?? ? ??/?? (4-5)

5. RESULTS AND DISCUSSION

5.1. Factors for assessment of environmental vulnerability

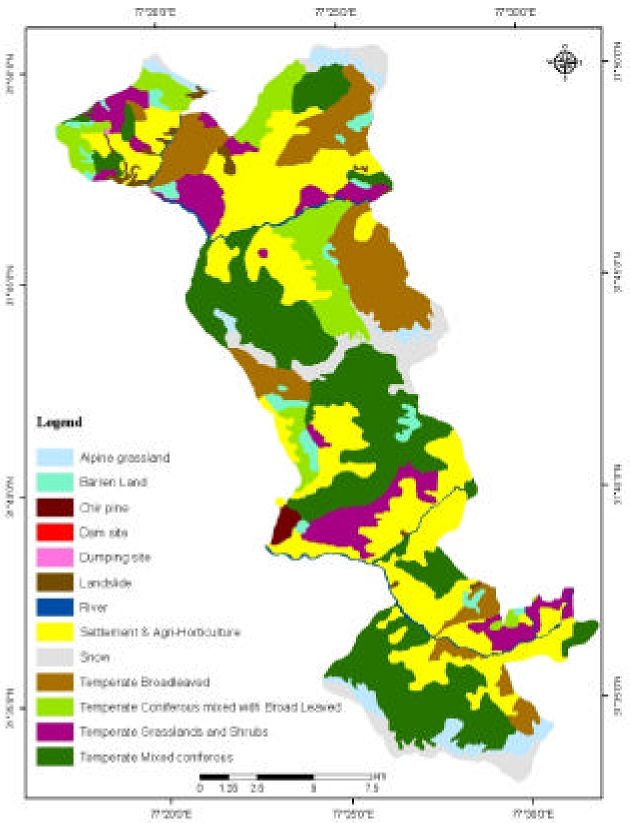
Five factors are taken for assessment of environmental vulnerability.

- Land use land cover map
- Forest density Map
- Forest fire Map
- Landslide risk zonation Map
- Population density map



(a) (b)

These factors are major driving forces in study area regarding environmental studies.thease factors are chosen qualitatively on the basis of knowledge of local area.



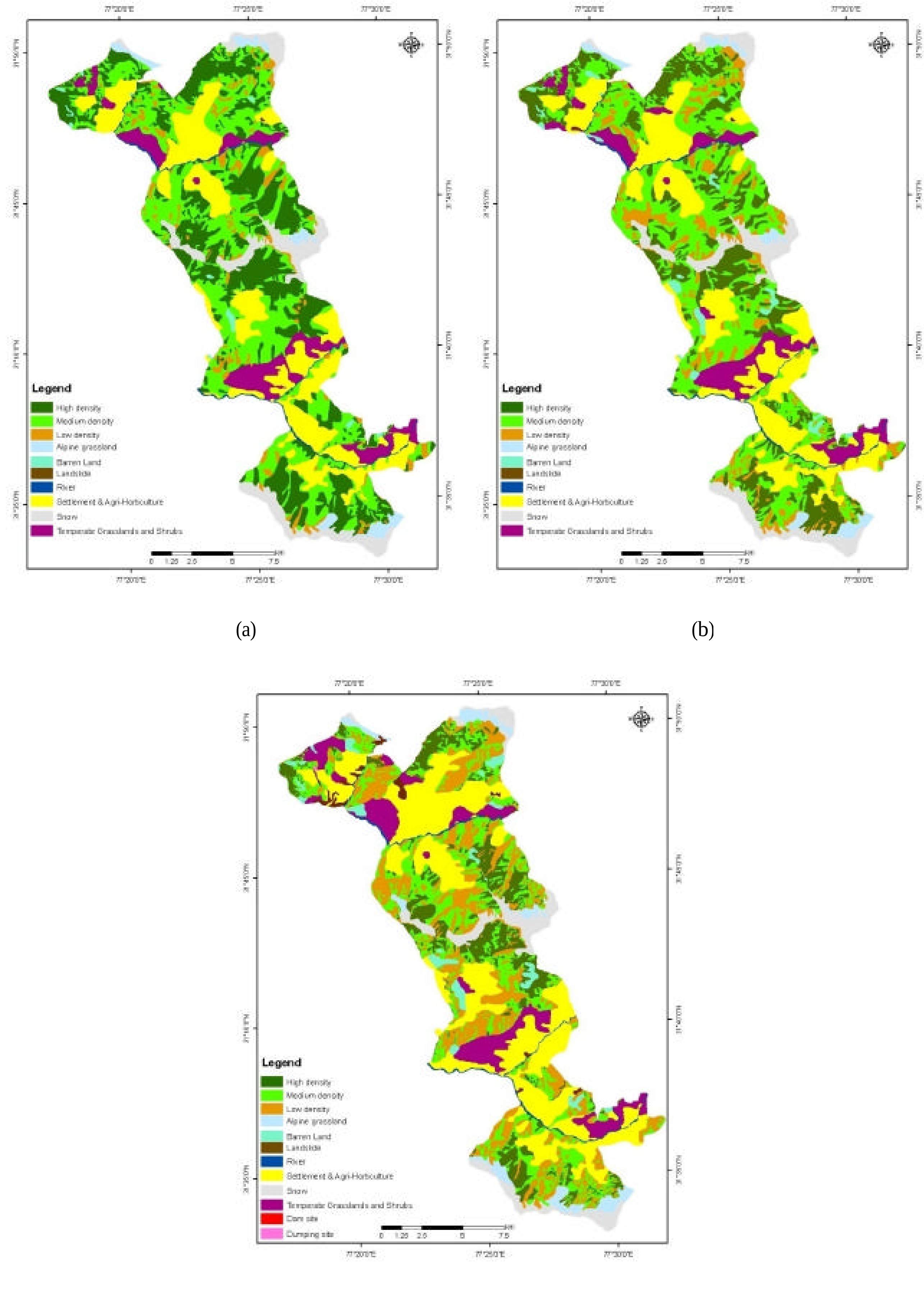
(c)

Figure 5-1: (a) LULC map 1990 (b) 2000 (c) 2010

The figures 5-1 (a), (b) and (c) represents the LULC maps for the three time periods 1990, 2000 and 2010. Land cover change is gaining recognition as a key driver of environment change in a region (Zhi et al., 2009). Some researchers analyzed the spatial and temporal pattern of land use / land cover changes in micro watershed in Central Himalaya during 1967–1997 (Wakeel et al. 2005). There has been increase of about 9 km^2 area under habitation/agriculture/orchard with a corresponding decline of about 4 km^2 forest area between 1961 and 1993 (Mathur and Naithani, 1999). The study showed that the forest density reduced to a significant level with increasing population pressure and agricultural expansion and developmental activities aggravates it further. These facts proved that the natural forest covers are removed considerably and replaced by human managed systems.

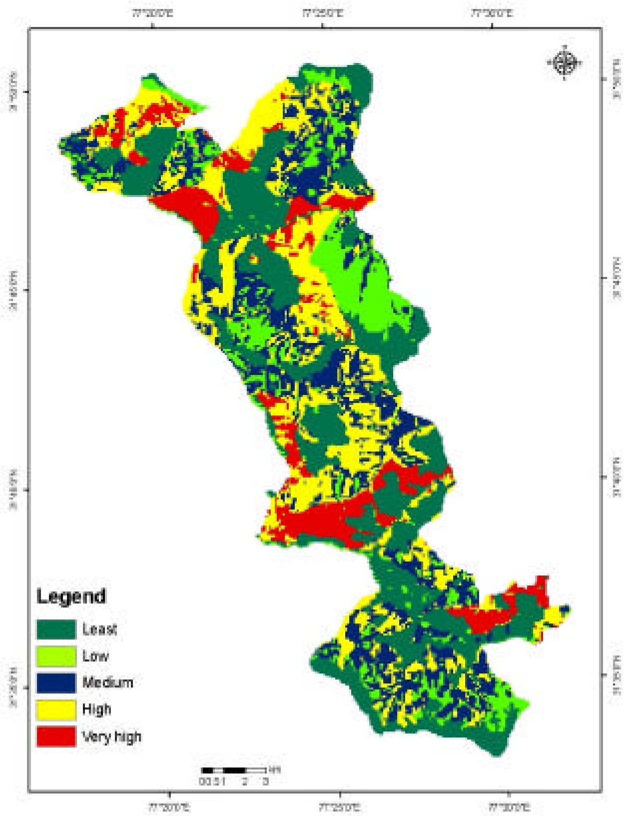
Forest fire is also a major factor for environmental degradation. The western Himalayan coniferous forests are very prone to fire and being ecologically very sensitive, impact of fire on forest and environment is more lasting , irreversible and beyond repair (Planning commission of India 2005). Most of the fire incidents are intentional by local people for timber harvesting, land conversion and for forage as the part of traditional rights conflict. Approximately 90 percent of forest fire in the region is human induced (Anon., 2011b). Hence, in the context of the Himalayan region, it is an important factor for vulnerability studies.

Anthropogenic changes of natural landscape by means of population growth and agricultural expansion have been increasing in Himalayan region (Rao and Pant 2001). Population in study area is also showing a increasing trend. The rapid population growth has resulted into environmental quality deterioration by increasing pressure on land, shrinking forest cover, loss of floral and faunal diversity etc.

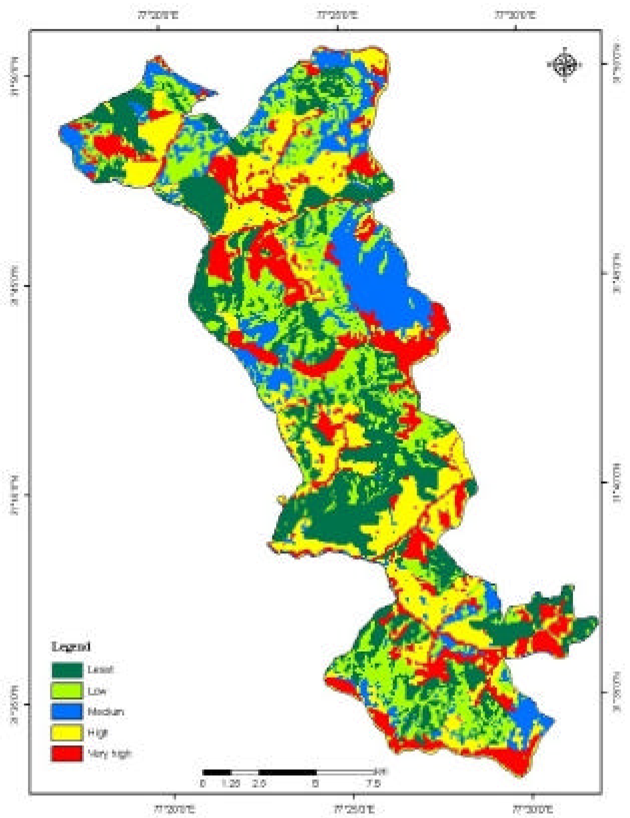


(c)

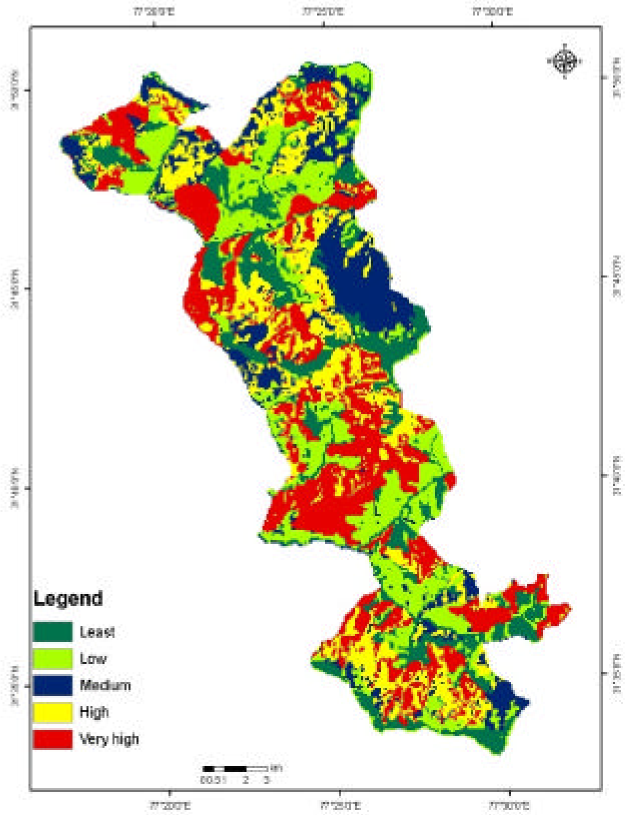
Figure 5-2: Forest density maps (a) 1990 (b) 2000 (c) 2010



(a)

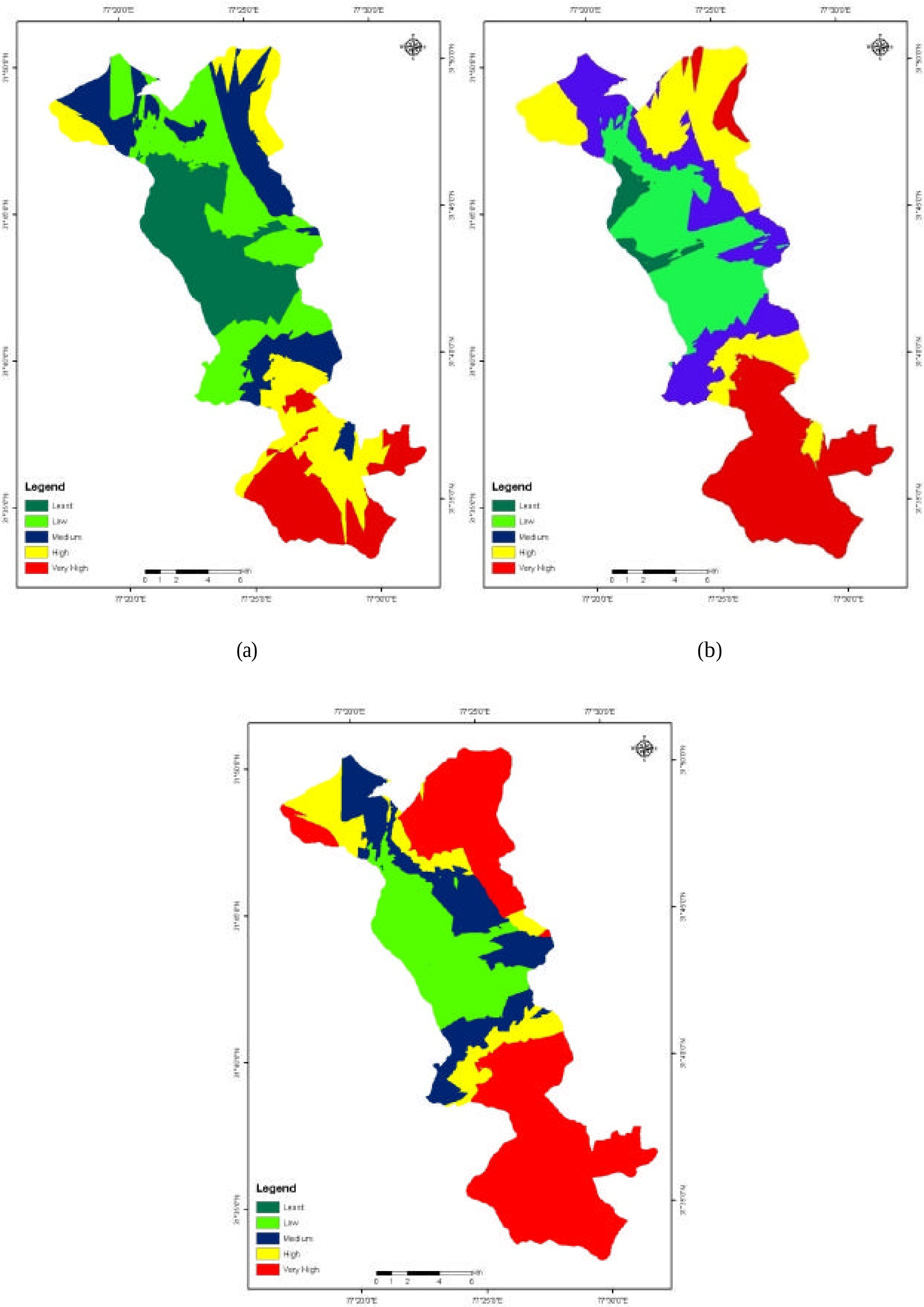


(b)



(c)

Figure 5-3: Forest fire maps (a) 1990 (b) 2000 (c) 2010

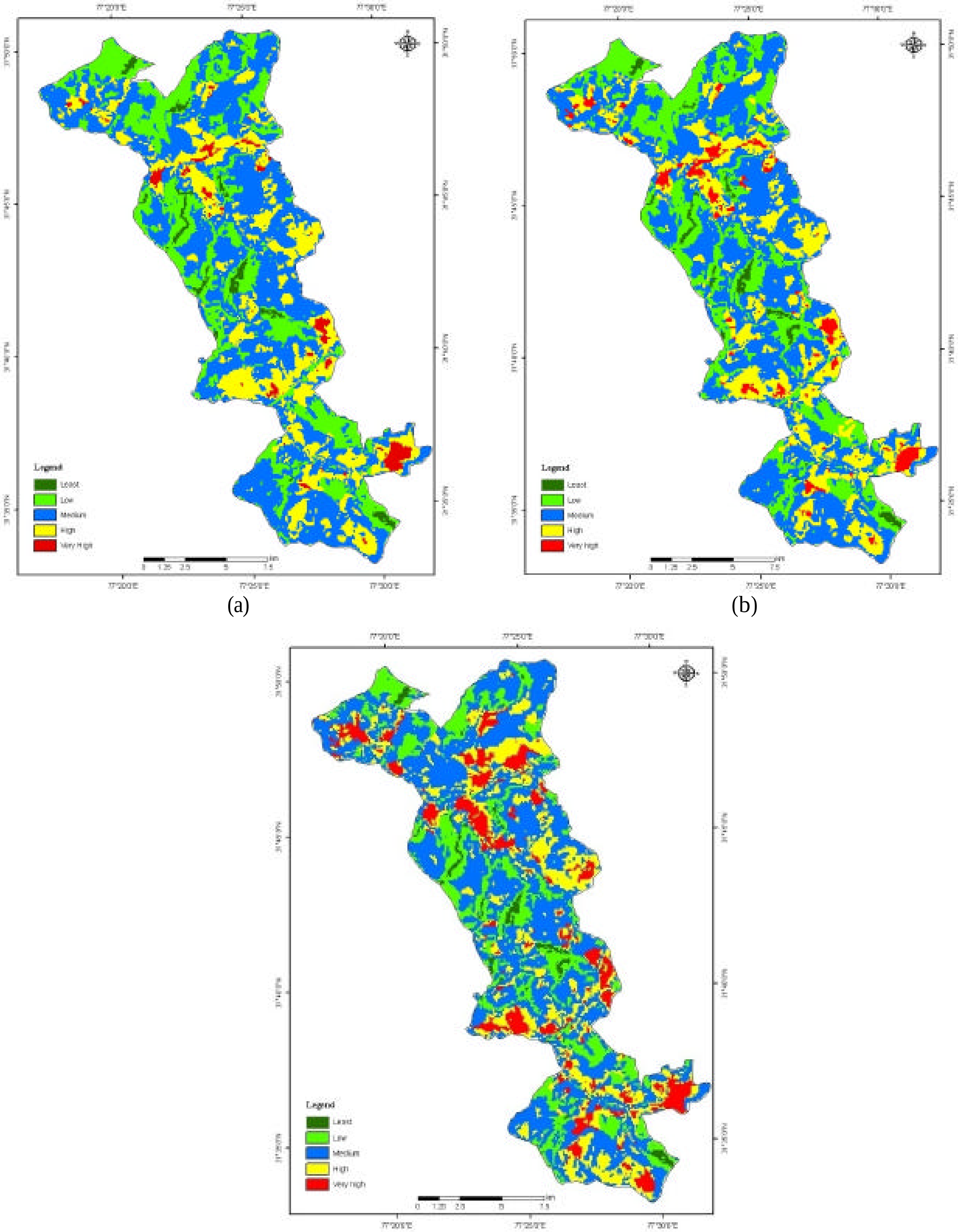


(a) (b)

(c)

Figure 5-4: Population density maps (a) 1990 (b) 2000 (c) 2010

The figures 5-2 (a), (b) and (c), 5-3 (a), (b) and (c), 5-4 (a), (b) and (c) depicts the forest density, forest fire and population density maps for 1990, 2000 and 2010. Previous studies on landslides shows on the basis of remote sensing and GIS inventories that landslide hazard zonation is one of the frequent occurring natural hazards in Kullu district with massive destruction to life and property and sometime leads to large scale landscape transformations(Chandel et al., 2011).



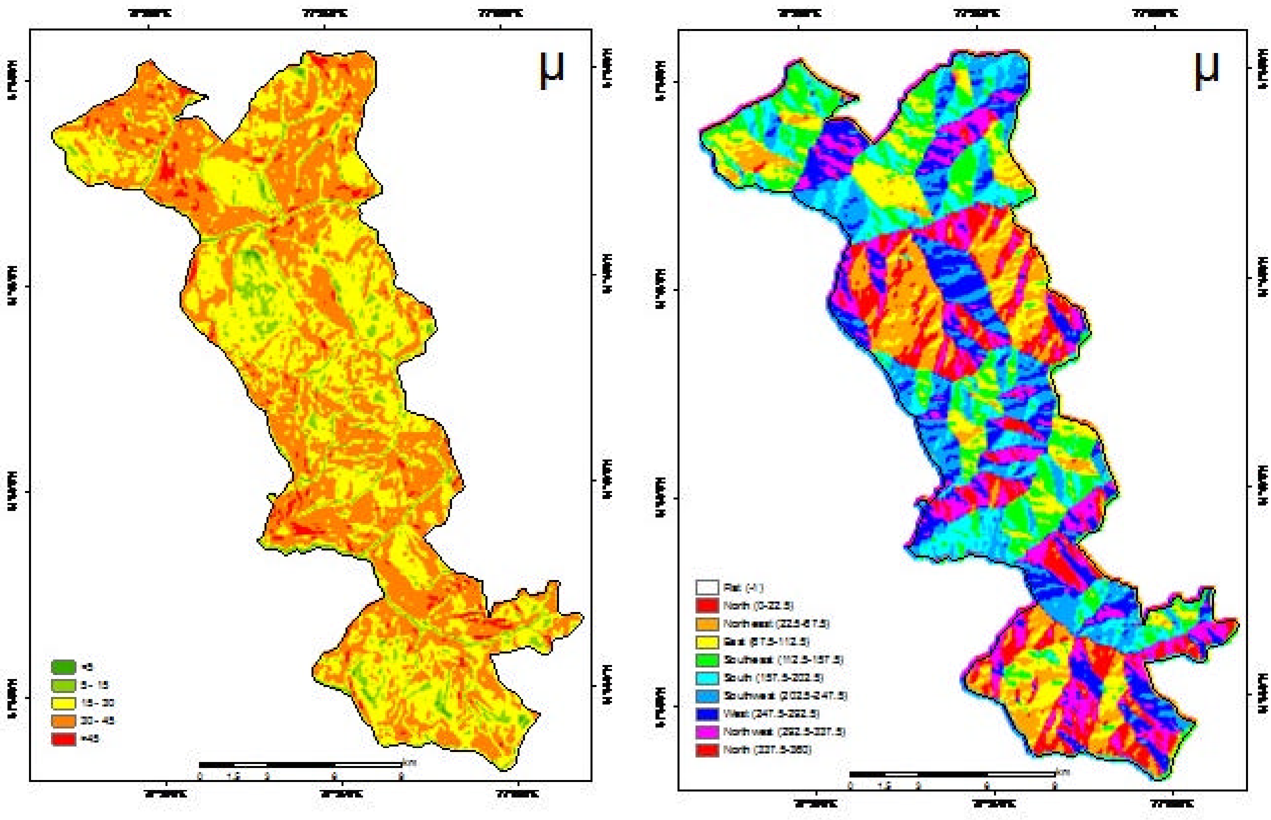
(a) (b)

Figure 5-5: Landslide maps (a) 1990 (b) 2000 (c) 2010

During the monsoons, heavy rain cause large scale landslides and huge damage, affecting normal life adversely. Over the years human activities has contributed to an increase in slope failure in Himalayas because of the development activities (Haigh et al., 1989). These facts make it essential to quantify affect of landslides as it occupies a position of major concern in context of environmental vulnerability

5.1.1. Input maps for Forest fire risk zonation

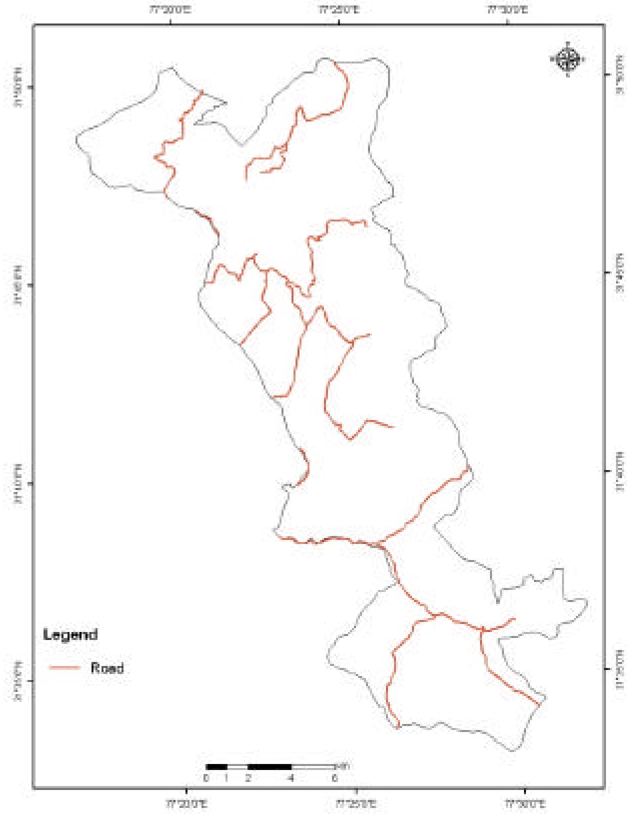
Aspect and exposure dry up the fuel load. The direction of slope determines the how much light it received. Forest fire risk zonation is done with seven factors and each factor has its own contribution to fire risk. Slope aggravates the forest fire and acts as connective way of ignition and heating by point of contact. More steep slopes increase the burning and spreading rate of fire.



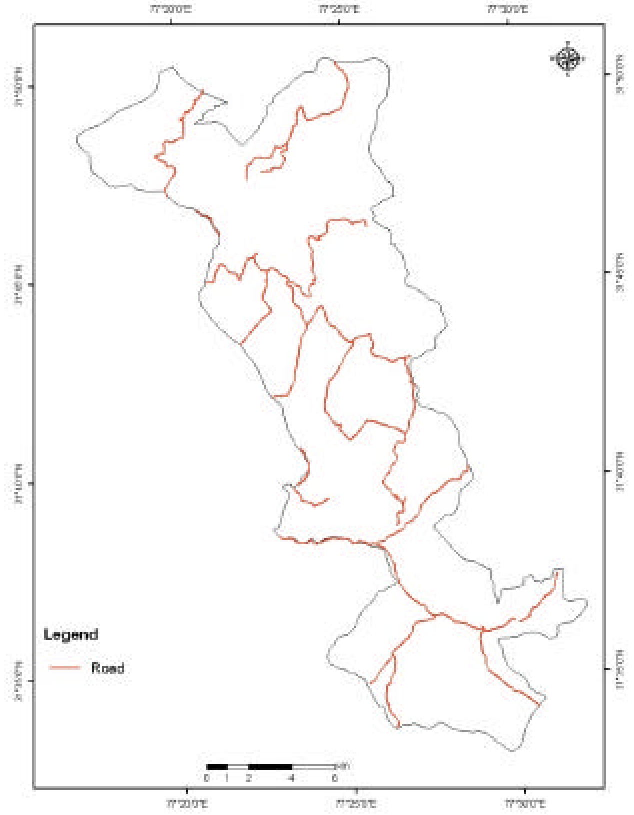
(a) (b)

Figure 5-6: (a) Slope map (b) aspect map

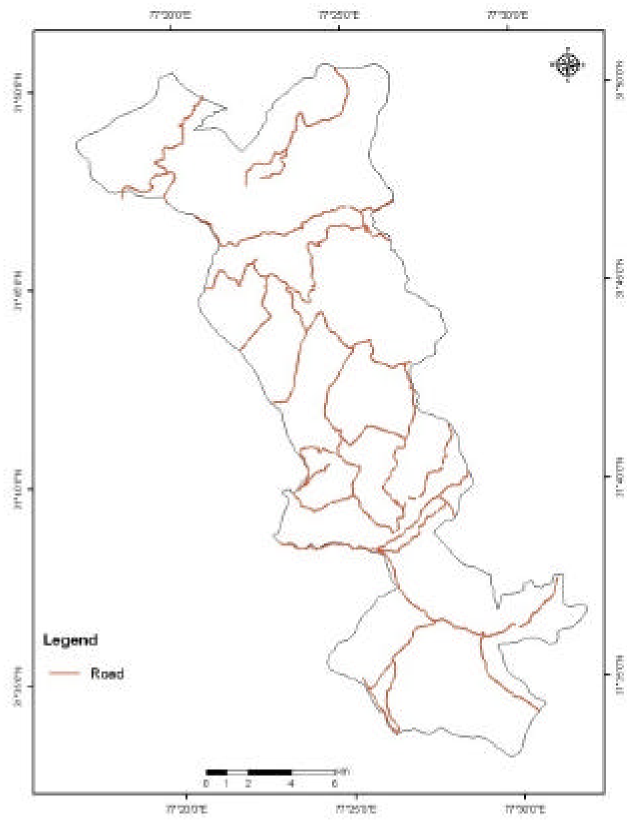
The figures 5-6 (a) and (b) represent the slope and aspect map. South and slopes receive more sunlight and most sunlight and northern slopes receive least amount, the area received direct sunlight represents high degree risk because of higher degree of insulation. Roads and settlements one of the major cause of the forest fire is presence of human settlement and road near to the forest or inside the forest area on the other hand they also help the suppression of fire sometimes roads acts as a fire lines.



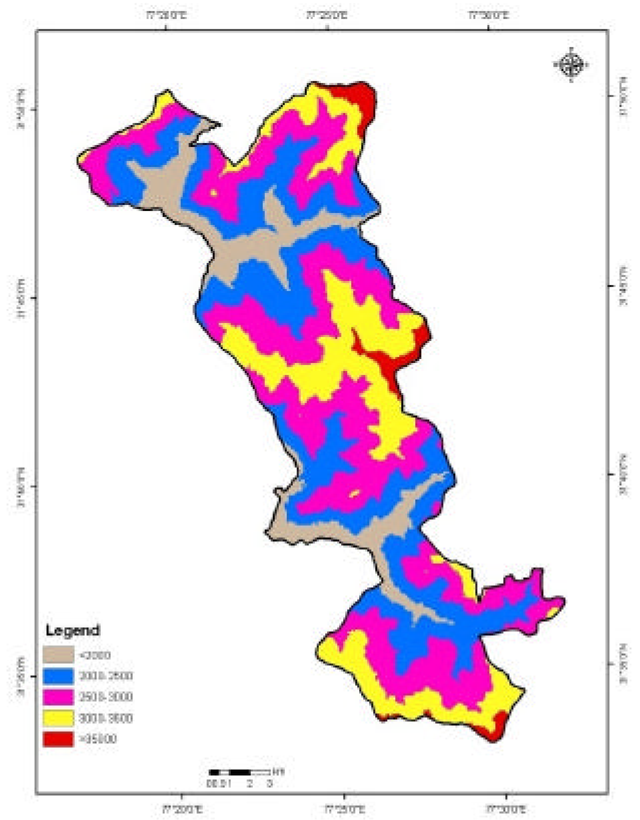
(a)



(b)



(c)



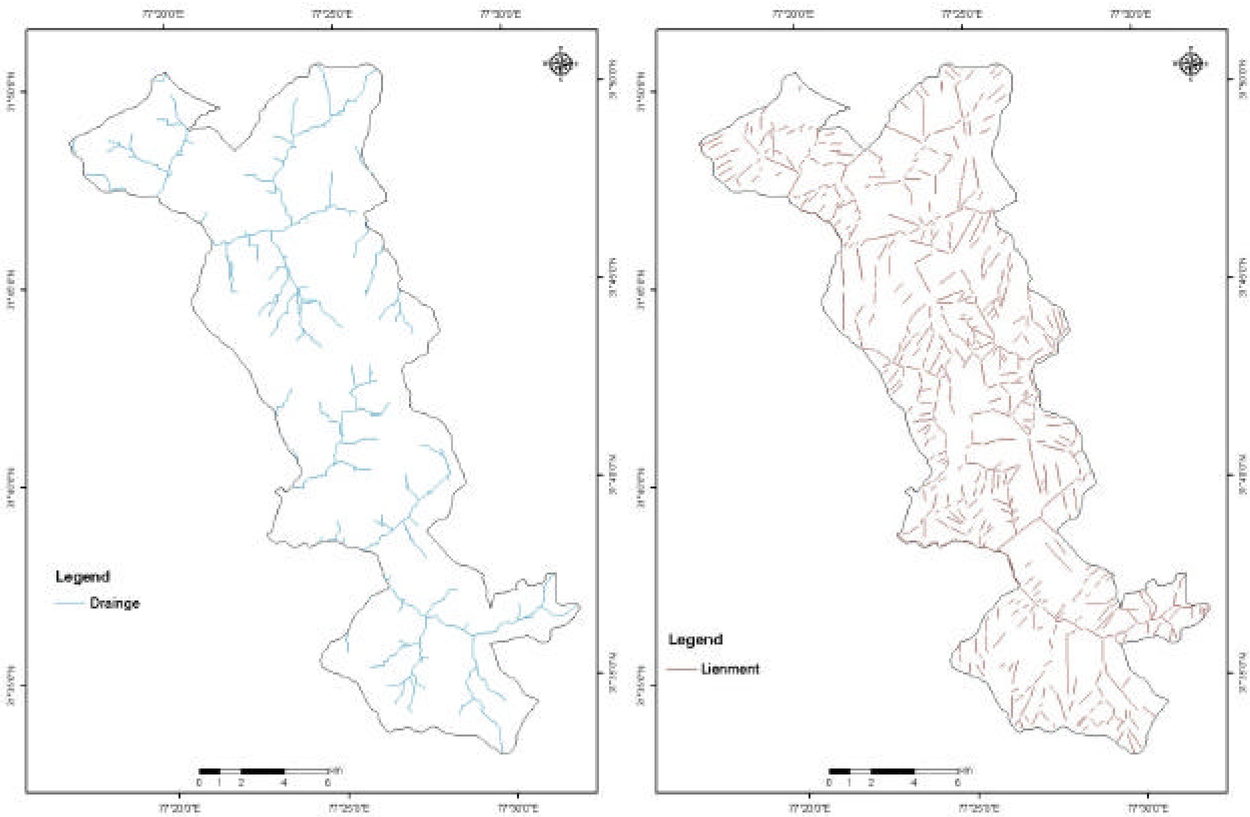
(d)

Figure 5-7: Road maps (a) 1990 (b) 2000 (c) 2010 (d) elevation map

The figures 5-7 (a), (b), (c) represent the road maps for 1990, 2000 and 2010 with elevation map depicted in (d). Elevation plays important role in fire risk because in western Himalayas higher elevation are cool and retain more moisture and less prone to the fire as compare to the lower elevation. The forest density has important role spread vegetation is drier and increase the chances of the fire because less moisture content ignite more easily and quickly (Porwal et al. 2009). The vegetation type is important parameter for forest fire because vegetation acts as fuel for fire. In the Himalayan region the chir pine is more sensitive to fire because of resin content and other conifers, broad leaved plant are fire hardy.(Khanna., 1998).

5.1.2. Input maps for Landslide hazards zonation

Landslide risk zonation six factor are chosen for the landslide risk zonation mapping



(a) (b)

Figure 5-8: (a) Drainage map (b) lineament map

The figures 5-8 (a) and (b) represent the drainage map and the lineament map with figure 5-9 depicting geological map.

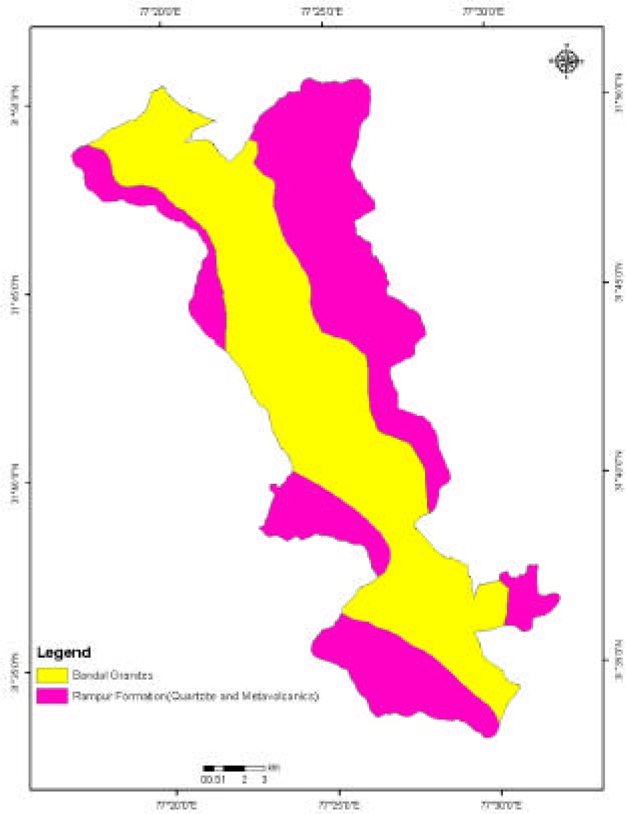


Figure 5-9: Geological map

5.1.3. Weights for each factors

On the basis of scale, imagery available and kind of information to be interpreted a visual interpretation key has been prepared according to the basic visual interpretation elements. The visual interpretation key for land cover land use mapping is mentioned in table 3.

Table 5: Interpretation key

Land cover Land Use Type	Tone	Association	Texture	Shadow	Shape	Pattern
Alpine Grassland	Light Greenish pink	Snow and Forest	Fine to medium	No	Irregular	Continuous to Non continuous and patches
Barren Land	Light pinkish to brown	Grassland, Settlements	Rough	No	Irregular	Non-Continuous and Patchy
Chir Pine	Red to Brownish Red	Grasslands ,Settlement and other Forest Type	Smooth to fine	No	Irregular	Continuous to Non Continuous
Dam Site	Cyan	River and settlements	Fine to Rough	No	Regular	Non continuous

Dumping Site	Light Brown	Grasslands an d Barren Land	Fine to rough	No	Regular	Continuous
Landslide	Light Greenish Blue to White	Smooth	Smooth	No	Irregular	Continuous to Non Continuous
River	Light Blue	Forest ,Grassland Settlement	Linear	No	Irregular	Continuous To Non Continuous
Settlement-Agri-Horti	Light Pink to Light Bluish	Forest,Grassland,River	Smooth to medium	Patchy	Irregular	Non Continuous
Snow	White to Light blur	Alpine Grassland and Forest	Smooth	No	Irregular	Continuous Non Continuous
Temperate Broad leaved	Dark Brown to Reddish	Grasslands ,Settlement –Agri Horti ,Alpine Grasslands And Snow	Smooth to Medium	Very less to No	Irregular	Continuous to non Continuous
Temperate conifer Mixed with broad leaved	Reddish Brown	Grasslands ,Settlement –Agri Horti ,Alpine Grasslands And Snow	Smooth to Medium	Less tom Vey Less	Irregular	Continuous to non Continuous
Temperate Grassland and Shrubs	Light Reddish grey to Greenish	Grasslands ,Settlement –Agri Horti ,Alpine Grasslands And Snow	Smooth to Medium	Less	Irregular	Continuous to non Continuous
Temperate mixed Conifer	Red to Brown	Grasslands ,Settlement –Agri Horti ,Alpine Grasslands And Snow	Smooth to Medium	Very Less	Irregular	Continuous to non Continuous

5.1.4. Forest canopy density mapping

Forest canopy density map has been classified in to three class's viz. Low (10-30%), Medium(40-70) and High(>70%).The classification scheme for forest density is mention in Table 6.

Table 6: Classification Scheme for forest density

Density Class	Percentage
Low	10-40 percent
Medium	40-70 percent
High	>70 percent
Non-Forest	>10 percent

5.1.5. Forest Fire Risk Zonation

The Fire risk zonation rating is mention in table 7.very high class is given rating 1, high 2, Moderate 3, Low4 and least 5.

Table 7: Forest Fire risk zonation rating

Class	Rating
Very high	1
High	2
Moderate	3
Low	4
Least	5

Each class and in every map is classified and given ratings for forest fire zonation details of ratings is given in table 8.

Table 8: Rating of Layers for Forest Fire Risk Zonation.

S.No.	Data Layers	Classes	Rating
1.	LULC	Alpine grassland	4
		Barren Land	5
		Dam Site	5
		Chirpine	1
		Landslide	5
		Settlement+agri_Horti	5
		Snow	5
		Temperate Broadleaved	3
		Temperate conifers mixed with broad Leaved	2
		Temperate mixed conifer	1
		Temperate Grasslands and scrubs	1
		Dumping site	5
		River	5
2.	Forest Density	High	3
		Medium	2
		Low	1
		Alpine Grasslands	1
		Barren land	4
		Dam site	5
		Landslide	5
		River	5
		Settlement +Agi+Horti	4
		Snow	5
		Temperate Grasslands and Scrubs	1
		Dumping Site	5

3.	Slope(Degree)	0-5	5
		5-15	4
		15-30	3
		30-45	2
		>45	1
4.	Aspect	Flat	5
		North	4
		North-East	4
		North-West	3
		South	1
		South-West	1
		South-East	2
		East	2
		West	3
5.	Habitation Euclidian Distance(M)	>1000	1
		1000-2000	2
		2000-3000	3
		3000-4000	4
		>4000	5
6.	Road (Euclidian Distance(M)	>1000	1
		1000-2000	2
		2000-3000	3
		3000-4000	4
		>40000	5
7.	Elevation (M)	<2000	1
		2000-2500	2
		2500-3000	3
		3000-3500	4
		>35000	5

According to steepness the weights to slope map have been given. Flat slope were given least value, gentle slightly more value and accordingly to other classes. Aspect Map and classified in to Flat, North, North East, South East, South, and South west, West and North West. More weights have been given to warmer aspect because of high risk due to high insulation.

Euclidean distance around roads and settlement location has been calculated .Higher weights were assigned to near to road and settlements as it is considered that area near to road and Settlements are more prone to fire hazards due to more human interferences.. Higher elevation has given less weights and lower has given more because according to study area as elevation go high temperature goes down and rainfall increase The different land use and land cover classes has been given rating according to their relative importance to fire. The forest classes have given more Weights because forest acts as fuel for fire. Within the forest classes rating are based on species type and their response to fire. The low density forests has given very high preference because if vegetation are more spread and dry as compare to medium dense and high density classes.

5.1.6. Analytical Hierarchal Process (AHP)

In present study pair-wise comparison matrix of seven variables has been calculated and corresponding results are shown as below in table 9.

Table 9: Pair-wise comparison matrix

Class	Forest type	Forest density	Slope	Aspect	Road	Habitation	Elevation
Forest type	**1**	2	3	4	6	7	9
Forest density	1/2	**1**	2	3	5	7	9
Slope	1/3	1/2	**1**	2	3	5	8
Aspect	1/4	1/3	1/2	**1**	2	4	7
Road	1/6	1/5	1/3	1/2	**1**	2	3
Habitation	1/7	1/7	1/5	1/4	1/2	**1**	2
Elevation	1/9	1/9	1/8	1/7	1/3	1/2	**1**
Total	**2.454**	**4.204**	**7.042**	**12.676**	**19.833**	**28.500**	**39.000**

Then synthesised matrix was prepared by dividing each element of its column total and after that priority vector was calculated by finding the row average. The synthesised matrix is shown in table 10

Table 10: Synthesized matrix

Class	Forest type	Forest density	Slope	Aspect	Road	Habitation	Elevation	Priority vector
Forest type	0.399	0.466	0.419	0.367	0.336	0.264	0.231	**0.355**
Forest density	0.200	0.233	0.279	0.275	0.280	0.264	0.231	**0.252**
Slope	0.133	0.117	0.140	0.184	0.168	0.189	0.205	**0.162**
Aspect	0.100	0.078	0.070	0.092	0.112	0.151	0.179	**0.112**
Road	0.067	0.047	0.047	0.046	0.056	0.075	0.077	**0.059**
Habitation	0.057	0.033	0.028	0.023	0.028	0.038	0.051	**0.037**
Elevation	0.044	0.026	0.017	0.013	0.019	0.019	0.026	**0.023**
Total								1.000

After calculating synthesised matrix the weighted sum matrix is calculated by multiplying each column with its corresponding priority vector.

?G?? ?? ? ?G?? ?? ? ?G?? ?? ? ?G?? ?? ? ?G?? ?? ? ?G?? ?? ? ?G?? ?? ?

?G??
?G??
?G??
?G??
?G??
?G??
?G?? (5-1)

Subsequently priority vector is used to divide all respective elements of the weight sum matrices.

2.616 / 0.355 = 7.373
1.854 / 0.252 = 7.360
1.179 / 0.162 = 7.272
0.795 / 0.112 = 7.112
0.423 / 0.059 = 7.144
0.260 / 0.037 = 7.056
0.165 / 0.023 = 7.050

Average of these values was used to compute ????

???? ? ??G?? ? ?G?? ? ?G?? ? ?G?? ? ?G?? ? ?G?? ? ?G?????
=7.179 (5-2)

After that consistency index was calculated as:

CI = (7.179-7) / 7-1
= 0.033 (5-3)

Finally the consistency ratio (CR) for matrix was calculated by taking stranded value of random average consistency from table (RI)) for matrix size six as follows:

CR = 0.033 / 1.32
= 0.025 (5-4)

Since the value of consistency ratio is not exceeding 0.100 the above calculation are acceptable.

The fire risk zonation was calculated using linear additive equation and weights of variables are used in equation which is obtained from above analysis.

CFRZ =0.355*FTI+0.252*FDI+0.0162*SLI+0.012*ASI+0.059*RDI+0.037*STI+0.023*ELI (5-5)

Where
CFRZ = Cumulative Fire Risk
FTI = Forest Type Index
FDI = Forest Density Index
ASI = Aspect Index
SLI = Slope Index
RDI = Road Index
HBI = Habitation Index
ELI = Elevation index

This process was repeated for three time and fire risk zonation map for 2010, 2000 and 1990 has been developed.

5.1.7. Land slide Hazard zonation Mapping

Landslide hazard zonation map was classified in to five classes and the ratings are given in the table 11.

Table 11: Landslide Hazard zonation rating

Class	Rating
Very high	5
High	4
Moderate	3
Low	2
Least	1

5.1.8. Index Overlay method (IOM)

Each class and in every map is classified and given ratings for landslide risk zonation, details of ratings is given in table 12.

Table 12: Ranking and score for Landslide Hazard Zonation (After Bhoi 2000)

S.No.	Data Layers	Classes	Ranking	Score
1	LULC	Alpine grassland	2	3
		Barren Land	4	
		Dam Site	3	
		Chirpine	2	
		Landslide	5	
		Settlement+agri_Horti	4	
		Snow	1	
		Temperate Broadleaved	2	
		Temperate conifers mixed with broad Leaved	2	

		Temperate mixed conifer	2	
		Temperate Grasslands and scrubs	3	
		Dumping site	5	
		River	4	
2.	Drainage Density	very low	1	3
		Low	2	
		Medium	3	
		High	4	
		Very High	5	
3.	Slope(Degree)	0-5	5	3
		5-15	4	
		15-30	3	
		30-45	2	
		>45	1	
4.	Aspect(M)	Flat	5	3
		North	1	
		North-East	3	
		North-West	3	
		South	4	
		South-West	3	
		South-East	2	
		East	5	
		West	3	
5.	Geology	Bandal Granites	1	5
		Quartzite and Meta volcanic	2	
6.	Road Euclidian Distance(M)	>500	1	4
		500-1000	2	
		1000-2000	3	
		2000-3000	4	
		>3000	5	
7.	Linenement Density	Very Low	1	4
		Low	2	
		Moderate	3	
		High	4	
		Very High	5	

The major rock type of the area has been given score according to their relative importance for landslide hazard. Where lineament density is low less weights has been given and where lineament density is high more weights has been given The LULC map was reclassified in to five classes and it is assumed that forest areas are more stable than land use classes. The land use classes like Dumping site, Barren land are given high score because of high risk of landslide Slope classes are reclassified in to five classes according to steepness. Drainage density map were classified in to five classes and more score has been given to the high drainage density and less for low drainage density. Aspect map were classified in to five classes and less score has been given to warmer and dry aspect and more to wet and co ol. Accordingly, proximity to road higher score has been assign to area near to road are more prone to landslide hazards due to more chances of slope failure.

5.1.9. Variation in area change over the three time periods

The change area in km under land use land cover classes during the 1990, 2000 and 2010 is shown in table 15. Results shows that in year 1990 total forest area was 60.81percent dominant forest class was temperate mixed conifers with area 32.81percent followed by Temperate Broad leaved ,Temperate coniferous mixed with broad leaved, and Chir Pine with corresponding area 16.8 percent, 10.92 percent and 1.01 percent respectively.Amoung the other land cover and land use classes area occupied by Settlement-Agri-Horticulture was 20.81percent ,temperate grassland and scrubs7.03 percent, Snow 7.69 percent, Alpine grasslands percent ,Barren land percent, and landslide percent. In year 2000 forest area decreased to 57.35 percent and further decrease to 50.40 percent in 2011, the change of 3.47 percent from1990 to 2000 and change of 6.95 percent and from 2000 to 2011 has been observed. Although there is increase in Settlement-Agri-Horticulture, Landslide, Barren land and temperate Grasslands and scrubs classes, it was found that from 1990 to 2000 area under Settlement-Agri-Horticulture increased by 1.44 percent from 2000 to 2011 by 5.05 percent .Two more land use classes viz. Dumping site and dam site are included in 2011. The most significant changes took place in forest and settlement-Agri-Horticulture classes, forest cover has declined and replaced by Settlement-Agri-Horticulture and other human managed systems. The change area in km under land use land cover classes during the 1990, 2000 and 2010 is shown in table. The

Table 13: Comparisons of Land Use Land Cover area for three time periods.

Sl. No.	Land use/land cover	Area(km^2)		
		1990	2000	2010
1.	Chir pine	2.65	2.40	1.30
2.	Temperate Mixed coniferous	86.63	81.17	74.34
3.	Temperate Coniferous mixed with Broad Leaved	28.82	26.49	21.39
4.	Temperate Broadleaved	42.45	41.35	36.02
5.	Temperate Grasslands and Scrubs	18.55	20.52	21.62
6.	Alpine grassland	5.41	5.64	8.59
7.	Snow	20.31	20.22	16.70
8.	River	2.85	2.85	2.82
9.	Settlement - Agri-Horticulture	54.93	58.74	72.07
10.	Barren Land	1.35	4.38	6.65
11.	Landslide	0.05	0.25	2.41
12.	Dam site	0.00	0.00	0.04
13.	Dumping site	0.00	0.00	0.06
	Total	264.00	264.00	264.00

5.2. Forest density

The change area in km^2 under forest density classes during the 1990, 2000 and 2010 is shown in table 16. In year 1990 the high density class occupied 26.81percent, medium 29.30 percent and low 4.93 percent. Area under high density class decreased to 19.07 percent in 2000 and followed by 12.4 percent in year 2011. Medium density class also shows decreasing trends over three time periods. Low density class increased in year 2000 and in year 2011 increases to 19.2 percent. The decrease trend of forest density is because of increased human interference in forest areas for extraction of various forest recourses. According to report of forest department of Himachal Pradesh in 2002 forest canopy density above 40 percent to total forest area in state was 24.6 percent and 10-40 percent class it was 10.7 percent.(Anon 2002)

Table 14: Comparisons of forest density area for three time periods.

Sl. No.	Forest Density	Area(km²)		
		1990	2000	2010
1	High density (>70 percent)	70.79	50.35	32.87
2	Medium density (40-70 percent)	77.35	76.72	49.37
3	Low density (10-40 percent)	12.41	24.33	50.81
4	Temperate Grasslands and Shrubs	18.55	20.52	21.62
5	Alpine grassland	5.41	5.64	8.59
6	Snow	20.31	20.22	16.70
7	River	2.85	2.85	2.82
8	Settlement & Agri-Horticulture	54.93	58.74	72.07
9	Barren Land	1.35	4.38	6.65
10	Landslide	0.05	0.25	2.41
11	Dam site	0.00	0.00	0.04
12	Dumping site	0.00	0.00	0.06
	Total	264.00	264.00	264.00

5.3. Forest fire risk Zonation

In the year 1990 the area under very high risk was 11.18 percent followed by 23.74, 22.29, 12.54 and 30.25 percent for high, moderate, low and least respectively. High risk area is increased to 16.65 percent and in 2000 increased up to 25.83 percent in 2011.There is slight increase in high risk area in 2000 and decrease in 2011and for moderate class area decreased in 2000 and then increased .and then increased in 2011 again.

Table 15: Comparisons of forest fire area for three time periods.

Sl. No.	Forest fire risk zone	Area(km2)		
		1990	2000	2010
1.	Least	29.52	43.95	68.18
2.	Low	62.67	63.95	53.56
3.	Moderate	58.84	33.80	40.07
4.	High	33.11	46.41	56.84
5.	Very High	79.86	75.90	45.35
	Total	264.00	264.00	264.00

5.4. Landslide hazard zonation

Table 16: Comparisons of landslide hazard zonation area for three time periods

Sl. No.	Landslide Risk Zone	Area (km^2)		
		1990	**2000**	**2010**
1	Least	28.48	10.20	3.15
2	Low	51.63	23.17	19.25
3	Moderate	92.68	53.85	50.75
4	High	69.82	90.45	82.78
5	Very high	21.39	86.33	108.07
	Total	**264.00**	**264.00**	**264.00**

In the year 1990 10.79 percent area was in least class and in 2000 it decrease to 3.86 percent and decrease further 1.19 percent in 2011. Low and moderate class shows same trend over the years. area in high class was 26.45 percent in 1990 and it increase to 34.26 percent in 2000 than it shows decrease of 3percen.In very high class area increases very drastically, in 1990 it was 8.10 percent and increased by 24.60 percent due to construction of roads and increased development activities and increased further to by 8.22 percent in 2011. According to Chandel et al., 2011 the 32 percent area of Kullu district comes under severe zone for landslide ,only 19.42 percent comes under moderate and 0.42 percent area under low` or no risk.

5.5. Population density

The population density increase trend over the years. Total population of study area was 10131 in 1990 and increase to 12610 in 2000 and further increase to 15580 in 2010

5.6. Applicability of SPCA for assessing the environmental vulnerability

The results computed from spatial principal component are described in table 13. Covariance matrix for each variable is established and eigenvalue for each year were calculated. On the basis of eigenvalue contribution of each component were calculated.

Table 17: Results of spatial principal component analysis

	Principal Components				
	I	II	III	IV	V
2010					
Eigenvalue	1.3654	0.6763	0.4206	0.2709	0.0647
Contribution Ratio (percent)	48.79	24.17	15.03	9.68	2.31
Cumulative Ratio (percent)	49.67	67.59	83.71	98.24	100
2000					
Eigenvalue	1.3328	0.6347	0.4164	0.2618	0.0620
Contribution Ratio (	49.22	23.44	15.38	9.67	2.29

percent)					
Cumulative Ratio (percent)	49.22	72.66	88.04	97.71	100
1990					
Eigenvalue	1.3292	0.6255	0.4125	0.2650	0.0616
Contribution Ratio (percent)	49.34	23.22	15.31	9.84	2.29
Cumulative Ratio (percent)	49.34	72.56	87.77	97.71	100

On the basis of confirmed principal components the integrated evaluation index was computed

EVI 2010 = 1.3654*P1+0.6763*P2+0.4206*P3+0.2709+P4*0.0647

EVI 2000 = 1.3328*P1+0.6345*P2+0.4164+P3*0.2618+P4+0.0620*P5

EVI 1990 = 1.3292*P1+0.6255*P2+0.4125+P3*0.2650*P4+0.0616*P5

5.6.1. Vulnerability Gradation

Result computed from EVI are continuous value and these are classified in to several classes which stands for the different environmental vulnerability classes on the basis of histogram analysis. Histogram is a graphical tool to explore the statistical distribution of classes and cluster in attribute space(Apan 1997).Computed results are analysed through histogram of index distribution to line out the dividing points between cluster .The analysed results divided in to five classes viz. Potential vulnerability. Slight .Medium, High and severe. Vulnerability classification is shown in table 14.

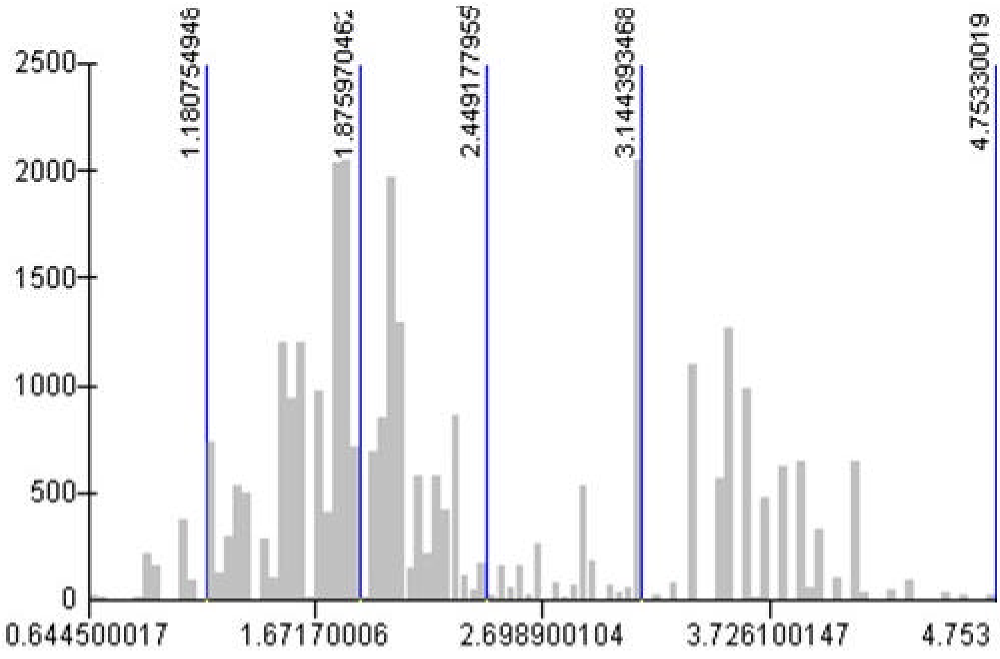
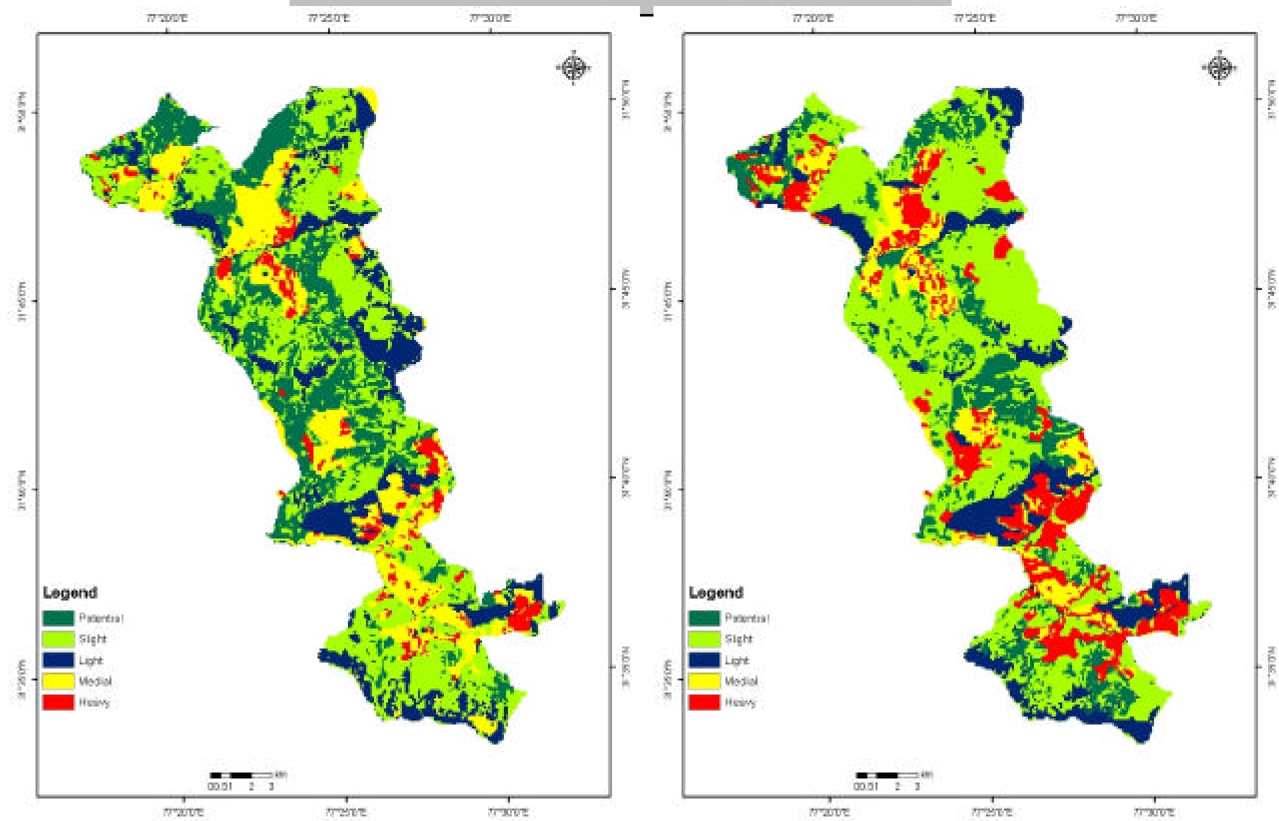


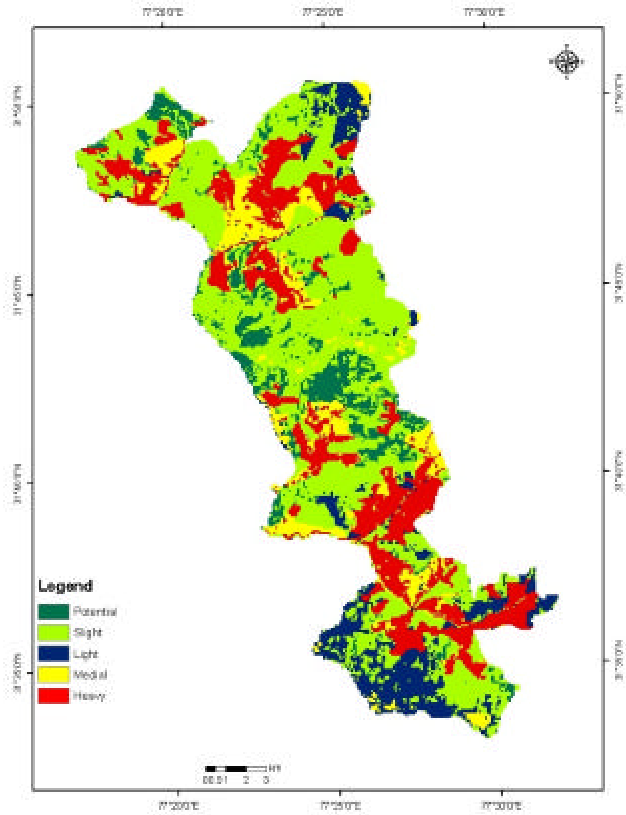
Figure 5-10: Histogram showing integrated evaluating results for the year 2010

Table 18: Vulnerability classification

Evaluation Level	Number	EVI
Potential Vulnerability	I	<1.18
Slight Vulnerability	II	1.18-1.87
Medium Vulnerability		1.87-2.44
High Vulnerability	IV	2.44-3.14
Severe Vulnerability	V	>3.14



(a) (b)



(c)

Figure 5-11: Environmental vulnerability maps (a) 1990 (b) 2000 (c) 2010

The figures 5-11 (a),(b) and (c) shows the final environmental vulnerability maps for all the three time periods 1990, 2000 and 2010.

Table 19: Result computed from the equation (4-5) and proportion of each level in study area

Time Period	**1990**			**2000**			**2010**		
Environmental Vulnerability Class	Grid Number	Percentage	EVSI	Grid Number	Percentage	EVSI	Grid Number	Percentage	EVSI
I	7173	22.47	2.4457	5165	16.18	2.6139	3044	9.53	2.8898
II	12050	37.14		14461	45.29		14885	46.62	
III	5540	17.35		4532	14.19		3548	11.11	
IV	5450	17.07		3076	9.63		3440	10.77	
V	1716	5.37		4693	14.70		7010	21.95	

Table 19 shows the percentage of area coming under each vulnerability class with respective grid number. On the basis of equation (4-5), EVSI value of whole study area has been calculated for year 1990, 2000 and 2010 and change trend of vulnerability is analysed. EVSI value for 1990, 2000 and 2010 was 2.4457, 2.6139 and 2.8898 for year 1999, 2000 and 2010 respectively. Higher is the EVSI value, higher the environmental vulnerability. According to EVSI value the state of environment was better in 1990 as compared to 2000 and 2010.

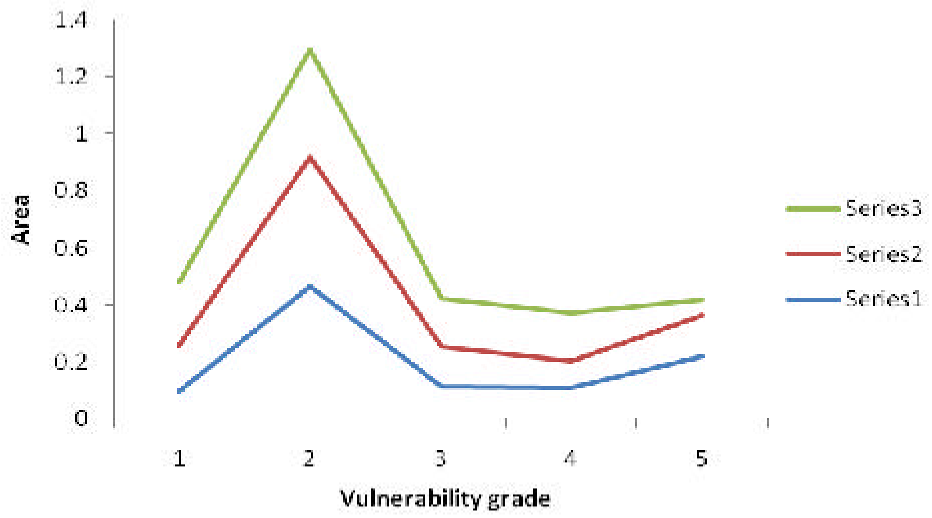


Figure 5-12: Distribution of vulnerability over the three time periods

Series 3 represents the year 1990, series 2 represent 2000 and series 1 represent 2010.the vulnerability trend is showing normal distribution. Above graph shows that the area under level I decreased from 1990 to 2010.Correspondingly area under level V increased over the years. level III and level IV showing decreasing trend from 1990 to 2010.while area under level II is increasing from 1990 to 2010.These profiles indicates that environmental vulnerability is increasing in the study area.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The overall aim of the study was to assess the environmental vulnerability of the study area. The results of the study fulfil the aim of the work and are able to provide satisfactory answers to all the research questions raised in the beginning of the project.

Research Question 1: *What are the factors responsible for environmental vulnerability in the study area?*

Answer: Based on the reconnaissance survey, preliminary information from local authorities and previous studies, five relevant factors were identified as the major cause of environmental vulnerability of the study area. The factors are landslide, forest fire, landuse land cover change, forest density and population density. The outcome of the study confirmed the observation as there was a significant increase in the vulnerability of the region as indicated by high EVSI value for the present time period.

Research Question 2: *What is the change pattern of environmental vulnerability in the study area?*

Answer: As evident from the EVSI values obtained from the study, the environmental vulnerability of the study area is increasing. The EVSI in 1990 is 2.44 which increased to 2.61 and further to 2.88 for 2000 and 2010 respectively. The increase in the environmental vulnerability may be attributed to ongoing construction of hydro power projects within and close proximity to study area, increasing road network and destruction of natural resources due to anthropogenic pressure and natural factors such as forest fire and landslide.

Research Question 3: *What are the alternative measures available for decreasing the environmental vulnerability in the study area?*

Answer: In order to suggest alternatives measure to Great Himalayan National Park authority and to make results effective for practical use and as a base of recovery for local ecosystem, the regionalization of environmental vulnerability so assessed has been done in to three regions viz. Region of Strict Protection, Region of Focal Protection and Region of Compositive development. The figure 6-1 represents the regionalization of vulnerability with the indication of three sub regions.

I. **Region of Strict Protection:** The region where environmental vulnerability is severe is identified as region of strict protection .This region comprises 66.76 km^2 area and constitutes 25.82 percent of the total area. Pertaining to the severity of the area all the development activities must be monitoring effectively by authority and proper reclamation plan for ecological recovery is immediately needed.

II. **Region of Focal protection:** Light and medial vulnerability is for focal protection area under this region is 75.11 km^2 and constitute 29.04 percent of total area. In this region the improvement of implementation of conservation measures is needed. These measures can be to provide alternative sources of income to local people and active participation of local people in effective manner is recommended.

III. **Region of Compositive development:** Slight vulnerability region for Compositive development. This region comprises 116.74 km^2 and constitutes 45.14 percent of the total study area. In this region human activities should reduced as much as possible.

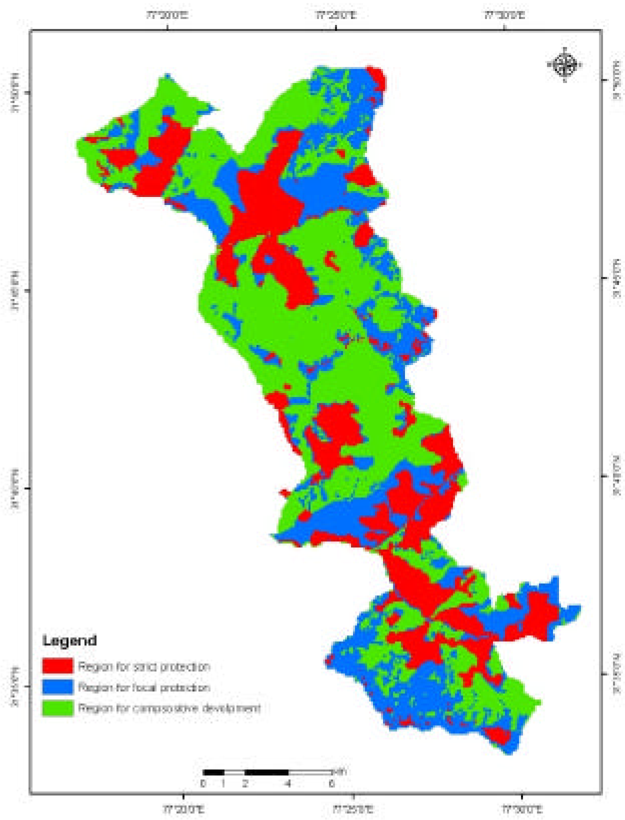


Figure 6-1: Regionalization of vulnerability

6.2. Recommendations

While this study provided a clear insight of the state of environment in the study area, more precise assessment and quantification of environmental vulnerability is possible. The future studies based on the themes of the present work should consider the following points to achieve more improved outcomes:

- Incorporating more number of factors such as climatic, soil, socio-economic and environmental quality parameters which the present work didn`t considered due to time limitation of MSc project may improve the overall environmental vulnerability estimates.

- Use of participatory GIS method is recommended as interest of the local stakeholders are well represented, hence the outcomes may provide better vulnerability assessment and subsequently more relevant mitigation plans.

LIST OF REFERENCES

Ainong, Li. et al., 2006. Integrated evaluation model for eco-environmental quality in mountainous region Based on Remote Sensing and GIS. *Wuhan University Journal of Natural Sciences*, 11(4), pp.969–976.

Anon, Building Resilience in SIDS The Environmental Vulnerability Index. *Vulnerability Index*. Available at: http://www.vulnerabilityindex.net/Files/EVI%20Final%20Report%202005.pdf [Accessed August 21, 2011a].

Anon, 2002. *Himachal Forest*, Shimla, Himachal Pradesh: Forest department Himachal Pradesh.

Anon, 2011a. IUCN to inspect Great himalayan national park Next Year. *Times of India*.

Anon, 2011b. *Kullu District Disaster Management Plan*, Kullu, Himachal Pradesh: District Administration Kullu.

Anon, 2009a. *State of Environment Report Himachal Pradesh*, Shimla, Himachal Pradesh: Department of Environment,Science & Technology,Government of Himachal Predesh.

Anon, 2009b. UNISDER Termnilogy on Disaster Risk reduction.

Anon, Available at: http://www.faith.edu.tr/~mcadams/pob/PCA GIS 9.pdf.

Anthony, G.Y. & Li, X., 1998. Sustainble land development model for model for rapid growth areas using GIS. *Journal of Geoinformation Science*, 12(2), pp.169–189.

Bibby, C.J. et al., 1992. *Putting biodiversiy on map: priorty areas for conservation*, International Council for Bird Preservation.

Boori, M.S. & Amaro, V.E., 2010. Detecting and understaing drivers of natural and eco-environmental vulnerability due to hydro geophysical parameters,ecosystemm and land use change through multispectral satellite data sets in Apodii eturine,Northeast Brazil. *International Journal of Environmentall sciences*.

Bradley, M.P. & Smith, E.R., 2004. Using Science to Assess Environmental Vulnerabilities. *Environmental Monitoring and Assessment*, 94(1-3), pp.1–7.

Calais, M.D. et al., 1996. An indicator of solid waste generation potential for Illinois using principal component analysis and geographic information system. *Journal of the Air and Waste Management Association*, 46, pp.414–419.

Chambers, R., 1989. Vulnerability.Editorial introduction.

Chandel, V.B.S., Brar, K.K. & Chauhan, Y., 2011. RS & GIS Based Landslide hazard Zonation of Mountainous Terrains A Study from Middle Himalayan Kullu District, Himachal Predesh, india. *International Journal of Geomatics and geosciences*, 2.

Chang-Ching, Y. et al., 1998. Effective dimensionality of environmental indicators: a principal component analysis with boothstrap confidence intervals. *Journal of Environmental Management*, 53, pp.101–119.

Choubey, V.M. et al., 2007. "Geological and tectonic Influence on water-Soil-Radon Relationship in Mandi-manali area,Himachal Himalaya". *Environmental Geology*, 52, pp.1163–1171.

Dzeroski, S., 2001. Applications of symbolic machine learning to ecological modelling. *Ecological Modelling*, 146(1-3), pp.263–273.

Enea, M. & Salemi, G., 2001. Fuzzy approach to the environmental impact evaluation. *Ecological Modelling*, 136(2-3), pp.131–147.

Enete, I.C., Alabi, M.O. & Adoh, E.N., 2010. Evaluation of Eco-Environmental Vulnerability in Efon Alaye Using Remote Sensing and Geographic Information System (GIS) Techniques. *Journal of Sustainable Development in Africa*, 12(40.

Fan Zhewen et al., 2009. GIS-Based Assessment on Eco-vulnerability of Jiangxi Province. In *Environmental Science and Information Application Technology, 2009. ESIAT 2009. International Conference on.* Environmental Science and Information Application Technology, 2009. ESIAT 2009. International Conference on. pp. 426–431. Available at: http://ezproxy.itc.nl:3060/stamp/stamp.jsp?tp=&arnumber=5199724.

Fattahi, M., 2011. Landslide Hazard Zonation of Babolrood Watershed,Iran. *2nd International Conference on environmental Science andTechnology*, p.6.

Gaston, A.J. & Grason, P.J., 1993. A RE-Appraisal on the Great HimalayanNAational Park .

Gaston, A.J., Hunter, M.L. & Grason, P.J., 1981. The wildlife of Himachal Predesh,Westran himalayas. Report of Himachal Wildlife Project.

Geoff, C., 2004. *Practical Strategy*, Pearson Education Limited.

Goda, T. & Mastuoka, Y., 1986. Synthesis and analysis of a comprehencive lake model-with the evaluation of diversity of ecosystem. *Ecological Modelling*, 31, pp.11–32.

Haigh, M.J., Rawat, J.. S. & Bartaya, S.K., 1989. Environmental indicators of landslide activity alomg the kilbury road Naine Tal,Kumaun Lesser Himalaya. *Mountain Research and development*, 9, pp.25–33.

Hao, Y. & Zhou, H.C.H., 2002. A grey assessment model of regional ecoenvironment quality and its application. *Environmental Engineering*, 20(4), pp.66–68.

Hyandye, C., Tao, W. & Hua, C. zhi, 2008. Evaluation of Eco-Environmental Vulnerability Using RS and GIS: Case of Ma Keng Iron Mining Area in Fu Jain Province,China. *Environmental Research Journal*, 2(4).

Jain, A. et al., 1996. Forest Fire risk Modelling using remote sensing and geographic information system. *Current Science*, 70(10), pp.928–933.

Jaiswal, R.P., 1987. *Revised Working Plan for Seraj forest division*, Shimla, Himachal Pradesh: Deparment of Forest Farming and Conservation Himachal Pradesh.

Kaly, U. et al., 1999. *Environmental Vulnerability Index (EVI) to summarise national environmental vulnerability profiles*, Fijji: South Pacific Applied Geoscience Commission (SOPAC). Available at: http://dev.sopac.org.fj/VirLib/TR0375.pdf.

Kaly, U., Craig, P. & Howarth, R., 2002. Towards Managing environmental Vulnerability in small island Developing States(SIDS).

Khanna, L.S., 1998. *Forest Protection*, Khanna Bhandhu.

Kristov, V., 2004. Investigations of indirect relationships in ecology and environmental sciences: a review and the implications for comparative theoretical ecosystem analysis. *Ecological Modelling*, pp.39–54.

Kvaerner, J.-N.I. for A. and E.R., Swensen, G. & Erikstad, L., 2006. *Assessing environmental vulnerability in EIA-The content and context of the vulnerability concept in an alternative approach to standard EIA procedure*, USA.

Li, A. et al., 2006. Eco-environmental vulnerability evaluation in mountainous region using remote sensing and GIS--A case study in the upper reaches of Minjiang River, China. *Ecological Modelling*, 192(1-2), pp.175–187.

Mathur, V.B. & Naithani, S., 1999. *Development of a Spatial Database of the Great Himalayan National Park Conservation Area (GHNPCA) in GIS Domain*, Kullu: Great Himalayan National Park. Available at: http://oldwww.wii.gov.in/envis/ghnp_reports/1_3_mathur_naithani.pdf [Accessed August 7, 2011].

Mehaffey, M. et al., 2008. Assessing vulnerabilities from alternative development patterns. *Landscape and Urban Planning*, 87(1), pp.84–95.

Metzger, M.J. et al., 2006. The vulnerability of ecosystem services to land use change. *Agriculture, Ecosystems & Environment*, 114(1), pp.69–85.

Nagia, S. & Kumar, P., 2001. Population And Environment Interface in the Great Himalayan National Park. Available at: http://www.iussp.org/Brazil2001/s00/S08_P08_Sudesh.pdf [Accessed August 7, 2011].

Nagia, S., Kumar, P. & Rathore, M.P., 1999. *Social Context and Socio-Economic Conditions of People Using GHNP and WLSs*, Kullu: Great Himalayan National Park. Available at: http://wiienvis.nic.in/ghnp_reports/4_15_nangia_kumar_rathore.pdf [Accessed August 7, 2011].

Nilsson, C. & Grelsson, G., 1995. The fergility of ecosystem: a review. *Journal of Appalied Ecology*, 32(4), p.677–92.

PANDEY, S. & WELLS, M., 1997. Ecodevelopment planning at India'sGreat Himalayan National Parkfor biodiversity conservationand participatory rural development. *Biodiversity and Conservation*, 6(9), pp.1277–1292–1292.

Parinet, B., Lhote, A. & Legube, B., 2004. Principal component analysis: an appropriate tool for water quality evaluation and management--application to a tropical lake system. *Ecological Modelling*, 178(3-4), pp.295–311.

Planning commission of India, 2005. *Himachal Pradesh Development Report* 2005th ed., New Delhi.: Academic Foundation with Planning Commission, Government of India. Available at: http://www.easternbookcorporation.com/moreinfo.php?txt_searchstring=10131.

Porwal, M.C. et al., 1997. Spasial modelimg for fire risk zonation using Remote sensing and GIS. *Applicatonof remote sensing and GIS for sustainble development,Hydrabad.*

Porwal, M.C., Nandy, S. & Lal, J., 2009. *A Geospatial apporch for identifiying areas prone to fire in Ghori Range(Part of Gharwal Himalayas)utterakhand, India* first., Rawat Brothers.

Pressey, R.L. & Taffs, K.H., 2001. Scheduling conservation action in production landscapes: priority areas in western New South Wales defined by irreplaceability and vulnerability to vegetation loss. *Biological Conservation*, 100(3), pp.355–376.

Ramesh, K., Satayakumar, S. & Rawat, G.S., 1998. Rsent Trends in the pheasent population in Great Himalayan NationalPark,Westran Himalaya.National semonar on wildlife research and conseravation.

Rao, K.S. & Pant, R., 2001. Land use dynamics and landscape change pattern in a typical micro watershed in the mid elevation zone of central Himalaya, India. *Agriculture, ecosystems & environment*, 86(2), pp.113–124.

Roy, P.S. & Porwal, M.C., 2004. Forest Fire Risk Zonation using Geo-Spatial Modeling in part of Rajaji national Park,Uttaranchal. *Asian Journal of Geoinformatics*, 5(3), pp.40–46.

Sabbwrwal, V. k. & Chhatre, A., 2003. The Parvati and the Tragopan: Conservation and Development in the Great Himalayan National Park. *Himalayan Research Bulletin*, 21(2), pp.79–88.

Sarkar, S., Kaunungo, D.P. & Mehrotra, G.S., 1995. "Landslide Hazard zonation:A case study in gharhwal Himalaya, India". *Mountain Research and development*, 15(4), pp.301–309.

Satty, T.L., 1980. The analytical hierarcchy Process? : Planning,pririrty setting,resourse allocation. *McGraw Hill*.

Shah, M.P. & Mazri, R.K., 2007. An overview of the Geoenvironmental Status of the Kullu Valley, Himachal predesh,India.Journal of Mountain Science. *Journal of Mountain Science*, 4(1), pp.3–23.

Singh, S.K. & Rawat, G.S., 1998. vegetation monitoring in Great Himalayan National Park.

Tiwari, P.C., 2000. Land use changes in Himalayas and their impact on plains ecosystem? : need for sustainble land use. *Land use Policy*, 17(2).

Tixier, J. et al., 2004. Software for determining the environmental vulnerability index based on G.I.S. information.

Tucker, R., 1997. *The Historical Development of Human Impacts on Great Himalayan National Park*, Kullu: Great Himalayan National Park. Available at: http://wiienvis.nic.in/ghnp_reports/4_14_tucker.pdf [Accessed August 7, 1997].

Unyal, V.P. & Mathur, P.K., 1998. Study on insect diversityof Great himalayan National Park.

Vinod, T.R., Goyal, S.P. & Satyakumar, S., 1997. Habitat use by ungulates,bears and pheasants in Great Himalayan national Park,Westarn Himalaya.

Wakeel, A. et al., 2005. Forest management and land use/cover changes in a typical micro watershed in the mid elevation zone of Central Himalaya, India. *Forest Ecology and Management*, 213(1-3), pp.229–242.

Wang, X.D. et al., 2008. Regional assessment of environmental vulnerability in the Tibetan Plateau: Development and application of a new method. *Journal of Arid Environments*, 72, pp.1929 – 1939.

Wilson, K. et al., 2005. A vulnerability analysis of the temperate forests of south central Chile. *Biological Conservation*, 122(1), pp.9–21.

Zhi, H.S. et al., 2009. The affect of land use change on environmental quality in red soil hilly region: A cae study in Xianning country. *Environmental Monitoring and Assessment*, 150, pp.295–306.