CRITICAL ECOSYSTEM MODELING AND ANALYSIS OF DARJEELING DISTRICT, WEST BENGAL, INDIA USING GEOSPATIAL TECHNIQUES

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CERTIFICATE

This is to certify that **Mr. Sivi Mor** has carried out his project entitled **"Critical ecosystem modeling and analysis of Darjeeling district, West Bengal, India using Geospatial techniques",** in partial fulfillment for the award of degree of **Master of Technology in Remote Sensing and Geographic Information System**. The project has been carried out in **Forestry and Ecology Department** and is original work of the candidate under the guidance of **Dr. Arijit Roy,** Scientist/Engineer-SE and **Dr. Hitendra Padalia,** Scientist/Engineer-SE, at Indian Institute of Remote Sensing, Dehradun, India.

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ABSTRACT

Owing to the ever increasing demand for space and resources, conservation has become the last resort for protecting nature and ecosystem. In the recent years, in many places in the world, natural ecosystems are being threatened by human activities. Vulnerability assessment has become necessary in order to improve efficiency and effectiveness for management. Besides that, the vulnerability information can be a consideration for regional management authorities. This paper provides an analysis of land use land cover (LULC) changes in the study area with different biophysical environments in the Darjeeling district. Landsat images acquired during the years of 1977 and 1985 and LISS I image of 1997, LISS III Images of 2005 and 2012 were used to examine LULC change trajectories. A classification system composed of sixteen classes – sub-tropical broadleaved, temperate broadleaved, sal, mixed moist deciduous, temperate coniferous, bamboo, tree clad, scrub, shrubland, agriculture, plantation, tea, dry river bed, perennial river, lake/pond and built up. The study sought to identify prevalent land use changes and link them to socio-economic factors that drive them using hotspot identification procedures. To achieve this post classification, change detection was conducted between each successive two time periods using Landsat 5 1977 and Landsat 5 1985, Landsat 1985 and LISS I 1997, LISS I 1997 and LISS III 2005, and LISS III 2005 and LISS III 2012 to detect changes at the district level to produce a change matrix of each time period and change map. Hotspot identification procedures were also applied to identify local areas with high concentration of LULC changes. The analysis of the change detection revealed that forest area has decreased from 1422.88 sq. km. in 1977 to 1343.17 sq. km. in 2012 due to transfers to tea plantations. Hotspot identification resulted in an area of 1607. 76 sq. km. which is 51.06% of the total geographical area of the district. The analysis of hotspot indicated that Gorubathan is the block undergoing most forest transfers followed by Darjeeling Pulbazar with the least area in Kharibari. The ecological vulnerability area of the district is computed to be 1605.27 sq. km. which is 50.98% of the total geographical area of the district. Gorubathan block is found to have the largest area with 346.44 sq. km. under different ecological vulnerability zones. However, the maximum area of 48.43 sq. km. under zone 10 of the ecological vulnerability area which is also considered to be critical ecosystem is found in Kalimpong I block. Kharibari block with an ecological vulnerability area of 7.52 sq. km. is the block with the least area under ecological vulnerability zone. The total area of 232.50 sq. km. in the district which falls in the zone 10 of ecological vulnerability area can be considered as the critical ecosystem.

Keywords: Land use and land cover (LULC), change detection, hotspot, threat, vulnerability, critical ecosystem.

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I dedicate this piece of work to my loving father ***Shri. Zakiezoto Mor*** *and mother* ***Smti. Lhouyievino Mor***

"We do not inherit the earth from our ancestors, we borrow it from our children".

~Native American Proverb~

CHAPTER-1

INTRODUCTION

1.1 General introduction

Various aspects of our planet are altering rapidly at unprecedented rate, magnitudes and spatial scales due to human activities and these changes are expected to accelerate during the next decades (Vitousek et al., 1997, IPCC, 2001a). Many species are threatened with extinction (Thomas et al., 2004), and rising atmospheric carbon dioxide has resulted in global warming (IPCC, 2001a). Many of these changes will have an immediate and strong effect on soil and water quality, ecosystem processes, function, and global climatic systems as a whole (Chen et al., 2001; Kilic et al., 2006; Turner, 1994).

Land use and land cover change is gaining recognition as a key driver of environmental change (Dale, 1997; Imbernon, 1999; Meyer and Turner, 1991). The modification and conversion of land cover is driven by interaction in space and time between biophysical and human dimensions (Turner et al., 1993). However, human factors determine where and to what extent land use is modified at a certain location (Verburg and Chen, 2000). With the awareness of the importance of land-use in global change, the study of regional or global land use and land cover change has become the focus of much scientific endeavor internationally (Turner et al., 1993). In the past research was focused only on land use and land cover conversions. Therefore, a need to better understand the relationship between land use and land cover changes, and regional environment change that drive them. With a more complete understanding of those drivers, it is possible to project changes that are likely to occur, proposed management options that might be successful for a given biophysical/socioeconomic/ political situation, and the potential impacts on environment quality.

Darjeeling Hill areas are unique from environmental Eco-perception. The relief of the district varies from about 100 Mts. above sea level to the mighty Kanchenjunga at 8586 Mts. The region has different climatic zones with distinctive attributes and home to endangered animals like red panda etc. along with numerous orchids and medicinal plants. The ecosystem in the Darjeeling Hill has been under tremendous human pressure over the years due to influx of tourists. Due to unprecedented growth of population in the hills, forests are being cleared for the extension of agricultural lands, introduction of new settlements, roadways etc. The incessant changes in the wake of urbanization and industrialization has resulted in disruption of normal ecosystem functioning. Even though some remedial measures have been initiated by involving the local communities and the government agencies, success have been only partial. The consequences of the continuing exploitation of the ecosystem if unchecked will have a major impact on the state of the environment (http://www.unep.org/maweb/en/SGA.Eastern Himalayas.aspx).

This present work has been carried out to assess and model the environmental vulnerability in Darjeeling Himalayas and identify critical ecosystem, with respect to stress factors on the local environment. Environmental vulnerability assessment is an important tool to know how natural and anthropogenic stresses are affecting the local environment. For this 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 critical ecosystem affected by natural condition as well as those influenced by human activities (Fan et al., 2009). Moreover it is an important method to determine the potential causes of environmental vulnerability, for formulating proper conservation and restoration measures for sustaining the mountain ecosystem as well as generation of future forecast of threats to environment for reduction of risk.

The present study aims at assessing and modeling the trend of environmental vulnerability and analyzing and identifying the critical ecosystem of Darjeeling Hill area, West Bengal over five time period (1977, 1985, 1997, 2005 and 2012). This assessment of critical ecosystems can be of great value to the policy makers and environmentalists for further conservation process and sustainability of the study area.

1.2 Need of the study

The environmental degradation due to aggravated impacts of rapidly increasing population pressure and developmental activities, pose great threat to ecosystem and biodiversity of Darjeeling Hill area. The Darjeeling Himalayan Area is famous for tourism, tea, and timber, with tourism being its most important source of revenue. The area is, however, ecologically fragile and under severe pressure due to the demands made on environmental resources by growing tourist traffic and rapid urbanization. Environmental stress is evident from the degradation of forests and deforestation due to an increased demand for fuel wood and timber, air pollution because of an increasing reliance on motor vehicles, and lack of basic urban infrastructure such as water supply, sanitation, and solid waste management systems. As the mountains serve as the repositories of resources for the population residing in the hills as well as in the plains, extensive environmental degradation in form of extraction of timber and other forest produces, mining and agriculture is leading to irreparable damage to the ecosystem structure and functioning. Many of the ecosystems in the Darjeeling Hill area have become vulnerable and it is imperative that the critical areas are identified for their conservation and protection.

This research project on critical ecosystem assessment/modeling will identify available data, methods, analytical tools, and gaps and develop GIS applications to identify critical ecosystems or to assess environmental impacts. Based on this collective assessment of available resources, this research identifies the existing opportunities, important challenges and research priorities for enhancing future regional critical ecosystems assessments.

1.3 Research Objectives

The main objective of the research is to detect the spatial and temporal patterns of critical ecosystem in the mountainous region of Darjeeling Hill with specifics objectives pertaining:

- To identify and prepare the drivers for critical ecosystem analysis in the study area.
- To develop model for assessment and evaluation of critical ecosystem.
- To analyse the trend of change in critical ecosystem in the study area.
- To project the future status of critical ecosystem in the study area.

1.4 Research Questions

- How to identify the factors that contribute to critical ecosystem?
- How to determine and evaluate the critical ecosystem through various methods/models?

1. 5 Structure of the thesis

The entire content of the thesis has been divided into following chapters:

1. Introduction: The thesis starts with a synoptic view on the general introduction, including the need and aim of the study.

2. Review of literature: This chapter includes the review of various literatures related with ecosystem and modeling using geospatial techniques.

3. Study area: The chapter gives a glimpse of the study area chosen for present study with its various features.

4. Materials and methods: This chapter elucidates the materials and methods used in the study to achieve the desired objectives and results.

5. Results: The chapter deals with all the outcomes of the results of the study.

6. Discussions: In this chapter all the major findings of the present study are discussed.

7. Conclusions and recommendations: The chapter was drawn upon the results and discussions of the study.

CHAPTER-2

LITERATURE REVIEW

2.1. Ecosystem definition and concept

There are many definitions for ecosystem. The definition given by Christopherson (1997) sums up the essence of ecosystem. An ecosystem is a natural system consisting of all plants, animals and microorganisms (biotic factors) in an area functioning together with all the non-living physical (abiotic) factors of the environment (Christopherson, 1997).

The term ecosystem was coined in 1930 by Roy Clapham, to denote the physical and biological components of an environment considered in relation to each other as a unit. British ecologist Arthur Tansley later refined the term, describing it as the interactive system established between biocoenosis (a group of living creatures) and their biotope (the environment in which they live). Central to the ecosystem concept is the idea that living organisms are continually engaged in a set of relationships with every other element constituting the environment in which they exist. Ecosystems can be bounded and discussed with tremendous variety of scope, and describe any situation where there is relationship between organisms and their environment. There are no conceptual restrictions on how large or small a space or an area must be to host an ecosystem, nor on the minimum numbers species or individual organisms to be present.

Early conceptions of an ecosystem were as a structured functional unit in equilibrium of energy and matter flows among constituent elements. Some considered this vision limited, and preferred to view an ecosystem in terms of cybernetics, which, like any other type of system, is governed by the rules of systems science and cybernetics, as applied specifically to collections of organisms and relevant abiotic components. The branch of ecology that gave rise to this view has become known as systems ecology.

Politically, the concept has become important, since the Convention on Biological Diversity, (CBD), signed by almost 200 nations. The CBD formulates the concept in the following definition: "Ecosystem" means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (Convention on the Biological Diversity, 1992).

2.2 Importance of ecosystem: Ecosystem goods and services

Ecosystems and the biological diversity contained within them provide a stream of goods and services, the continued delivery of which remains essential to our economic prosperity and other aspects of our welfare. Ecosystem goods refer to the natural products harvested or used by humans such as wild fruit and nuts, forage, timber, game, natural fibres, medicines and so on. More importantly, ecosystem services support life by regulating essential processes such as purification of air and water, pollination of crops, nutrient cycling, decomposition of wastes, and generation and renewal of soils, as well as by moderating environmental conditions by stabilizing climate, reducing the risk of extreme weather events, mitigating droughts and floods, and protecting soils from erosion. The benefits of these services manifest themselves at local, regional and global scales with often conflicting demands between stakeholders at these different levels.

One of the most pervasive impacts of current global change is the rapid decline in species and habitat diversity and its replacement with biologically poorer and more homogenous human dominated landscapes. The loss of species is the most widely recognized consequence of such change, and as biodiversity underpins human life support systems, its loss implies significant consequences for humanity. The consequences of ecosystem degradation are experienced more severely in developing countries, the home of the vast majority of the world’s natural capital and to the world’s poor, who are heavily reliant on natural resources for their livelihood and income.

2.3 Ecosystem dynamics

Ecosystems are dynamic entities invariably subject to periodic disturbances and are in the process of recovering from some past disturbance. When an ecosystem is subject to some sort of perturbation, it responds by moving away from its initial state. The tendency of a system to remain close to its equilibrium state, despite that disturbance, is termed its resistance. On the other hand, the speed with which it returns to its initial state after disturbance is called its resilience.

The biotic and abiotic environments of the ecosystems experience variation from year to year. A period of drought, cold winter and even a pest outbreak all constitute short-term variability in environmental conditions. Animal populations vary from year to year, building up during resource-rich periods and crashing as they overshoot their food supply. These changes play out in changes in NPP, decomposition rates, and other ecosystem processes.

Disturbance also plays an important role in ecological processes. F. Stuart Chapin and coauthors define disturbance as "a relatively discrete event in time and space that alters the structure of populations, communities and ecosystems and causes changes in resources availability or the physical environment. Disturbance is followed by succession, a "directional change in ecosystem structure and functioning resulting from biotically driven changes in resources supply (Chapin et al., 2002).

The frequency and severity of disturbance determines the way it impacts ecosystem function. Major disturbance like a volcanic eruption or glacial advance and retreat leave behind soils that lack plants, animals or organic matter. Ecosystems that experience disturbances that sever undergo primary succession. Less severe disturbance like forest fires, hurricanes or cultivation result in secondary succession. More severe disturbance and more frequent disturbance result in longer recovery times. Ecosystems recover more quickly from less severe disturbance events (Chapin et al., 2002).

2.4 Ecosystem vulnerability

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”. 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, 2009b).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 environmental vulnerability is concerned with the damage to the natural environment due to the various stress factors in a particular region. In the present study, the vulnerability is expressed as threat or negative impact to protected area and its resources.

2.5 Critical ecosystem

Research in both landscape ecology and conservation biology makes clear that habitat loss and fragmentation are the primary threats to biodiversity and ecosystem function (Wilcox and Murphy, 1985; Harris and Silva-Lopez, 1992; Forman 1995; Wilcove et al., 1998). As land is converted to intensive uses, landscapes become less capable of supporting wildlife, filtering water, abating floods, cleaning air, and providing a variety of other benefits characteristic of functional ecosystems (Daily 1997; Pimentel et al., 2000). In response, an important application of landscape ecology has been the development of regional-scale conservation analysis and planning. Regional-scale assessments are needed to understand relationships between ecosystems and to better integrate protection and management efforts (Harris 1984; Forman 1995; Turner et al., 1995; Harris et al., 1996a). In particular, the identification of critical areas that is critical ecosystems for protecting various ecosystem functions is essential for conserving natural resources and minimizing the degradation of ecological integrity caused by habitat fragmentation and other impacts (Noss and Harris, 1986; Noss and Cooperrider, 1994; Margules and Pressey, 2000).

In the last two decades, advances in Geographic Information Systems (GIS) technology have led to significant improvements in the amount and quality of spatial data, analysis tools, and applications. These trends have allowed researchers and other organizations to develop spatial data and analytical tools relevant to identifying critical ecosystems. Regional-scale identification of critical ecosystems provides an important foundation for proactive and efficient environmental protection. Therefore, the identification of critical ecosystems could be considered an essential step in ecosystem research to safeguard the environment for present and future generations. The identification of critical ecosystems can provide a coherent framework of protection and management priorities, and such a framework will allow policy makers to target resources more efficiently and develop better policies and programs to protect environmental quality.

2.6 Environmental vulnerability assessment

Environmental vulnerability analysis is innately multidimensional. It is necessary to determine the interrelationship of all factors of vulnerability in order to assess overall environmental vulnerability. 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 modeling (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 method (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 weightage 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).

Human driven land use and land cover change is one of the important causes for depletion of biodiversity. Spatial information on the land use and land cover change hotspots within the biodiversity hotspots and their overlap with the biologically rich areas can help in prioritizing the conservation approach in the study area. Although biodiversity plays an important role in ecosystem functioning, very little is known about the mechanism by which it influences ecosystem function at the landscape level. To understand this, the study should include the influence of external stressors like land use and land cover change, climate and biotic stresses on the biologically rich ecosystems. A method of geospatial modeling used by Roy and Srivastava (2012) to identify the hotspots of land use and land cover change for environmental vulnerability assessment has been found to be very good; hence their method has been used for the present study. Roy and Srivastava, involves the use of different landscape-based indices, terrain features and anthropogenic influences for assessment of environmental vulnerability. The major inputs of the model are: (i) weighed cumulative LULC, (ii) population variability, (iii) terrain impedance, and (iv) naturalness index. This model enables identification of the potential areas of change in the natural vegetation in the biodiversity rich areas and accordingly prioritizes the areas for conservation.

2.7 Land use and land cover change

Land use refers to the function of land to humans which usually emphasis the importance of land in an economic activity. It includes all the arrangements, activities, and inputs undertaken in a certain land cover type in order to reap social, cultural and economic benefits whereas land cover is the physical appearance of land surface which provide visible prove of land use (Campbell, 2002; Meyer and Turner II, 1992). In essence land cover is more obvious on the field than land use which is usually inferred from the cover. These two words are closely linked such that in mapping they are treated together to avoid ambiguity (Lillesand and Kiefer, 1994). Nagendra et al (2004) highlighted the difficulty in splitting the two terms due to the complex feedback loop that exist between them, making it difficult to distinguish effect from cause. According to (Meyer and Turner II, 1992) land use and land cover share a common source of change in the form of human activities that directly alter the physical environment.
Over the years humans have strived to extract higher value from land by converting or modifying the natural cover types through diverse uses. In trying to get benefits from land, a series of transfers is triggered in the use of land which subsequently causes a change of the cover to another state.

Transfers are used as a synonym to change. Land use has been changing since people first began to manage their environment (Metzger et al., 2006). Braissoulis (2000) defines land use and land cover change as the quantitative change in the areal extent of a given type of land use or land cover, respectively. Dyes (2003) limits land cover change to alteration or removal of the vegetation in a landscape. Land cover change is a complex process and deserves a careful study to understand. Land use change is pervasive and spatially heterogeneous; its global significance results primarily from the accumulation of many local changes in many local landscapes (Lambin et al., 2001; Vitousek, 1994).

Changes exist as a complex between subtle modification and total conversion as seen in a change in forest density and from forest to agriculture land (Geist and Lambin, 2001; Meyer and Turner II, 1992; Veldkamp and Lambin, 2001). Meyer and Turner II (1992) observed that landscape conversion is easily monitored and documented due to ease in measuring compared to modifications. For example it is easier to monitor total transfers of forest to agriculture than a change in tree density. However over emphasis on conversion will divert attention from land cover modification which has gained frequency in recent past. The complexity of land cover change is illustrated by the functional differences within types of land cover, structural variance between types of land cover change with regards to spatial arrangement and temporal patterns of change (Geist and Lambin, 2001). The high spatial variability in land cover type, biophysical and socio-economic drivers of land use change around the world result in the variability in the causes and processes of land use change (Serneels and Lambin, 2001).

2.8 Application of Remote Sensing and GIS in Environmental vulnerability assessment

Vulnerability has been associated with spatio-temporal dimensions. Remote Sensing (RS) and Geographic information system (GIS) played a significant 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 environmental 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). RS, GIS and numerical modeling has been developed as a powerful tool for ecological environment assessment (Kristov, 2004).

2.9 Hotspot analysis of the ecosystem

Land use and land cover change and its various dimensions have been an issue of great concern politically and scientifically. This is due to the eminent role these aggregates play in global change. Measurements and analysis of land use and land cover change have often been done at the global level. Geist and Lambin (2001) acclaimed this trend to the need for data as input for carbon cycle analysis and global change modeling. FAO conducted a global forest survey using remotely sensed data in 1990 (FAO, 1996). Global studies have the tendency to generalize issues resulting in the masking of national and local level characteristics. According to Etter et al (2006) even regions and landscape levels show contrasting biophysical and socioeconomic characteristics which differentially affect the potential land use and land cover change. Patterns of land cover change in most tropical developing countries relate significantly to anthropogenic impacts and are extremely complex, with changes occurring across multiple spatial and temporal scales (Southworth et al., 2004). Van Laake and Sanchez- Azofeifa (2004) also argued that global statistics derived from administrative regions and ecological zones fall short in incorporating spatial heterogeneity found in deforestation. Data on land-cover change are relevant for local decision-makers, and those data need to be linked with ground data on human activities (Geist and Lambin, 2001). Hence it is pertinent that studies in land cover changes are done in local areas where they are concentrated in order to establish a link with drivers. Areas with high concentration of land use and land cover changes processes are herein termed as hotspots.

Hotspot analysis generally allows the identification of local areas with high concentration of a phenomenon within a landscape. According to Lambin and Ehrlich (1997) land cover change hotspot can be perceived at three levels: high rates of land cover change which are observed at present, or have been observed in the recent past; areas where land cover changes are likely to occur in the near future; and severity of the impact of the change.

2.10 Review of studies in the past

A method for assessing the vulnerability of socio-ecological systems that is explicitly linked to multiple stakeholder values enabling multiple assessments of vulnerability in the same or different locations. Five thematic layers were used geology, geomorphology, soil, vegetation and land use to define vulnerability and environmental change. The model uses a new approach to ecosystem assessment by integrating the potential impacts in a vulnerability assessment.
So directly applying the vulnerability methodology to the land use change scenarios helps in understanding land use change impacts across the Apodi Valley Region, Northeast Brazil. Scatter plots summarizing impacts per principal unit zone, help in interpreting how the impacts of the scenarios differ between ecosystem services and the environments (Boori and Amaro, 2011)

Hyandey et al (2008) carried out are search to evaluate the eco-environmental vulnerability of Ma Keng mining area for the past 15 years using a numerical environmental evaluation model. Application of GIS and RS technology, assisted by statistical software (SPSS) enabled the extraction and preparation of eco-vulnerability factors and development of the environmental numeric model. This was eventually used to evaluate eco-environmental model namely slope, elevation, soil types, land use, vegetation types, industrial dust pollution, industrial sulfur dioxide gas (SO2) emission and soil erosion. An Eco-environmental Vulnerability Index (EVI) of the study area for the years 1992, 1998, 2001, 2004 and 2007 were calculated using the environmental numeric model and the results were classified using the cluster principle. The research results showed that the Eco-environmental Vulnerability Integrated Index (EVSI) was increasing with time from 1992-2007. The results further revealed that the eco-vulnerability degree is vertically distributed, whereby the low elevation regions are worse than those in higher elevations.

Another basic issue for the evaluation of a model is to assign weights to each factor according to its relative effects of factors considered on the ecological vulnerability in a thematic layer. The analytic hierarchy process, a theory dealing with complex technological, economical, and socio-political problems (Saaty and Vargas, 1991), is an appropriate method for deriving the weight assigned to each factor. The degree of membership within different levels of different indices was integrated using weight and the total degrees of membership for different thematic layers were used to calculate the whole study area natural and environmental vulnerability.

CHAPTER-3

STUDY AREA

"The one land that all men desire to see, and having seen once- by even a glimpse- would not give that glimpse for the shows of the rest of the world combined.": Mark Twain

3.1 General description

Nestled among the rolling mountains with the glistening Mt Kanchenjunga towering over the azure sky, Darjeeling fondly called "Queen of the Hills" provides a perfect gateway for those seeking to be in harmony with nature. A popular tourist destination, it is located in the Mahabharat Range or Lesser Himalaya at an average elevation of 6,710 ft. (2,045.2 m). The principal town is Darjeeling. This is the administrative headquarter of the district. The town Darjeeling is situated in the lower Himalayas in 27°13' north latitude and 38°16' east longitude. The district has four sub-divisions namely Darjeeling, Kalimpong, Kurseong and Siliguri. The name Darjeeling is believed to have been derived from the Tibetan word 'Dorje' which is the scepter of Indra, the God of thunderbolt and 'ling' means the place. The name therefore means the place of Dorje or the thunderbolt.

This is the land of the muscatel flavoured Darjeeling tea which is internationally recognized and ranks among the most popular of the black teas revered by tea connoisseurs across the globe (Srivastava, 2003). This is the land of the Darjeeling Himalayan Railway, a UNESCO World Heritage one of the last few century old miniature steam engines that still chugs uphill vying for space with the fast disappearing Land Rovers.

The development of the town dates back to the mid-19th century, when the colonial British administration set up a sanatorium and a military depot. Subsequently, there was extensive tea plantation done in the region, and tea growers developed hybrids of black tea and created new fermentation techniques.

It is certainly that Darjeeling in the post modern era comprises of six T's -Tea, Teak, Tourism, Toy Train, Tiger Hill and Trekkers' paradise.

Darjeeling lies in active seismic zone where earthquakes are a frequent phenomenon. The active tectonic forces make Darjeeling an active seismic area with zonation up to IV (very high). Earthquake coupled with landslide has had devastating effect on Darjeeling (http://www.imd.gov.in/section/seismo/static/seismozone.html).

3.2 Geographical location

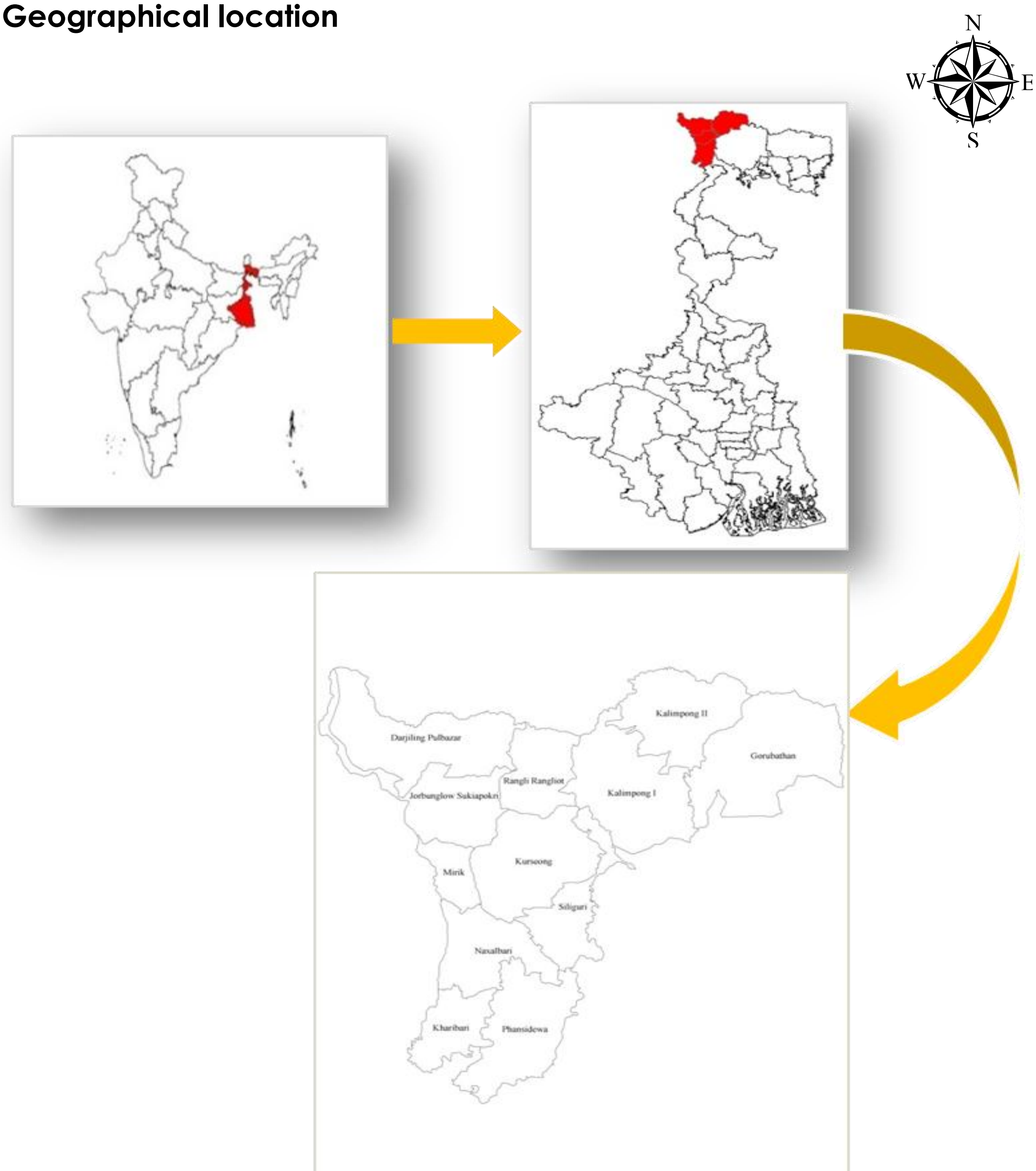

Fig. 3.1: Location of study area (Darjeeling district, West Bengal) in India.

Darjeeling district of West Bengal lies between 26° 31' and 27° 13' north latitude and between 87° 59' and 88° 53' east longitude and its total area is about 3149 sq. km. The area is bounded by Nepal on the west, Sikkim on the north, Bhutan on the north-east, Purnea district of Bihar abutting on the south and district Jalpaiguri of West Bengal on the south-east. The southern foothill belt is demarcated by a highly dissipated platform of terrace deposits extending along the east west axis. The inner belt is defined by a ridgeline stretching from the Darjeeling Hill to the west and Kalimpong Hill to the east, overlooking the southerly flowing

Tista valley in between. Prominent rivulets contributing to the Rammam - Rangit basin, dissipate the northern slope of Darjeeling Hills.

3.3. Soil

The development of soils of Darjeeling Hill area depends upon the underlying geological structure. But, in general the soils have been developed by both fluvial action and lithological disintegration. The soils that have developed in the Kalimpong area are predominantly reddish in color. Occasional dark soils are found due to extensive existence of phyllitic and schists. Soils in the highlands stretching from the west to the east of the district along most of the interfluvial areas are mainly mixed sandy loam and loamy, while those on the southern slopes of Mirik and Kurseong are mainly clayey loam and reddish in color. Sandy soils are mainly found in the east of the river Tista.

All the soils are definitely acidic in nature with the tendency to increase slightly in depth in most cases indicating the lacking of bases from surface and accumulation in the lower horizons. The basic soil types are yellow soils, red brown soils and brown forest soils. Red and yellow soils have developed on gneiss while brown on schists and shales. Coarse pale yellow to red brown soils are found on the Siwaliks while clayey dark soils are developed on Daling series.

The character of the bedrock is reflected only in the grain size composition of the soil. On the Darjeeling gneiss, very coarse-grained (50% -80%) particles are found. In Damuda and Daling series percentage of sandy and coarse particles in the soils are high. On the Siwaliks, silty – clay fraction is higher. The chemical content of the soil over Darjeeling gneiss is characterized by a high proportion of potassium derived from feldspar and muscovite mica. This soil is poor in lime, magnesium, iron oxides, phosphorous and nitrogen. Therefore lime is used in the tea plantation areas.

3.4 Climate

The amount of rainfall plays a very important role in causing instability of slopes. A very high intensity of rainfall within a short span of time is not uncommon in Darjeeling Hill areas. It is found in the old records; that this natural phenomenon has occurred about 42 times during the period from 1891 to 1975 (http://darjeeling.gov.in/geography.html).

The isohyets, maps prepared on the basis of average annual rainfall during last 25 years in 3 subdivisions in Darjeeling Hill areas, shows that the value increases from west to east, a maximum concentration of landslides fall between 210cm and 410cm of Isohyets.

Besides seasonality, another climatic feature in the Darjeeling Hills is created by orographic factor; causing the vertical zonation of temperature and decline of precipitation. Thus the mountain front is exposed to heavy rainfall, especially the middle parts of the southern hills. The mean annual temperature fluctuate from 24ºc in the plains and drops below 12ºc on the ridge. During summer month the temperature reaches 16ºc-17ºc on the ridge and during winter drops at 5ºc-6ºc.

There is no distinct relation between total rainfall and altitude. The southern slopes of the ridges get much higher (4000-5000mm) precipitation than the leeward sides (2000-2500mm). The next main ridge with Tiger Hill gets 3000mm while to the north the Great Rangit valley receives about 2000mm of rainfall. The annual total rainfall in Darjeeling town fluctuates between 1870-3690mm.

3.5 Demography

According to the 2011 census Darjeeling district has a population of 1,842,034. The district has a population density of 585 inhabitants per square kilometer (1,520 /sq. mi.). Its population growth rate over the decade 2001-2011 was 14.47%.Darjeeling has a sex ratio of 971 females for every 1000 males, and a literacy rate of 79.92% (District Census, 2011).In 2001, the total population of the district was 1,609,172. The total rural population was 1,088,740 and total urban population was 520,432. Total males were 830,644 and total females were 778,528. The density of population was 511 per km^2. The decennial population growth rate (1991–2001) was 23.79% (Census, 2011).

The original inhabitants of the Darjeeling Hills were the Lepchas or Rongpa (the ravine folks) as they prefer themselves to be known as. They are decidedly Mongolian in physical features. The Limbus are another ancient inhabitants of this district. The greater bulk of the people in the hills today are the Gorkhas. They are industrious and enterprising as a race and speak Nepali and various other dialects. Among the population are the Sherpas. They are well known for their contributions to mountaineering. Also much in evidence in the hills are the Bhutias. There is also a sizable population of Tibetans who arrived from Tibet since the 1950s. In the plains, one will find several communities like the Gorkhas, the adivasi people originally from Chotanagpur and Santhal Parganas, and a greater bulk of Bengali people.

3.6Forest type

(a) Natural forest:

The natural forests of Darjeeling district may be grouped into following broad categories:

a) Tropical Semi-Evergreen Forest: these types of forests are restricted to foothills. The important species are *Michelia champaca, Terminalia myriocarpa. Ailanthus grandis, Phoebe species.* All these species yield valuable commercial timbers.

b) Tropical Moist Deciduous Forest: Most deciduous forests have *Shorea robusta* as important species. Among its associates, the species like *Michelia champaca, Schima wallichii* and *Chukrassia velutina* which are interspersed with riveraine forests of *Acacia catechu, Dalbergia sissoo* and *Bombax ceiba* exist.

c) Sub-Tropical Forest: these forests occur up to an elevation of 1,824 m (refer under sub-tropical broad-leaved hill forests by Champion and Seth, 1968). The common species are *Betula cylindrostachys* and *Alnus nepalensis, Schima wallichii* and *Engelhardtia spectata* etc.

d) Eastern Himalayan Wet Temperate Forest: These forest occurs from about 1,824 m and extend upto 3000m (refer under Montane wet temperate forests by Champion and Seth, 1968). The major species are *Michelia excelsa, Abies densa, Tsuga brunoniana* and species of *Machilus, Acer, Quercus* (oaks) etc.

e) Alpine Forest: These forest are found over 3000 m (refer sub-alpine, dry and moist alpine forest of Champion and Seth, 1968). The characteristic stunted species are *Rhododendron, Salix, Berberis,* often *Junipers, Abies* and *Tsuga*.

(b) Manmade forest:

The valuable indigenous species form the main component of the plantation in the district. An exotic conifer, *Cryptomeria japonica*, has done exceedingly well in the hill forests of the Darjeeling district. Other exotic conifers like *Pinus petula, Cupressus* species etc. have also shown great promise in the region (http://www.exploredarjeeling.com/).

3.7 River

The rivers of the district drain ultimately to the south, though the west to east ridge across it causes a series of Tista tributaries rising on its northern face to flow northwards and others flow east or west before joining the main rivers. Dominating all the other rivers in the district is the Tista which rises in a glacier in north Sikkim 21,000 feet above sea-level and drains the whole of Sikkim. It forms the boundary of the district from the point where it is joined by the Rangpo down to its junction with the Darjeeling district until it leaves it at Sevok, ultimately entering the Brahmaputra in Rangpur district. In Darjeeling district, its principal tributaries are the Rangpo and the Rilli on its left bank and the Great Rangit, the Riyang and the Sivok on the right bank (Bengal District Gazetteer).

3.8 Road

The road system in the district is not only of local utility but also of importance to the province and to Sikkim and Tibet. These facts explain the number of authorities controlling the roads of the district. The Central Public Works Department controls parts of certain major roads leading to Sikkim and Tibet. Other parts of these roads and the other more important roads in the district are directly maintained by the Communications and Works Department of the Provincial Government which is interested in the main lines of communication with the neighbouring provinces of Bihar and Assam and in an adequate road system for the summer capital of the province. The District Board is responsible for subsidiary lines of road communication and in addition there are roads of importance to the public maintained by the Forest Department and the villagers of Government Estates in the district.

According to the District Gazetteer of Darjeeling district (1980) the road lengths (in km) in the district are as follows;

i. National Highway------------ 100km
ii. State Highway--------------- 80km
iii. Major district road --------- 37km
iv. Ordinary district road------ 516km

3.9 Land- Use Pattern

The main problem in respect of land use in the Darjeeling Hill Areas is related to high density of population. There is very limited scope for extension of agricultural land to cope up with increasing pressure of population. As a result pressure on forested and other restricted areas is gradually increasing.

The land use practices play the most important role in determining the stability factors in respect of landslide hazards. The land use map of Darjeeling Hill Areas explains that there are agricultural activities, tea and medicinal plant plantations, construction works along with forests, rivers, jhoras etc.

Another problem related to land use and consequent landslide is that in Darjeeling Hill Areas, roads have never been examined with its carrying capacity with respect to geology etc. Along with new road construction the vehicular movements have increased to a great extent with the rapid growth of trade and commerce. Heavy traffic movements along with heavy rainfall are responsible for most of the landslide occurrences especially on the roads. In recent years, it has been observed that there is a constant increase in the vehicular traffic, especially heavy vehicles like trucks and buses.

3.10 Socio-economy

The major ethnic communities of Darjeeling hills whose descendants continue to live in remote areas are Lepchas, Bhutias and Nepalese. Each of these groups has its own distinct form of worship, culture, language and tradition. All of them are exceedingly generous, light-hearted and law-abiding people bonded together by Nepali language, which is the medium of communication among them.

Traditionally, the chief occupation of the people of Darjeeling had been agriculture, agro-forestry, horticulture, animal husbandry, etc. Agriculture practices in these hills are mostly subsistence agriculture, which is characterized by low input, low risk and low yield. The geometric progression in human population has been exerting pressure on traditional practice and leading to the fragmentation of land-holding size. At present, only 13% of the total land is utilized for cropping, which is low compared to other zones. Utilization of land for tea plantation and timber extraction has changed the traditional practices and people have turned to various secondary occupations as tea leaf pluckers, labourers, masons, carpenters, etc.

Also, too much reliance on tourism has forced the people of this region to a marginal role of commission agents, menials, cooks, drivers, etc. The result of all these factors has been devastating for the people of Darjeeling hills. They have been pushed to a marginal existence, while the wealth generated here has been siphoned-off to the plains or translated into consolidation of power in the hands of the government. Thus one of the richest regions of the world in terms of natural resources has become the abode of one of the poorest groups of people in the universe. To date, drinking water, healthcare, communication and transportation are the biggest problems here (Chhetri et al., 2005).

3.11 Problem of the study area

Darjeeling Hills suffers from a vicious cycle of development process. Along with a burgeoning population, there has been a constant increase on the area under subsistence crops followed by an increased dependency on livestock farming. Such sequences intensify the demand on the fragile mountain land. Excessive encroachment of forest lands to meet the mushrooming demands for fodder, fuel wood, and other requirements has led to unprecedented damage to forest lands, livestock grazing more than often in this fragile environment has led to overgrazing impacting the environment. Tourism in the area is another factor that has its share in the degradation and pollution of environment in this mountain area. Besides, the physical isolation, economic backwardness, social heterogeneity and unstable politics have a bearing on the social life of the hill folk which is often ventilated through disbelief, frustration and demand for linguistic and political autonomy (Khawas, 2002).

CHAPTER-4
MATERIALS AND METHODS

4.1 Data

4.1.1 Satellite Data

The details of satellite data used in the present study are given in Table 4.1.

Table 4.1: Details of satellite data used in the study

Year	Satellite	Sensor	Path/ Row	Total bands	Spectral bands used (µm)	Spatial Resolution (m)	Swath Width (km)
1977 & 1985	Landast 5	TM	139/42	7	Band 1 Visible(0.45 - 0.52) Band 2 Visible(0.52 - 0.60) Band 3 Visible(0.63 - 0.69) Band 4 NIR(0.76 - 0.90) Band 5 NIR(1.55 - 1.75) Band 6 Thermal(10.40 - 12.50) Band 7 MIR(2.08 - 2.35)	30	185
1997	IRS-1B	LISS I		4	Band 1 Visible (0.45-0.52) Band 2 Visible (0.52-0.59) Band 3 Visible (0.62-0.68) Band 4 NIR (0.77-0.86)	72	148
2005 & 2012	IRS-P6	LISS III	107/53	4	Band 2 Visible (0.52-0.59) Band 3 Visible (0.62-0.68) Band 4 NIR (0.77-0.86) Band 5 Mid-IR (1.55-1.70)	23	142
	SRTM DEM	C-band and X-band	-	-	-	90	255

4.1.2 Ancillary Data

- Ground truth with interpreted LULC maps and GPS.
- Survey of India Topographic Maps of 1:50,000 scale.
- Population data 1981, 1991 and 2001, from West Bengal Biodiversity Board, Kolkata, West Bengal, India.
- Elevation, slope and aspect were generated from SRTM DEM.
- Data on Soil texture, soil depth and soil pH were from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur.

- Climatic variables precipitation, temperature minimum (*t*min) and temperature maximum (*t*max) were downloaded from Worldclim data of IPCC scenario A &B for the year 2050.

4.2 Instruments, software and hardware used

The instruments, software and hardware used in the study were shown in Table 4.2

Table 4.2: List of instruments, software and hardware used

Type	**Name**	**Utility**
Instrument	GPS	Collection of ground truth
	Magnetic compass	Field navigation and survey
Software	ERDAS Imagine -9.2	Image processing and data analysis
	Arc GIS – 10	Database creation
	SPLAM	Landscape analysis
	IDRISI	Change analysis and decision support system
	DIVA GIS	Worldclim data
	MS Office	Documentation, statistical analysis and presentation
Hardware	Computer	Data storage, software and internet support

4.3 Methodology

The study was undertaken to model and analyse critical ecosystem of Darjeeling district, West Bengal, India using various geospatial techniques. The various steps performed under different methodological approaches have been discussed and also systematically arranged in a flow chart in Figure 4.1.

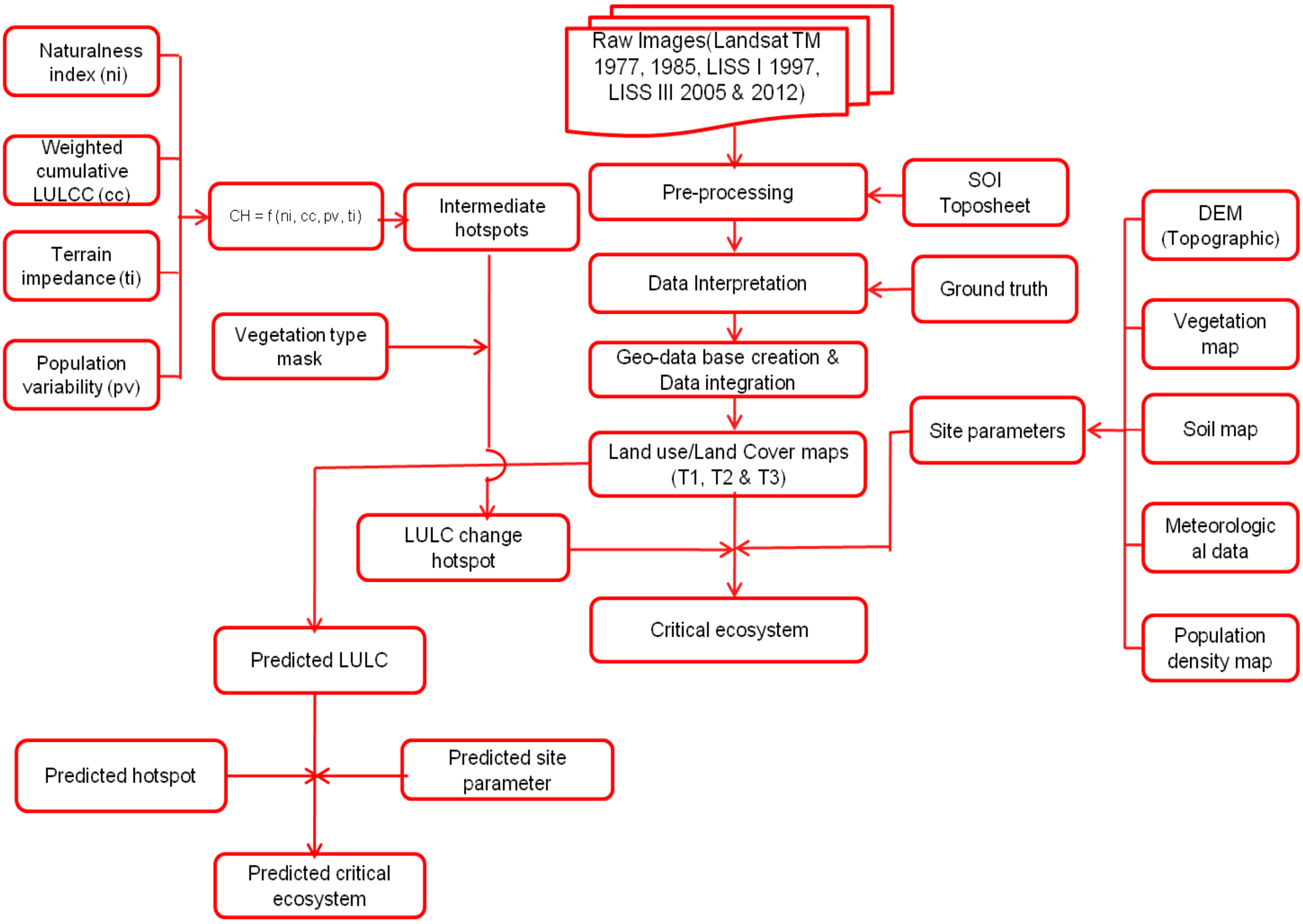

Fig 4.1: Methodology approach flow diagram

4.3.1 Data pre-processing

4.3.1.1 Radiometric correction

Various atmospheric effects cause absorption and scattering of the solar radiation. In order to remove the haze component, histogram minimum method was applied. In this method, it assumes that there is a high probability that there are some areas in the image with low reflectance (clear water, deep shadow, etc). The histogram of all the bands in the image is computed for the full image. The lowest pixel value in the histogram of all bands is taken as the first approximation of the atmospheric path radiance and these minimum values are subtracted from the respective images.

4.3.1.2 Geometric correction

Geometric correction of image is the process of digitally manipulating image data to avoid geometric distortions from a distorted image such that the image's projection precisely matches a specific projection surface or shape. Subsets of LISS III satellite image was rectified first for their inherent geometric errors with digital topographic maps in Modified Universal Transverse Mercator coordinate system using distinctive features such as road intersections, stream confluences which were clearly visible in the image. Polynomial model and nearest neighbour resampling method were applied. Then the TM and MSS images were registered to the already registered LISS III image through image to image registration technique with rectification errors of less than 1 pixel.

4.3.2 Field work

Field work is a very important part of the entire study. Most of the important information is collected only from the field.

4.3.2.1 Preparation for field data collection

In order to get sufficient data in a limited field visits, sufficient preparation is required. Thus a broad visual interpretation was done before going to field, and then hard copy of preliminary map was made together with satellite image FCC and base map.

4.3.2.2 Field work

Ground truth was collected in the field with the help of satellite FCC image hardcopy, toposheet and magnetic compass. Pre-field interpretation was verified using satellite image, ground truth and the interpretation elements and final interpretation keys were developed and recorded. Suitable connection was made on pre-field interpreted map. The population densities of each village within the district for different time periods were collected from statistical department, West Bengal. Forest working plans were obtained from Forest Working Plan Officer, Darjeeling.

4.3.2.3 Visual interpretation

In the Himalayas, due to the complex mountain terrains the spectral signature are influenced by elevation, aspect, slope, which might lead to same object showing different reflectance or the different objects could have the same reflectance, especially in dark shadow area. Since the satellite imageries have certain constraint with respect to above factors. A more rational approach was adopted by judiciously employing subjective and objective methods and then interpreting imageries by screen visual interpretation technique. Thus, the approach of generalization of features by effectively utilizing intensive ground truth information for image interpretation was adopted in doubtful areas.

4.3.3 Database creation

4.3.3.1. Base line information

Study area boundary map was generated using the district boundary outlay prepared by Natural Resources Data Management System (NRDMS), Jalpaiguri, West Bengal. The map was systematically rectified using physiographic barrier such as ridge of the mountain, drainage pattern and spot height drainages were drawn along with existing river tracks. DEM, slope and aspect of the study area were generated from SRTM DEM. Data on Soil texture, soil depth and soil pH were obtained from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur.

4.3.3.2 Land use and land cover (LULC) mapping

Initially a land use and land cover (LULC) map of 2012 with sixteen classes was prepared using IRS-P6 LISS III data of 2012. The same vector layer which was interpreted and field validated was modified by displaying over the LISS III image of 2005 for depicting LULC map in 2005. Further, the same method was followed for the generation of consequent LULC maps of 1995, 1985 and 1977 where redrawing and editing were carried out wherever necessary by studying the respective images. The maps were generated at 1:50,000 scale. The five time period LULC maps were used as the base for future analysis.

4.3.4 Land use and land cover change during study period

To assess the change in land use and land cover change status of the Darjeeling district for five decades, the data of 1977, 1985, 1977, 2005 and 2012 were selected. The land use polygon themes for these five years, obtained from the visual interpretation were converted into grid format and imported to ERDAS as image file for further analysis. Then 1977, 1985, 1997, 2005 and 2012 maps were overlaid respectively using matrix option in ERDAS IMAGE 9.2 to find changes. Change and no-change matrix were made from attribute table of the overlaid 1977-1985, 1985-1997, 1997-2005 and 2005-2012 images. The area of change and no-change area and present change were also calculated using Excel. On the basis of these matrices the results and conclusion were derived.

4.3.5 Modeling ecosystem change

4.3.5.1 CA_Markov Modeling

The purpose of this study is to simulate land use land cover change in the future time period and assess the impact of the changes in the surrounding ecosystem. The model applied in this study, CA_Markov, allows us to predict and project land use land cover change of the study area. The Markov chain analysis predicts the future land use pattern only on the basis of the known land use patterns of the past. It is also supplemented by the CA approach and a number of change drivers to better understand the change. To incorporate the effect of drivers into land use land cover change modeling, the independent variables (drivers) were analyzed by MCE (Multi Criteria Evaluation) procedure and used for land use land cover change suitability map. This suitability map along with other inputs helped in projecting land use land cover change map for 2045.

4.3.5.2 Cellular Automata model (CA)

Cellular automata model was developed by Ulam in the 1940’s (Anu, 2003; Sudhira et al., 2005) and soon used by Von Newmann to investigate the logical nature of self reproducible system. CA is defined as a dynamic discrete system in space and time that operates on a uniform grid based space (Yikalo, 2009). The approach in this model is “bottom up”. The final global structure emerges from purely local interactions among the cells. CA not only offers a new way of thinking for dynamic process modeling it also provides a laboratory for testing the decisions making process (Anuj, 2003).

Cellular Automata (CA) get their name from the fact that they consists of cells, like the cells on the check board, and that cells states may evolve according to a simple transition rule, the automation. Cellular automata are dynamic model that inherently integrate spatial and temporal dimension. Cellular automata are composed of five elements as described below:

Cell space: The cell space is composed of individual cell. Theoretically these cells may be in any geometric shape. Yet most CA's adopt regular grids to represent such a space, which make CA very similar to a raster GIS. **Cell states:** the states of each cell may represent any spatial variable, e.g. the various types of land use. Time steps: a cell evolves at a sequence of discrete time steps. At each step, the cells will be updated simultaneously based on transition rules. **Transition rules:** These rules are the heart of the CA that guides its dynamic evolution. A transition rules normally specifies the state of cell before and after updating based on its neighborhood conditions. **Neighborhood**: Each cell has two neighbors in one dimensional cellular automata, where as in two dimensional cellular automata model, there are two ways to define it.

Von Neumann has considered four neighboring cells as neighbors. Moore considers eight neighboring cells as neighbors. As shown in Figure 4.2 the green color cells are neighbors to the center cell which is in blue color.

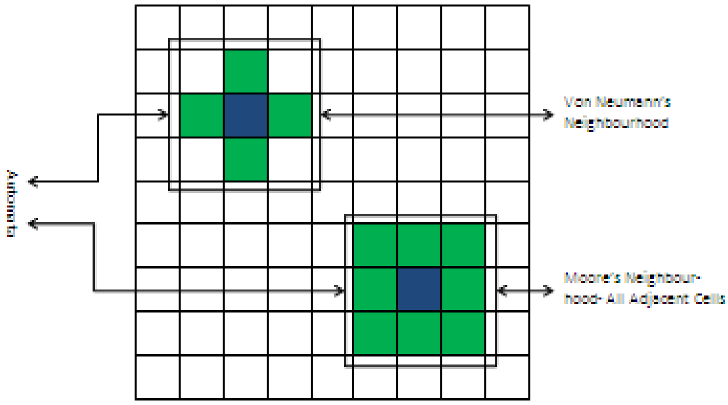

Fig 4.2: Cells and Neighbourhood (Source: Sudhira *et al*, 2005)

4.3.5.3 Modeling in IDRISI Taiga

Idrisi is the industry leader in raster analytical functionality covering the full spectrum of GIS and remote sensing needs (Eastman, 2001). Some of the functionalities included in the package are image analysis, change and time series analysis, spatial modeling, decision support system etc. Some of the modeling techniques embedded in the Idrisi Taiga is logistic regression, stochastic, GEOMOD and CA-Markov chain analysis. As mentioned above, CA operates on a grid based cells and transition rules are applied to determine the state of cell. Markov chain analysis on the other hand, is a system in which the future state of the system is modeled on the basis of the immediate proceeding state.

Markov chain analysis is named after Andy Markov, who was a Russian mathematician and best known for his work on the theory of stochastic process. It is based on the principle that gives the present state and future state is independent of the past state. Many CA models are being developed so far especially in urban growth process studies. Depending upon their transition rules, and calibration methods they differ from each other. Some of the CA models are: Macro and micro integrated CA model (RIKS models), SLUTH model, ANN CA model, Fuzzy CA model, MCE CA model, Multi-CA model, Statistic CA model and Stochastic CA model (Anuj, 2003)

4.3.5.4 MCE_CA_Markov model

The transition rules have been defined by various ways. The combination of three elements GIS, CA_Markov, and MCE, has several advantages; visualization of decision making, easier access to spatial information and the more realistic definition of transition rule in CA. In order to explore forest cover change dynamics, this study employed CA_Markov chain analysis integrated with raster based remote sensing. The CA_Markov chain analysis uses a MCE to generate the decision rules in the form of suitability maps. The transition rule was based on the factors that have impacts on land use land cover changes. These include agriculture, market, road, settlement, population density, slope, etc. and other reserved areas (e.g. water bodies, settlement and forest). The effect of these factors were first evaluated using MCE (criteria development) transition rules and resulted in generating potential "suitable" or "susceptible" areas for land use land cover change.

Therefore, MCE is most commonly achieved by one or two procedures. The first involves Boolean overlay where by all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators, such as intersection (AND) and union (OR). The second is known as Weighted linear combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average (Zeelam, 2007).

Hence Markov Chain Analysis is a convenient tool for modeling land use change when changes and processes in the landscape are difficult to describe. A Markovian process is one in which the future state of a system can be modeled purely on the basis of the immediately preceding state. Markovian chain analysis will describe land use change from one period to another and use this as the basis to project future changes. This is achieved by developing a transition probability matrix of land use change from time one to time two, which shows the nature of change while still serving as the basis for projecting to a later time period. The transition probability may be accurate on a per category basis, but there is no knowledge of the spatial distribution of occurrences within each land use category. Hence, Cellular Automata (CA) was used to add spatial character to the model.

CA_Markov uses the output from the Markov Chain Analysis particularly Transition Area file to apply a contiguity filter to "grow out" land use from time two to a later time period. In essence, the CA will develop a spatially explicit weighting more heavily areas that proximate to existing like land uses. This will ensure that land use change occurs proximate to existing like land use classes, and not wholly random. Overlay operations which is the last method of the three, identifies the actual location and magnitude of change although this was limited to the built-up land. Boolean logic was applied to the result through the re-class module of Idrisi which assisted in mapping out separately areas of change for which magnitude was later calculated for (Zubair, 2006).

4.3.5.5 Methodology for CA_Markov modeling

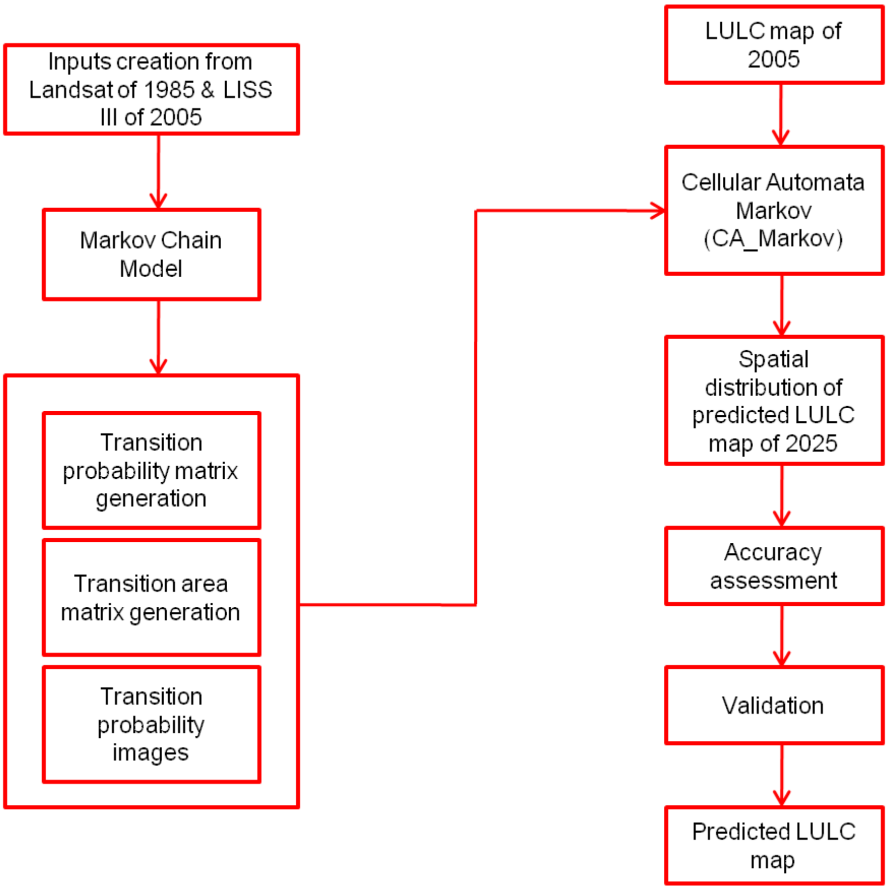

Fig 4.3: Methodology flow diagram for CA_Markov Modeling

4.3.5.6 Model description

CA provides a powerful tool for modeling the dynamic nature of land use and is a commonly used method to take spatial interaction into consideration. There are many different CA models in various software platforms and are different options to implement: using an existing model or developing a new model. The later requires extensive and advanced programming knowledge. This study is based on the existing modeling technique

"CA_Markov". The CA_Markov integrates two techniques: Markov Chain Analysis and Cellular Automata Analysis. The Markov Chain Analysis describes the probability matrix between t1 (1985) and t2 (2005). The probabilities may be accurate on a per category basis but there is no knowledge of the spatial distribution of occurrences within each land use classes (Eastman, 2001). This is the inherent problem of the Markov Analysis. In order to add the spatial character to the model, therefore, Cellular Automata (CA) is integrated to the approach. In the CA analysis, the land use was treated as a dynamic system in which space, time and the states of the system were treated discretely. The Cellular Automata component of the CA_Markov model allows the transition probabilities of one pixel to be a function of neighboring. Cellular automata can be represented as quadruple as follows:

(U, S, N, T)

Where U is universe (cell space or lattice) S is set of all possible states which a cell can attain, N is neighborhood of a cell, and T is a set of transition rules. We can represent a state of a cell at time t+1 as a function of its state at time t, its neighborhood and rule as follows:

$$\mathbf{S_{t+1} = f\,(S_t, N, T)}$$

$$\mathbf{Sc = Su + N}$$

Where S_t+1 is state of a cell at time (t+1), S_t is a state of a cell at time t, N is neighborhood and T is a set of transition rules followed by the cells. Where Sc is final score of a cell, Su is suitability score and N is neighborhood influence. Suitability again can be divided into two parts. First is due to some inherent geo-physical properties like slop, aspect, etc. and other are due to dynamic properties such as LULC, change hotspot etc. therefore, Su becomes Su=Su (physical factors) + Su (proximity factors). Based on this formulation the most selective change drivers (parameters) were selected and quantified for this research.

4.3.5.7 Markov Chain Analysis

A Markovian process is simple process in which the future state of the system can be modeled purely on the basis of the immediately preceding state. This can be represented as:

$$\left\{ X_{T_{n+1}} / X_{T_1}, X_{T_2} \ldots\ldots\ldots.., X_{T_n} \right\} = \left\{ X_{T_{n+1}} / X_{T_n} \right\}$$

Where, X_{Tn+1} is the future state of the system and X_{Tn} is the preceding state of the system. X_{T1}, X_{T2}…are the state of the system at time T_1 and T_2.

The land use land cover change image of 1985 and 2005 was given as input for Markov Chain analysis which gives three outputs namely- (1) *Transition Probability Matrix*: It is a text file that records the probability that each land cover category will change to every other category. (2) *Transition Area Matrix*: It is a text file that records the number of pixels that are expected to change from each land cover type over the specified number of units. In both of these files, the rows represent the older land cover categories and the columns represent the newer categories and (3) *Conditional Probability Images*: It reports the probability that each land cover type would be found at each pixel after the specified number of time units. These images are calculated as projections from the later of the two input land cover images.

The other parameters were number of time periods between the first and second input land cover images and the number of time periods to project into the future for the output images and the proportional error associated with the input maps. The proportional error expresses the probability that the land cover classes in the input maps are incorrect. The output conditional probabilities are multiplied by (1-proportional error) to produce the final output conditional probability values. The transition probability matrix is the result of cross tabulation of the two images adjusted by the proportional error. The transition area matrix is produced by multiplication of each column in the transition probability matrix by the number of cells of the corresponding land use in the latter image.

4.3.5.8CA_Markov model calibration and prediction

The first step in CA_Markov analysis is to develop a transition probability matrix using the Markov module in Idrisi. The transition probability matrix for each land cover classes was developed between 1977 -1985, 1985-1997, 1997-2005 and 2005-2012 and hence used as input for projecting land use change. A transition probability matrix records the probability that each land cover category will change to every other category. The transition area matrix indicates the number of cells that are expected to change from each existing land use class in1985 to each new class in 1997.

Based on the transition area matrix and the suitability map of land use land cover change for the 2045 (generated in MCE process). LULC map of 2045 was predicted. Using the outputs from the Markov Chain Analysis, specifically the transitions area matrix and the base images of 2025 the land use land cover change

The rules state that a pixel which is near one land use category (e.g. Forest) is more likely to become a forest pixel than pixel that is farther. The definition of nearby is determined by a spatial filter that the user specifies. In this study, the default contiguity filter in Idrisi “5X5” was applied. The 5X5 contiguity filter considers the predicted land use change to be within two pixels of the edge including the diagonal. Based on these inputs, the module determines the location of change, the number of pixels that must undergo each transition and selects the pixels according to the largest suitability for a particular transition.

4.3.6 Ecosystem Hotspot evaluation

The hotspot of change involves the use of different landscape based indices, terrain features and anthropogenic influences (Roy and Srivastava, 2012). The major inputs of the model are: (i) weighed cumulative LULCC (cc), (ii) population variability (pv), (iii) terrain impedance (ti), and (iv) naturalness index (ni). Weighted cumulative LULCC map (cc), using five times period LULC maps for the year 1977, 1985, 1997, 2005 and 2012 were generated. The LULCC was assigned weightages based on the degree of change. The 1977–1985and 1985–2005 weighted change maps were geospatially modeled to produce the cumulative change maps.

4.3.6.1 Calculation of Fractal Dimension (FD)

Fractal Dimension (FD) is a measure of distribution of landscape diversity in a classified GIS image. FD is derived by calculating the area and perimeter of each patch of a landscape. FD is calculated by the following equation:

$$FD = 2 * \ln(P/4) / \ln(A)$$

Where,

A= area of patch within sample landscape
P= perimeter of patch within sample landscape,

4.3.6.2 Calculation of Landscape Variability (LV)

Landscape Variability (LV) is a measure of variability in a unit area. LV indicates different types of classes present say in 1 km area. The LV is generated from zonal statistics with input raster or feature zone data of 1km grid shapefile and LULC raster of particular year. The statistics type with the option of variety gives LV of the study area.

4.3.6.3 Calculation of Proportion of Natural Ecosystem (VT)

Proportion of natural ecosystem (VT) is the proportion of natural ecosystem in the 1 km grid estimated by giving weightage to the LULC map from 1 to 9. VT is generated from union of 1 km grid shapefile and LULC of particular year. The attribute table of union LULC is added with area field obtained by geometric calculation. The attribute table is exported to excel file where VT field is added and calculated as VT= Area/1000000. The excel file is joined with LULC taking one common field. The output LULC is exported and saved as VT for that particular year LULC.

4.3.6.4 Calculation of Naturalness Index (ni)

Naturalness Index (ni) is a representation of the level of disturbance to the landscape in terms of fractal dimension, landscape variability and proportion of the natural ecosystem as compared to managed ecosystems. 'ni' is calculated by the following:
*ni= f(FD*LV*VT)*

4.3.6.5 Weighted cumulative LULCC map (cc)

Weighted cumulative LULCC map (cc) is generated by using five time period LULC maps for the year 1977, 1985, 1997, 2005 and 2012. The LULCC was assigned weightage based on the degree of change computed by AHP matrix of LULC classes pair-wise relative importance as shown in Table 4.3. The weights were assigned from 1 to 9 according to Saaty's classification to the various classes on priority as it changes from one class to another. The 1977-1985, 1985-1997, 1997-2005 and 2005-2012 weighted change maps were geospatially modeled to produce the cumulative change maps.

4.3.6.6 Calculation of Population Variability (pv)

Population variability (pv) layer was prepared from the village level population density of Darjeeling district using census data from Census of India for the years 1981, 1991, 2001 and 2011 where the increase or decrease of the population had been geospatially computed to generate the population variability map for 2012 change hotspot. Similarly, population variability map is prepared for 2045 integrating all the population density layers of 2021, 2031 and 2041 which were generated from "The Future Population of India, Population Foundation of India.

4.3.6.7 Calculation of Terrain Impedance (ti)

Terrain Impedance (ti) has been computed from the elevation and slope maps derived from SRTM DEM. Using the following equation, ti has been geospatially computed;

ti=ln(sl) + ln(ele)

where *'sl'* represents slope and *'ele'* represents elevation.

4.3.6.8 Calculation of present Change Hotspot (ch)

The hotspot of land use and land cover change map in Darjeeling district in 2012 is computed by integrating the following layers of factor of change such as naturalness index (ni), terrain impedance (ti), weighted cumulative land use and land cover change map (cc) and population variability (pv) using the equation;

ch= f(cc, pv, ti, ni)

where *'f'* is an additive function

The intermediate change layer was again subjected to a geospatial logical modeling to identify the hotspots of land use and land cover change only in the natural areas. The hotspot map generated was classified into different categories where each class represents the areas under various land use and land cover and the status at which they are changing as a result of environmental factors and the anthropogenic activities. For identification of biodiversity-rich areas, the spatial database of the biodiversity characterization at landscape level data of vegetation type, fragmentation and biological richness was used.

4.3.6.9 Calculation of future Change Hotspot (ch)

The prediction of hotspot of land use and land cover change map in Darjeeling district in 2045 was done following the same method used in the modeling of hotspot in 2012. The layers of naturalness index, terrain impedance, weighted land use and land cover change map and population variability were prepared individually for the time periods 1985, 2005, 2025 and 2045. The layers were finally integrated to give a cumulative map output to model change hotspot in 2045. The final output map of change hotspot in 2045 is obtained exclusively for the natural areas through a geospatial logical modeling.

4.3.7 Analysis of Vulnerability

4.3.7.1 Factors of vulnerability

The various factors which have a significant impact on the vulnerability of the study area were selected. There are thirteen (13) factors which are found to have pertinent importance for the present study which includes; LULC, Hotspot, population density, distance from road, elevation, slope, aspect, soil texture, soil depth, soil pH, precipitation, temperature minimum (*t*min) and temperature maximum (*t*max).

The LULC is selected as one of the factors as the mapping of the study area in different time periods shows the temporal changes in net area of various classes. Hotspot is an aggregate of change factors which indicates the areas which experience the most land use and land cover change at the particular instance of time. The population density has a major influence on the utilization of the natural ecosystem. The distance of natural ecosystem to roads is a major factor in exploitation of the natural ecosystem. Topographic factors such as elevation, slope and aspect determined the suitability of natural ecosystem for various land uses. Soil depth defines the root space and the volume of soil from where the plants fulfil their water and nutrient demands. Soil texture (e.g. loam, sandy loam or clay) refers to the proportion of sand, silt and clay sized particles that make up the mineral fraction of the soil. Soil pH is the measure of the acidity or alkalinity level of the soil. The most important climatic factors that influence growth, development and yield of crops are solar radiation, temperature and rainfall. Climate is the most important dominating factor influencing the suitability of a crop to a particular region.

LULC, hotspot and population density layers were already generated in the preceding hotspot evaluation. Distance from road was extracted from open street map and Euclidian distance was generated into required distance. Elevation, slope and aspect were generated from SRTM DEM. Soil texture, soil depth and soil pH were extracted from NBSS&LUP. Climatic variables precipitation, temperature minimum (*t*min) and temperature maximum (*t*max) were downloaded from Worldclim data of IPCC scenario B for the year 2050.

4.3.7.2 Weighting of factors

The next step was to establish a set of weights for each of the factors studied and the analyst has to fill out the pair wise comparison matrix using the weight module in Idrisi. The pair wise comparison was developed by (Saaty, 1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). This module uses a pair-by-pair technique to compare the relative importance of one factor (e.g. hotspot) against another factor (e.g. population). The rating ranges from “extremely less important” (1/9) to “extremely more important” (9).

4.3.7.3 Ranking of factors

The ranking of various factors was done on the basis of individual weightage computed from the Analytical Hierarchy Process (AHP). The factor with the highest weightage value (e.g. hotspot) was considered to be the most important among all the other factors and assigned the rank 1. Similarly all the factors were ranked on the basis of weightage value accordingly

4.3.7.4 Normalization of factors

The various factors were in different raster formats with varying minimum and maximum values which rendered error in analysis. All the factors were brought to a common format and normalization was done to bring all the values in the range of 0 to 1 for further analysis.

4.3.7.5 Re-assigned weights of factors

The normalized factors were multiplied to its own respective values obtained in AHP, with the resultant values assigned as the final weightage for vulnerability assessment.

4.3.7.6 Ecological vulnerability assessment of the present scenario (2012)

The ecological vulnerability assessment was carried out in ArcMap modeler with the 13 factors as input. It was geospatially modeled with all the factors collectively added together. The resultant layer gave the ecological vulnerability status of the study area for the present year 2012.

4.3.7.7 Ecological vulnerability assessment of the future scenario (2045)

The ecological vulnerability assessment of the study area in the future for the year 2045 is carried out in the same modeling technique with the factors taken from the future layers prepared for various factors. The resultant layer will give the predicted future ecological vulnerability of the study area.

4.3.7.8 Ecological vulnerability gradation and identification of critical ecosystem

The ecological vulnerability status obtained from ArcMap modeler is in continuous floating value which needs to be classified into several classes for different ecological vulnerability. The classification is crucial to evaluation so it should be objective and logical. The value was classified into different classes of ecological vulnerability taking the method of natural breaks. Thereafter, the standardized classification is done and graded into different classes of ecological vulnerability. The ecological vulnerability class with the highest grade is identified as the critical ecosystem of the study area. The other intermediates classes defined as potential to heavy levels of ecological vulnerability.

4.3.7.9 Ecological vulnerability with respect to biological richness

The standardized classified graded layer of ecological vulnerability with different classes is geospatially interpreted with the biological richness layer of the study area. The interpretation is done with the Summary function where it produces cross-tabulation statistics that compare class value areas between two thematic files, including number of points in common, number of acres (or hectares or square miles) in common, and percentages.

The output from the summary gives an idea about the areas under different classes of ecological vulnerability with the amount of biological diversity present in each of the respective classes. The information obtained will give insight about the areas of highly ecological vulnerability classes with rich biological diversity which must be assigned top priority for proper conservation and management practices.

CHAPTER-5

RESULTS

5.1 General overview

The main objective of the study was to model and analyze critical ecosystem of Darjeeling district, West Bengal using various geospatial techniques. In this chapter various outputs generated during the data preparation, input generation for models, modeling land use land cover change and validation has been dealt with. The respective discussions regarding the results have been also presented along with the results.

5.2 Land use and land cover change analysis

5.2.1 Land use and land cover Images 1977- 2012

The various land use and land cover maps prepared for the five time periods from 1977 to 2012 are depicted in the Figure 5.1.The change maps of land use and land cover from one time period 1977-1985 to 2005-2012 with major land use and land cover classes are depicted in Figure 5.2. The change area and percentage under the land use and land cover classes during the 1977, 1985, 1997, 2005 and 2012 is shown in Table 5.1.

Results from Tables 5.3 to 5.7 shows that sub-tropical broadleaved, sal, temperate broadleaved and temperate coniferousforests increased during the first (1977-1985) period, there was decreased in the mixed moist deciduous forest during the same period. In the succeeding periods (1985-2012) there was variability in change in the different forest classes with increased in some classes and decreased in other classes. The net result showed increased in sub-tropical broadleaved, sal and temperate coniferous forests but there was considerable decreased in temperatebroadleaved and mixed moist deciduous forests. Excepting the initial period there was significant increase in the areas with respect to tea and plantation as shown in the net result. Agriculture, shrubland and scrub increased occasionally, whereas there was an erratic change in area in lake/pond.

Although there was increase in sub-tropical broadleaved, sal and temperate coniferous, the decreased in temperate broadleaved and mixed moist deciduous forest results from conversion of these areas mostly into tea and plantation as well as degradation into shrubland and scrub.

Among the major land use classes as shown in Table 5.8, around 94.40% of the forest area and 88.28% of the tree clad area in 1977 remained unchanged until 2012. Forest lost

18.22% of its area to other classes but gained only 13.37% from other classes resulting in a net 79.71 sq. km. decrease in forest area during the study period. Agriculture area gained 20.60% from other classes but lost 19.16% to other classes with a net 11.85 sq. km. increase in area. The maximum net increase in area was in plantation with an increase of 95.42 sq. km. The area under other classes like settlements and water bodies also showed an increase of 17.27 sq. km. during the study period.

5.2.2. Validation of land use and land cover Images 1977- 2012

Accuracy assessment is often required to better understand the quality and reliability of a classified image. In general, overall classification accuracy and kappa coefficient are often used to assess the overall performance in a classification, while producer's accuracy and user's accuracy are used to evaluate the performance of each land use and land cover change class. The confusion matrix method was used for validating the results of land use and land cover classification of year 1977, 1985, 1997, 2005 and 2012. The results of the validation have been presented in the Table 5.2.

Table5.1: Comparison of areas under different land uses during the five time periods

Land use	1977		1985		1997		2005		2012		Land use change									
											1977-1985		1985-1997		1997-2005		2005-2012		1977-2012	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Sub-tropical broad leaved	297.98	9.46	363.84	11.55	374.16	11.88	405.32	12.87	343.43	10.91	65.87	22.10	10.31	2.83	31.17	8.33	-61.89	-15.27	45.45	15.25
Temperate broad leaved	579.79	18.41	599.92	19.05	488.68	15.52	488.81	15.52	440.61	13.99	20.13	3.47	-111.23	-18.54	0.13	0.03	-48.20	-9.86	-139.18	-24.01
Sal	96.37	3.06	121.33	3.85	117.83	3.74	113.04	3.59	101.14	3.21	24.96	25.90	-3.50	-2.88	-4.79	-4.06	-11.90	-10.53	4.77	4.95
Mixed moist deciduous	325.16	10.33	288.87	9.17	299.26	9.50	297.25	9.44	290.97	9.24	-36.29	-11.16	10.39	3.60	-2.01	-0.67	-6.28	-2.11	-34.19	-10.52
Temperate coniferous	112.49	3.57	114.14	3.62	121.07	3.84	127.49	4.05	171.62	5.45	1.65	1.47	6.94	6.08	6.42	5.30	44.12	34.61	59.13	52.57
Bamboo	11.17	0.35	11.77	0.37	11.59	0.37	11.69	0.37	0.10	0.00	0.60	5.33	-0.18	-1.50	0.10	0.87	-11.59	-99.15	-11.07	-99.11
Tree clad area	296.91	9.43	212.28	6.74	270.32	8.58	203.33	6.46	222.67	7.07	-84.63	-28.50	58.04	27.34	-66.99	-24.78	19.34	9.51	-74.24	-25.00
Scrub	31.73	1.01	40.54	1.29	38.46	1.22	41.05	1.30	56.24	1.79	8.81	27.78	-2.09	-5.15	2.59	6.75	15.19	37.01	24.51	77.25
Shrub land	53.79	1.71	62.98	2.00	66.08	2.10	61.46	1.95	59.54	1.89	9.19	17.08	3.10	4.92	-4.62	-6.99	-1.93	-3.13	5.75	10.68
Agriculture	651.99	20.70	671.77	21.33	693.53	22.02	644.07	20.45	666.59	21.17	19.78	3.03	21.76	3.24	-49.45	-7.13	22.51	3.50	14.60	2.24
Plantation	43.66	1.39	36.14	1.15	34.39	1.09	51.91	1.65	51.37	1.63	-7.52	-17.23	-1.75	-4.84	17.52	50.94	-0.53	-1.03	7.71	17.66
Tea	411.28	13.06	392.80	12.47	402.16	12.77	466.51	14.81	500.68	15.90	-18.48	-4.49	9.36	2.38	64.35	16.00	34.17	7.32	89.40	21.74
Dry river-bed	104.02	3.30	76.77	2.44	74.81	2.38	64.89	2.06	70.23	2.23	-27.25	-26.19	-1.96	-2.56	-9.91	-13.25	5.34	8.22	-33.79	-32.48
Perennial river	41.16	1.31	59.42	1.89	58.21	1.85	52.91	1.68	48.47	1.54	18.26	44.35	-1.21	-2.03	-5.30	-9.11	-4.45	-8.41	7.30	17.74
Lake/Pond	0.09	0.00	0.09	0.00	0.09	0.00	0.27	0.01	0.42	0.01	0.00	0.06	0.00	0.00	0.19	220.02	0.15	54.92	0.34	396.12
Built Up	91.41	2.90	96.35	3.06	98.37	3.12	118.99	3.78	124.93	3.97	4.94	5.40	2.02	2.09	20.62	20.96	5.94	5.00	33.52	36.67

Table 5.2: Accuracy assessment of LULCs of various time periods

LULC time period	Accuracy assessment	Sub-tropical broadleaved	Temperate broadleaved	Sal	Mixed moist deciduous	Temperate coniferous	Bam-boo	Tree clad area	Scrub	Shrub land	Agri-culture	Planta-tion	Tea	Dry river bed	Peren-nial river	Lake/Pond	Built Up
2012	Users Accuracy	0.82	0.94	0.75	0.81	0.91	0.71	0.92	0.89	0.78	0.88	0.88	0.87	0.80	0.80	0.75	1.00
	Producers Accuracy	0.90	0.94	0.82	0.81	0.91	0.83	0.85	0.80	0.78	0.78	0.88	0.87	0.89	0.89	0.75	0.92
	Overall Accuracy	85.39%															
	Kappa	0.84															
2005	Users Accuracy	0.82	0.94	0.80	0.87	0.90	0.83	0.91	0.78	0.83	0.81	0.86	0.87	0.80	0.73	0.75	0.91
	Producers Accuracy	0.90	0.94	0.89	0.87	0.90	0.83	0.77	0.78	0.71	0.81	0.86	0.87	0.80	0.80	0.75	0.91
	Overall Accuracy	84.62%															
	Kappa	0.83															
1997	Users Accuracy	0.83	0.94	0.88	0.86	0.89	0.86	0.85	0.89	0.71	0.83	0.63	0.83	0.70	0.80	0.75	1.00
	Producers Accuracy	0.83	0.94	0.88	0.92	0.89	0.86	0.85	0.73	0.83	0.67	0.83	0.83	0.78	0.89	0.75	0.89
	Overall Accuracy	83.75%															
	Kappa	0.82															
1985	Users Accuracy	0.92	0.94	0.70	0.80	0.88	0.86	0.92	0.89	0.67	0.71	0.75	0.82	0.75	0.82	0.80	0.88
	Producers Accuracy	0.92	0.94	0.88	0.80	0.78	0.86	0.69	0.89	0.80	0.71	0.86	0.82	0.86	0.82	0.80	0.88
	Overall Accuracy	82.72															

LULC time period	Accuracy assessment	Sub-tropical broadleaved	Temperate broadleaved	Sal	Mixed moist deciduous	Temperate coniferous	Bam-boo	Tree clad area	Scrub	Shrub land	Agri-culture	Planta-tion	Tea	Dry river bed	Peren-nial river	Lake/P ond	Built Up
	Kappa	0.81															
1977	Users Accuracy	0.88	0.95	0.88	0.85	0.90	0.70	0.83	0.78	0.63	0.82	0.71	0.89	0.86	0.82	0.83	0.88
	Producers Accuracy	0.93	0.95	0.88	0.79	0.82	0.88	0.83	0.64	0.71	0.82	0.83	0.80	0.75	0.90	0.83	0.88
	Overall Accuracy	83.54															
	Kappa	0.82															

Table 5.3: Land use land cover change matrix during 1977 and 1985

	Sub-tropical broad-leaved	Temperate broad-leaved	Sal	Mixed moist deciduous	Temperate coniferous	Bamboo	Tree clad area	Scrub	Shrub land	Agricul-ture	Planta-tion	Tea	Dry river bed	Perennial river	Lake/ Pond	Built Up
Sub-tropical broadleaved	227.61	41.12	0.00	10.43	0.05	0.00	8.98	1.00	2.59	0.23	0.00	3.06	0.29	0.32	0.00	2.39
Temperate broadleaved	61.50	462.00	0.00	4.71	14.83	0.00	25.03	1.43	0.10	6.03	0.00	0.03	0.02	0.56	0.00	3.53
Sal	0.03	0.00	94.28	0.61	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	1.03	0.00	0.00	0.00
Mixed moist deciduous	40.01	18.34	17.87	224.71	0.00	0.00	7.89	1.87	0.12	3.07	0.00	6.40	1.94	0.59	0.00	2.34
Temperate coniferous	0.19	15.04	0.00	0.00	97.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bamboo	0.00	0.00	0.00	0.00	0.00	11.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tree clad area	12.34	40.71	0.00	13.11	0.00	0.00	166.73	0.14	3.12	45.97	0.58	12.02	0.10	0.05	0.00	1.92
Scrub	0.00	0.00	0.00	0.00	0.00	0.00	0.00	31.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shrub land	1.01	4.21	0.00	1.10	2.03	0.00	0.30	2.64	37.32	3.67	0.00	0.88	0.41	0.25	0.00	0.00
Agriculture	7.11	12.77	0.00	17.15	0.00	0.00	1.16	0.00	0.06	604.96	0.00	1.91	1.62	0.89	0.00	5.14
Plantation	1.11	0.00	0.74	3.12	0.00	0.00	0.00	0.00	6.24	0.00	31.86	0.00	0.50	0.08	0.00	0.00
Tea	12.25	5.23	6.24	2.90	0.00	0.00	0.06	1.63	1.26	6.25	3.18	365.83	4.00	0.17	0.00	2.31
Dry river bed	0.59	0.00	2.01	0.88	0.02	0.59	0.11	0.00	12.15	1.56	0.26	0.53	60.87	23.77	0.00	0.09
Perennial river	0.02	0.11	0.05	0.30	0.00	0.00	0.00	0.00	0.06	0.02	0.25	0.32	6.30	33.40	0.00	0.32
Lake/Pond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Built Up	0.00	0.00	0.00	9.50	0.00	0.00	1.93	0.00	0.00	0.00	0.00	1.77	0.00	0.00	0.00	78.13

Table 5.4: Land use that was converted from each of the classes into the rest during 1985 and 1997

	Sub-tropical broad-leaved	Temperate broad-leaved	Sal	Mixed moist deciduous	Temperate coniferous	Bamboo	Tree clad area	Scrub	Shrub land	Agri-culture	Planta-tion	Tea	Dry river bed	Perennial river	Lake/ Pond	Built Up
Sub-tropical broadleaved	284.19	22.27	0.44	21.67	0.91	0.60	15.21	0.00	0.43	8.53	0.00	9.42	0.03	0.07	0.00	0.00
Temperate broadleaved	61.82	440.25	0.03	4.51	22.25	0.00	45.36	0.36	0.00	15.54	0.00	8.39	0.00	0.00	0.00	1.02
Sal	1.44	0.11	113.82	2.47	0.08	0.00	0.09	0.00	0.21	2.17	0.00	0.44	0.11	0.00	0.00	0.26
Mixed moist deciduous	6.01	1.81	1.79	258.34	0.00	0.00	18.39	0.00	0.00	1.81	0.09	0.11	0.08	0.00	0.00	0.08
Temperate coniferous	0.00	16.95	0.00	0.00	94.05	0.00	0.08	0.00	0.00	3.01	0.00	0.00	0.00	0.02	0.00	0.02
Bam-boo	0.30	0.00	0.00	0.00	0.45	11.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tree clad area	9.63	4.36	0.24	4.81	2.78	0.00	187.19	0.00	0.06	1.88	0.00	1.24	0.00	0.01	0.00	0.00
Scrub	1.15	0.24	0.00	0.00	0.00	0.00	0.00	38.10	0.00	0.16	0.11	0.78	0.00	0.00	0.00	0.00
Shrub land	0.79	0.00	0.08	0.00	0.00	0.00	0.00	0.00	58.09	0.08	0.00	3.00	0.12	0.00	0.00	0.85
Agriculture	3.63	1.52	0.90	1.93	0.00	0.00	3.68	0.00	0.00	647.89	0.68	11.62	0.14	0.02	0.00	0.09
Plantation	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.00	0.00	0.88	32.87	1.55	0.00	0.00	0.00	0.00
Tea	4.81	0.82	0.37	2.06	0.46	0.00	0.05	0.00	7.00	11.64	0.00	364.74	0.31	0.17	0.00	0.34
Dry river bed	0.30	0.00	0.00	1.93	0.00	0.00	0.12	0.00	0.00	0.04	0.57	0.38	73.65	0.08	0.00	0.00
Perennial river	0.04	0.02	0.00	0.49	0.00	0.00	0.01	0.00	0.06	0.00	0.06	0.02	0.28	59.09	0.00	0.00
Lake/Pond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Built Up	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.42	0.00	0.00	0.00	95.53

Table 5.5: Land use that was converted from each of the classes into the rest during 1997 and 2005

	Sub-tropical broad-leaved	Temperate broad-leaved	Sal	Mixed moist deciduous	Temperate coniferous	Bamboo	Tree clad area	Scrub	Shrub land	Agri-culture	Planta-tion	Tea	Dry river bed	Perennial river	Lake/ Pond	Built Up
Sub-tropical broadleaved	248.62	44.95	0.96	28.04	0.00	0.30	18.37	0.99	2.54	7.66	4.30	17.13	0.09	0.00	0.00	0.17
Temperate broadleaved	45.19	350.62	1.12	3.66	22.41	0.06	8.92	1.40	0.50	10.26	0.00	43.39	0.00	0.00	0.08	0.73
Sal	4.54	0.14	98.76	7.29	0.00	0.00	1.61	0.00	0.02	1.38	0.00	3.94	0.00	0.00	0.00	0.00
Mixed moist deciduous	24.29	8.17	4.92	243.04	0.00	0.00	8.16	0.00	0.01	3.12	3.02	3.50	0.51	0.00	0.00	0.29
Temperate coniferous	1.47	18.11	0.00	0.00	98.46	0.29	1.24	0.05	0.00	0.74	0.00	0.59	0.00	0.00	0.00	0.00
Bam-boo	0.60	0.09	0.00	0.00	0.00	10.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tree clad area	45.06	37.19	1.17	6.35	1.05	0.08	143.75	0.11	1.42	18.21	0.11	15.51	0.12	0.05	0.00	0.00
Scrub	0.75	0.51	0.00	0.00	0.85	0.00	0.00	36.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shrub land	0.23	0.12	0.19	0.00	0.00	0.00	0.06	0.00	51.37	0.09	1.56	10.48	0.71	0.06	0.06	1.16
Agriculture	16.98	14.24	3.53	5.19	3.54	0.00	14.35	0.38	0.11	582.23	3.55	32.79	0.04	0.00	0.04	16.66
Plantation	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	1.09	3.27	25.18	4.00	0.57	0.06	0.00	0.10
Tea	18.19	10.86	1.03	1.21	0.46	0.00	6.29	1.68	2.05	11.58	13.65	327.45	0.00	0.00	0.00	7.68
Dry river bed	0.52	0.00	0.65	0.90	0.00	0.00	0.16	0.00	1.41	1.68	0.07	1.73	61.83	4.95	0.00	0.82
Perennial river	0.24	0.00	0.01	0.02	0.02	0.00	0.00	0.00	0.00	1.64	0.31	0.32	0.80	56.09	0.00	0.01
Lake/Pond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Built Up	0.07	2.09	0.26	0.18	0.00	0.00	0.00	0.00	0.71	0.00	0.00	4.02	0.00	0.00	0.00	90.85

Table 5.6: Land use that was converted from each of the classes into the rest during 2005 and 2012

	Sub-tropical broad-leaved	Temperate broad-leaved	Sal	Mixed moist deciduous	Temperate coniferous	Bamboo	Tree clad area	Scrub	Shrub land	Agri-culture	Planta-tion	Tea	Dry river bed	Perennial river	Lake/ Pond	Built Up
Sub-tropical broadleaved	323.84	41.92	0.09	5.07	3.60	0.00	8.19	0.15	0.00	2.96	0.00	18.34	1.15	0.11	0.00	1.32
Temperate broadleaved	0.29	382.76	0.00	1.65	49.63	0.00	12.59	6.84	0.56	10.71	0.00	19.89	0.00	0.22	0.11	1.81
Sal	0.32	0.41	99.14	5.64	0.00	0.00	0.50	1.32	0.00	4.37	0.00	0.87	0.00	0.02	0.00	0.00
Mixed moist deciduous	5.45	0.19	0.00	275.55	0.36	0.00	0.05	3.79	0.00	2.24	0.00	6.76	1.09	0.39	0.00	0.00
Temperate coniferous	0.06	7.57	0.00	0.00	117.01	0.00	0.55	0.00	0.00	1.58	0.00	0.11	0.00	0.00	0.00	0.00
Bam-boo	5.01	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	6.55	0.00	0.00	0.00	0.00	0.00	0.00
Tree clad area	0.99	0.23	0.00	0.51	0.02	0.00	194.67	0.58	0.01	0.53	0.00	4.83	0.23	0.00	0.00	0.33
Scrub	0.68	0.09	0.00	0.00	0.00	0.00	0.00	39.20	0.00	0.31	0.00	0.36	0.00	0.00	0.00	0.33
Shrub land	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.38	58.35	0.00	1.47	0.14	0.00	0.00	0.00	0.30
Agri-culture	1.12	1.64	0.16	0.00	0.36	0.00	2.65	0.12	0.00	624.57	0.85	9.68	0.36	0.11	0.00	0.26
Planta-tion	0.79	0.00	1.33	1.07	0.00	0.00	0.00	0.00	0.00	1.91	45.38	0.68	0.00	0.07	0.00	0.52
Tea	3.14	3.73	0.00	0.06	0.00	0.00	1.64	3.55	0.41	8.84	3.47	436.15	0.43	0.34	0.04	3.06
Dry river bed	0.35	0.00	0.00	0.03	0.02	0.00	0.31	0.00	0.00	0.00	0.00	0.05	63.59	0.32	0.00	0.00
Peren-nial river	0.05	0.00	0.00	0.24	0.00	0.00	1.00	0.00	0.00	0.01	0.01	0.03	3.25	56.62	0.00	0.00
Lake/Pond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
Built Up	0.24	0.10	0.00	0.00	0.00	0.00	0.02	0.17	0.00	0.03	0.00	1.30	0.00	0.00	0.01	116.59

Table 5.7: Land use that was converted from each of the classes into the rest during 1977 and 2012

	Sub-tropical broad-leaved	Temperate broad-leaved	Sal	Mixed moist deciduous	Temperate coniferous	Bam-boo	Tree clad area	Scrub	Shrub land	Agri-culture	Planta-tion	Tea	Dry river bed	Perennial river	Lake/ Pond	Built Up
Sub-tropical broadleaved	157.43	39.14	1.11	39.01	0.14	0.00	15.79	4.69	4.00	3.69	2.49	24.72	0.83	0.57	0.00	4.46
Temperate broadleaved	61.17	307.85	0.30	3.57	79.34	0.00	31.66	7.85	0.34	22.09	0.00	60.44	0.21	1.01	0.00	3.94
Sal	0.63	0.03	73.51	9.13	0.00	0.00	1.82	1.42	0.00	5.03	0.00	3.89	0.48	0.08	0.00	0.28
Mixed moist deciduous	57.77	6.07	12.99	200.83	0.10	0.00	9.01	0.80	0.43	12.27	1.53	17.79	2.88	0.41	0.00	2.28
Temperate coniferous	1.39	34.36	0.00	0.00	73.09	0.00	0.36	0.02	0.00	1.59	0.00	1.62	0.00	0.00	0.00	0.00
Bam-boo	4.41	0.24	0.00	0.00	0.00	0.03	0.00	0.00	0.00	6.49	0.00	0.00	0.00	0.00	0.00	0.00
Tree clad area	22.38	27.37	0.46	5.84	14.15	0.08	138.83	1.50	2.83	50.32	0.00	29.26	0.31	0.19	0.00	3.27
Scrub	0.00	0.14	0.00	0.00	0.00	0.00	0.00	31.42	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00
Shrub land	1.42	0.65	0.00	1.10	3.11	0.00	0.10	2.19	32.46	7.52	0.00	4.48	0.00	0.25	0.06	0.50
Agriculture	12.32	11.81	1.46	15.73	0.19	0.00	16.47	2.96	0.57	527.68	3.36	37.13	1.17	0.88	0.16	20.87
Plantation	0.21	0.00	1.93	1.79	0.00	0.00	0.52	0.00	4.79	5.11	27.28	1.03	0.62	0.11	0.00	0.26
Tea	20.85	11.49	6.33	3.01	0.74	0.00	3.77	3.05	1.27	19.02	14.75	311.13	2.85	0.27	0.12	12.67
Dry river bed	1.44	0.05	2.18	1.39	0.14	0.00	1.97	0.00	12.57	3.79	1.51	0.93	59.62	16.97	0.00	0.87
Perennial river	0.42	0.00	0.05	1.02	0.00	0.00	0.07	0.02	0.06	0.02	0.25	0.32	1.12	37.47	0.00	0.33
Lake/Pond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Built Up	0.47	0.03	0.39	7.41	0.00	0.00	1.81	0.19	0.00	0.00	0.00	6.22	0.00	0.00	0.00	74.82

Table 5.8: Overview of changes in major land use and land cover classes in between 1977 and 2012

Land use change compared with 1977 (%)				
Land use	Unchanged in 2012	Lost to other classes in 2012	Gained from other classes in 2012	Net gain loss
Forest	94.40	18.22	13.37	-4.85
Tree clad	88.28	45.26	37.99	-7.27
Agriculture	98.18	19.16	20.60	1.44
Plantation	79.03	22.15	35.65	13.50
Other	92.68	18.94	24.47	5.53

5.3 Prediction of future land use and land cover

5.3.1 CA_Markov modeling

The model takes input from Markov Chain analysis where land use and land cover map of 1985 and 2005 were taken as input which had 20 years' time period between the images to project forward 20 years into the future for the output images i.e., 2025 from the second image of 2005. The Markov Chain analysis gives following three outputs: (i) a transition probability matrix, (ii) a transition areas matrix, and (iii) a set of conditional probability images. Finally, using these inputs in CA_Markov model land use and land cover modeling for future time periods were done. The output land use and land cover maps for the year 2025 and 2045 are displayed in the Figure 5.3.

5.3.2 Predicted land use and land cover

The change area and net area gained or lost in the different land use and land cover classes during 2005, 2025 and 2045 are shown in Table 5.9, Table 5.10 and Table 5.11 respectively.

The Table 5.10 showed land use and land cover that was converted from each of the classes into the rest during 2005 and 2025. The table indicates the major area increase in tea where it gained 68.14 sq. km. and lost 14.61 sq. km. from other classes with a net gained of 53.53 sq. km. which is followed by built up class with a gained of 21.46 sq. km. and sub-tropical broadleaved class with a gained of 20.36 sq. km. The other classes such as mixed moist deciduous, temperate coniferous, plantation and perennial river all gained in net area in 2025. The largest decrease in area was observed in temperate broadleaved with a net loss of 70.82 sq. km. which is followed by agriculture with a loss of 25.21 sq. km. and dry river bed with a loss of 10.02 sq. km. Other classes such as sal, bamboo, scrub and shrubland all loss in net area in the same period.

The Table 5.11 showed land use and land cover that was converted from each of the classes into the rest during 2025 and 2045. The table indicates the maximum area increase in tea with a net area gained of 45.50 sq. km. which is followed by built up class with a gained of 20.66 sq. km. and plantation class with a gained of 15.34 sq. km. The only other classes with net gained in areas are sub-tropical broadleaved and mixed moist deciduous classes. The prominent classes which showed major decrease in net areas are temperate broadleaved with a net loss of 58.51 sq. km. which is followed by agriculture with a loss of 23.71 sq. km. and sal with a loss of 8.57 sq. km. All the remaining classes such as temperate coniferous, bamboo, tree clad, scrub, shrubland, dry river bed and perennial river all loss different net area in this period.

The Table 5.12 showed land use and land cover that was converted from each of the classes into the rest during 2005 and 2045. It is observed from the table that the significant increase in net area over the given time period was in tea which had gained 99.03 sq. km. which is followed by built up class with a gained of 42.14 sq. km. and sub-tropical broadleaved class with a gained of 35.30 sq. km. The other classes which had gained in net areas are mixed moist deciduous, temperate coniferous and plantation. The class with the highest decrease in net area was temperate broadleaved with a net area loss of 129.33 sq. km. Another class which had loss a substantial area was agriculture with a net area loss of 48.92 sq. km. The net loss in areas over the given period was observed in the classes of sal, bamboo, tree clad, scrub, shrubland, dry river bed and perennial river.

Table 5.9: Land use that was converted from each of the classes into the rest during 2005 and 2025

2005	Sub-tropical broad leaved	Temperate broad leaved	Sal	Mixed moist deciduous	Temperate coniferous	Bamboo	Tree clad area	Scrub	Shrub land	Agriculture	Plantation	Tea	Dry river-bed	Perennial river	Lake/ Pond	Built Up
Sub-tropical broad leaved	376.38	0.02		22.84					2.08		5.40	0.01				
Temperate broad leaved	41.09	402.74			3.12			0.05		7.34		32.75				
Sal	3.86		102.92	2.75			0.60					2.46				
Mixed moist deciduous		2.56		277.87			11.58		0.08	0.45	1.64	1.71				
Temperate coniferous					126.89											
Bamboo		0.15				11.50										
Tree clad area	1.58	9.94			0.11		183.50			0.03		7.78				
Scrub	0.74				0.91			39.27				0.04				
Shrub land									55.77	0.43	0.05	4.44				0.53
Agriculture	0.53		1.06				2.57			604.93		17.28				15.50
Plantation									0.03	0.47	51.14					0.12
Tea	2.07										7.03	450.24				5.50
Dry river-bed	0.54		0.44	1.49					0.44	1.35	0.63	1.67	54.65	2.81		0.66
Perennial river	0.30			0.37					0.00	1.65	0.30	0.01		58.56		
Lake/Pond															0.25	
Built Up		0.85														117.62

Table 5.10: Land use that was converted from each of the classes into the rest during 2025 and 2045

	Sub-tropical broad leaved	Temperate broad leaved	Sal	Mixed moist deciduous	Temperate coniferous	Bamboo	Tree clad area	Scrub	Shrub land	Agriculture	Plantation	Tea	Dry river-bed	Perennial river	Lake/ Pond	Built Up
Sub-tropical broad leaved	397.49			23.49							6.11					
Temperate broad leaved	37.84	344.29			2.63					5.72		25.78				
Sal	3.61		95.61	2.41			0.52					2.27				
Mixed moist deciduous		2.63		287.87			11.96				1.15	1.70				
Temperate coniferous					131.02											
Bamboo		0.15				11.35										
Tree clad area	1.50	9.69					179.46					7.59				
Scrub	0.75				0.90			37.67								
Shrub land									53.59	0.18		4.49				0.14
Agriculture							2.02			583.42		16.32				14.90
Plantation										0.50	65.69					
Tea	0.12										7.80	504.30				6.16
Dry river-bed	0.45		0.23	1.52						1.23	0.53	1.44	46.61	2.20		0.44
Perennial river	0.27			0.01						1.89	0.25			58.95		
Lake/Pond															0.25	
Built Up		0.98														138.95

Table 5.11: Land use that was converted from each of the classes into the rest during 2005 and 2045

	Sub-tropical broad leaved	Temperate broad leaved	Sal	Mixed moist deciduous	Temperate coniferous	Bamboo	Tree clad area	Scrub	Shrub land	Agriculture	Plantation	Tea	Dry river-bed	Perennial river	Lake/ Pond	Built Up
Sub-tropical broad leaved	348.52			43.68			0.84		1.97	0.23	11.21	0.26				
Temperate broad leaved	77.41	331.89		0.68	5.75			0.05		12.97		57.42				0.91
Sal	6.88		94.48	5.39			0.90					4.95				
Mixed moist deciduous	0.02	5.13		262.01			21.93		0.07	0.44	2.39	3.90				
Temperate coniferous					126.89											
Bamboo		0.30				11.35										
Tree clad area	3.57	18.79		0.03	0.11		165.70			0.04		14.68				
Scrub	1.04				1.81			37.62			0.46	0.04				
Shrub land									51.10	0.50	0.05	8.89				0.67
Agriculture	0.73	0.05	0.72	0.14			4.54			571.87	0.11	33.37				30.35
Plantation									0.03	0.71	50.90					0.12
Tea	2.01			0.17							14.55	437.32				10.80
Dry river-bed	1.00		0.65	2.97			0.04		0.42	2.58	1.35	2.94	46.61	5.00		1.11
Perennial river	0.57	0.15		0.23						3.58	0.53	0.01		56.14		
Lake/Pond															0.25	
Built Up	0.29	1.43										0.11				116.64

5.3.3 Predicted land use and land cover change in the future (2045) with respect to the present scenario

The computed areas in the Table 5.12 shows that in 2012 land use and land cover change class is dominated by agriculture with 666.59 sq. km. that is 21.17% of the total geographical area of the district. The class with the lowest area is found in bamboo with 0.10 sq. km. The other prominent classes with respect to their substantial areas are tea, temperate broadleaved and sub-tropical broadleaved, etc.

The computed areas of land use and land cover change class for the year 2045 in the same table also follows the same trend as observed in 2012 with agriculture as the dominated class but with decreased in areas. Whereas, there is a massive increased in areas with respect to classes in tea, sub-tropical broadleaved and built up.

Table 5.12: Land use and land cover class areas in 2012 and 2045

Land use and land cover class	Year Area (km^2) 2012	2045
Sub-tropical broad leaved	343.43	442.36
Temperate broad leaved	440.61	358.22
Sal	101.14	95.80
Mixed moist deciduous	290.97	315.68
Temperate coniferous	171.62	134.60
Bamboo	0.10	11.35
Tree clad area	222.67	194.00
Scrub	56.24	37.70
Shrub land	59.54	53.61
Agriculture	666.59	593.71
Plantation	51.37	81.56
Tea	500.68	564.22
Dry river-bed	70.23	46.21
Perennial river	48.47	59.21
Lake/Pond	0.42	0.23
Built Up	124.93	160.52

5.4 Evaluation of ecosystem hotspot

The hotspot of change involves the use of different landscape based indices as inputs for the model such as: (i) weighed cumulative LULCC (cc), (ii) population variability (pv), (iii) terrain impedance (ti), and (iv) naturalness index (ni). The above mentioned parameters were computed through the various landscape indices and other geospatial inputs.

5.4.1Fractal dimension (FD)

The fractal dimension maps are prepared for the five time periods from 1977 to 2012 which are depicted in Figure 5.4. The values vary from 0.99 to 1.38 indicating various levels of impact by different factors of change on the landscape. The values are classified into 10 classes with the lowest class 0.99-1.02 representing low impact to highest class 1.30-1.38 representing extreme impact by factors of change.

5.4.2 Landscape Variability (LV)

The landscape variability maps are prepared for the five time periods from 1977 to 2012 which are depicted in Figure 5.5. The variability indicates the number of land use and land cover classes in 1km grid of the landscape. It is found to vary from 1 to 7 classes in all the four time periods i.e., 1985, 1997, 2005 and 2012. While the variability ranges from 1 to 6 classes in the landscape of 1977.

5.4.3 Proportion of Natural Ecosystem (VT)

The proportion of natural ecosystem maps for the five time periods from 1977 to 2012 are prepared and depicted in Figure 5.6. The map indicates the proportion of natural vegetation in 1km grid of the landscape. It is found to vary from 0% to 100% as per the absence and presence of natural vegetation in each 1km grid of the landscape.

5.4.4 Naturalness index (ni)

Naturalness index (ni) is a multiplicative function of fractal dimension, landscape variability and proportion of the natural ecosystems. The naturalness index (ni) is calculated for all the time periods from the above three layers of each respective year. The naturalness index map is prepared and depicted in Figure 5.7.

5.4.5 Calculation of weight for cumulative LULCC map (CC)

Weighted cumulative LULCC map (CC) is generated by assigning weightage based on the degree of change computed by AHP matrix of LULC classes pair-wise relative importance as shown in Table 5.13. The weights were assigned from 1 to 9 according to Saaty's classification to the various classes on priority as it changes from one class to another. The 1977-1985, 1985-1997, 1997-2005 and 2005-2012 weighted change maps were geospatially modeled to produce the cumulative change maps.

Table 5.13: AHP Matrix- LULC classes pair-wise relative importance

Class	Sub tropical broad leaved	Temperate broad leaved	Sal	Mixed moist deciduous	Temperate coniferous	Bamboo	Tree clad area	Scrub	Shrub land	Agriculture	Planta-tion	Tea	Dry river bed	Perennial river	Lake/ Pond	Built Up
Sub tropical broad leaved	1	1/4	1/4	1/2	1/2	1/4	1/4	1/5	1/4	1/5	1/6	1/7	1/8	1/8	1/8	1/9
Temperate broad leaved	4	1	1/5	1/3	1/2	1/3	1/2	1/3	1/2	1/6	1/6	1/7	1/8	1/8	1/8	1/9
Sal	4	5	1	1/2	1/4	1/4	1/2	1/5	1/4	1/8	1/6	1/6	1/8	1/8	1/8	1/9
Mixed moist deciduous	2	3	2	1	1/4	1/3	1/2	1/5	1/4	1/8	1/5	1/6	1/8	1/8	1/8	1/9
Temperate coniferous	2	2	4	4	1	1/5	1/2	1/5	1/4	1/8	1/6	1/7	1/8	1/8	1/8	1/9
Bamboo	3	5	3	3	5	1	1/5	1/3	1/3	1/6	1/5	1/5	1/8	1/8	1/8	1/9
Tree clad area	4	2	2	2	2	5	1	1/4	1/3	1/6	1/2	1/3	1/8	1/8	1/8	1/8
Scrub	5	3	5	5	5	3	4	1	1/1	1/5	1/5	1/5	1/7	1/7	1/7	1/8
Shrub land	4	2	4	4	4	3	3	1	1	1/5	1/5	1/5	1/7	1/7	1/7	1/8
Agriculture	5	6	8	8	8	6	6	5	5	1	1/2	1/2	1/7	1/7	1/7	1/8
Plantation	6	6	5	5	6	5	2	5	5	2	1	1/2	1/7	1/7	1/7	1/8
Tea	7	7	6	6	7	5	3	5	5	2	2	1	1/7	1/7	1/7	1/8
Dry river bed	8	8	8	8	8	8	8	7	7	7	7	7	1	1/2	1/4	1/8
Perennial river	8	8	8	8	8	8	8	7	7	7	7	7	2	1	1/4	1/8
Lake/Pond	8	8	8	8	8	8	8	7	7	7	7	7	4	4	1	1/8
Built Up	9	9	9	9	9	9	8	8	8	8	8	8	8	8	8	1

Table 5.13: AHP Matrix- LULC classes pair-wise relative importance (cont.) A^2& B^2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	15.75	14.30	14.09	13.75	12.66	10.26	8.70	7.19	7.37	4.90	4.76	4.44	2.28	2.09	1.59	0.61
2	23.97	16.67	16.76	17.46	16.80	13.48	11.07	8.30	8.76	5.70	5.55	5.10	2.81	2.62	2.12	1.09
3	41.04	23.27	15.58	16.25	16.54	13.65	11.95	9.28	10.44	6.37	6.27	5.70	3.33	3.14	2.64	1.56
4	36.49	27.88	17.10	16.00	15.53	13.15	11.28	8.71	9.51	5.91	5.92	5.42	3.03	2.85	2.35	1.29
5	47.23	46.35	27.19	21.96	16.00	14.05	13.49	9.19	10.12	6.32	6.71	6.15	3.60	3.42	2.92	1.80
6	65.23	54.42	44.68	41.60	26.83	16.17	17.37	11.86	13.41	7.62	7.90	7.15	4.47	4.28	3.78	2.56
7	59.88	61.88	44.94	43.21	46.38	24.28	16.00	13.79	14.71	8.46	8.56	7.55	4.35	4.16	3.66	2.38
8	99.15	90.60	71.20	65.35	52.25	42.92	28.48	16.00	17.83	9.94	11.70	10.26	6.12	5.91	5.34	3.89
9	82.15	77.35	61.75	57.02	47.75	36.55	25.23	14.62	16.00	9.03	10.33	9.16	5.37	5.16	4.59	3.21
10	196.05	171.30	151.50	141.55	123.55	91.07	71.38	35.30	38.25	16.00	18.30	15.83	9.59	9.38	8.80	6.98
11	164.05	139.55	134.25	129.05	118.55	76.67	70.43	40.07	42.33	16.37	15.83	13.90	8.30	8.09	7.52	5.78
12	190.55	162.30	151.70	145.39	132.55	90.54	77.18	48.95	51.67	20.28	19.20	16.00	9.27	9.05	8.48	6.65
13	364.13	329.13	310.73	301.79	301.13	228.06	168.60	145.98	149.58	59.65	53.08	40.41	16.00	15.00	13.63	11.05
14	376.13	341.13	322.73	313.79	313.13	240.06	180.60	156.48	160.08	70.15	63.58	50.91	18.00	16.00	14.00	11.24
15	422.13	387.13	368.73	359.79	359.13	286.06	226.60	196.73	200.33	110.40	103.83	91.16	29.00	23.00	16.00	11.96
16	593.00	555.25	535.05	525.00	524.50	438.30	374.05	327.20	331.17	228.71	220.80	206.52	77.46	65.46	33.46	16.00

A2

Row sum	Normalized
124.74	0.01
158.25	0.01
187.03	0.01
182.43	0.01
236.49	0.01
329.34	0.02
364.18	0.02
536.96	0.03
465.29	0.02
1104.85	0.06
990.76	0.05
1139.76	0.06
2507.94	0.13
2648.00	0.14
3191.97	0.17
5051.94	0.26
19219.93	**1.00**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	10015.36	8722.77	7428.68	7076.70	6486.51	4818.26	3876.58	2817.35	2974.28	1544.33	1529.64	1340.81	672.96	626.67	527.44	355.17
2	12531.82	10949.23	9333.09	8893.59	8167.42	6089.80	4913.03	3614.35	3808.42	2007.55	1984.07	1745.07	863.14	800.31	664.23	442.27
3	14401.62	12637.19	10921.56	10434.09	9629.90	7214.75	5810.89	4317.52	4532.98	2412.84	2376.57	2094.58	1018.60	940.36	770.29	506.08
4	13534.50	11801.89	10175.65	9728.86	8971.02	6715.29	5414.79	4008.42	4214.90	2244.23	2212.30	1950.32	958.99	887.31	730.70	478.86
5	16399.26	14143.91	12239.55	11754.29	10925.29	8223.00	6644.79	4977.91	5230.00	2827.08	2776.81	2455.92	1200.82	1108.15	903.31	581.14
6	21824.15	18731.48	15975.09	15321.97	14264.12	10814.02	8761.13	6599.41	6942.41	3804.66	3741.67	3319.65	1626.74	1500.13	1216.54	773.11
7	23766.35	20448.80	17172.77	16373.37	15011.25	11386.43	9293.95	6907.03	7291.94	4001.37	3957.49	3515.18	1757.03	1626.79	1331.96	850.30
8	33898.91	29012.93	24493.08	23446.24	21592.56	16304.98	13354.38	10057.53	10608.53	5878.56	5792.08	5155.56	2561.29	2366.18	1921.49	1211.77
9	29625.12	25378.50	21374.12	20442.27	18809.14	14191.42	11611.93	8716.81	9199.42	5080.51	5010.54	4456.46	2221.34	2054.21	1673.92	1059.87
10	65300.17	55890.92	46197.42	44084.36	40359.94	30413.69	24939.73	18752.88	19853.80	11190.74	11089.16	9907.77	5016.08	4647.16	3786.22	2363.00
11	59540.11	51207.26	42002.27	39973.04	36491.38	27459.10	22382.86	16681.11	17689.90	9946.74	9902.67	8841.09	4514.46	4191.83	3436.85	2161.46
12	68785.82	59155.78	48613.45	46256.69	42124.17	31709.13	25841.88	19170.47	20336.33	11428.29	11392.37	10173.02	5205.44	4835.75	3968.40	2499.76
13	155221.64	133913.10	109280.02	103493.29	92720.15	69276.76	56323.80	40375.53	43066.26	23977.04	24183.11	21588.61	11402.47	10670.28	8911.06	5709.69
14	167756.16	144830.60	118616.33	112339.55	100661.51	74969.07	60938.30	43405.91	46298.53	25546.21	25772.68	22975.50	12170.17	11402.47	9557.87	6164.54
15	218447.42	189076.06	156670.65	148452.22	133300.68	98470.89	79888.55	56115.20	59807.15	32044.45	32302.75	28639.10	15239.63	14322.82	12136.09	7987.30
16	396031.32	344567.14	291101.18	276375.22	250298.69	183878.86	148233.30	104070.39	110473.86	56677.41	56734.87	49746.67	26108.91	24561.36	21054.01	14270.95

B2

Row sum	Normalized
60813.52	0.01
76807.39	0.01
90019.81	0.01
84028.04	0.01
102391.23	0.01
135216.30	0.02
144692.00	0.02
207656.08	0.03
180905.58	0.02
393793.04	0.05
356422.14	0.05
411496.77	0.05
910112.81	0.12
983405.40	0.13
1282900.95	0.17
2354184.13	0.30
7774845.18	**1.00**

Table 5.13: AHP Matrix- LULC classes pair-wise relative importance (cont.)

Nor_A²	Nor_B²	Difference
0.006490	0.007822	0.001331
0.008234	0.009879	0.001645
0.009731	0.011578	0.001847
0.009492	0.010808	0.001316
0.012304	0.013170	0.000865
0.017135	0.017392	0.000256
0.018948	0.018610	0.000338
0.027937	0.026709	0.001229
0.024209	0.023268	0.000941
0.057485	0.050650	0.006835
0.051549	0.045843	0.005706
0.059301	0.052927	0.006374
0.130486	0.117059	0.013428
0.137774	0.126486	0.011288
0.166076	0.165007	0.001069
0.262849	0.302795	0.039946

Ranking of Class	Weight
Built Up	0.039946
Dry river bed	0.013428
Perennial river	0.011288
Agriculture	0.006835
Tea	0.006374
Plantation	0.005706
Sal	0.001847
Temperate broadleaved	0.001645
Sub tropical broadleaved	0.001331
Mixed moist deciduous	0.001316
Scrub	0.001229
Lake/Pond	0.001069
Shrub land	0.000941
Temperate coniferous	0.000865
Tree clad area	0.000338
Bamboo	0.000256

5.4.6 Change Hotspot (ch) in the present scenario (2012)

The hotspot of land use and land cover change map in Darjeeling district in 2012 is computed using the layers depicted in Figure 5.8-A and 5.8-B. The method used to model land use and land cover hotspot of change integrating the layers of factors of change is depicted in Figure 5.9. The hotspot map generated as shown in Figure 5.10 was classified into ten (10) zones ranging from 1 to 10, where zone 1 represents the areas which are under managed ecosystem such as National parks, sanctuaries, etc., zone 2 represents the areas that are expected to undergo least land use and land cover change and zone 10 represents the areas subjected to most probable land use and land cover change or the land use and land cover change hotspots.

The computed hotspot area with the type of zone of Darjeeling district is presented in the Table 5.14. The total hotspot area in 2012 is 1607. 76 sq. km. which is 51.06% of the total geographical area of the district. The district has 12 administrative blocks where the hotspot areas occurring in each block were identified and classified. In the district it is observed that the block with the highest area under hotspot is Gorubathan with 347.30 sq. km. which is followed by Darjeeling Pulbazar with hotspot area of 274.01 sq. km. and the least is found in Kharibari with 7.49 sq. km. However, on analysis of hotspot based on the degree of land use and land cover change, Darjeeling Pulbazar with 135.06 sq. km. is the block which has most of the hotspot areas under zone 10 of the classification. Kharibari block in fact is one of the smallest blocks and as such it has only 5.11 sq. km. of area under zone 10 out of the total area of 7.49 sq. km. of the hotspot areas. The analysis of the other blocks more or less showed majority of the hotspot areas in the higher zones. The overall area under zone 10 of the hotspot areas is 598.74 sq. km. which is 37.24% of the total area under hotspot of land use and land cover change in the district.

5.4.7 Change Hotspot (ch) in the future scenario (2045)

The prediction of hotspot of land use and land cover change map in Darjeeling district in 2045 was done following the same method used in the modeling of hotspot in 2012 as depicted in Figure 5.11-A and 5.11-B. The method used to integrate the layers of factors of change to model land use and land cover change hotspot is depicted in Figure 5.12. The hotspot map generated as shown in Figure 5.13 was classified into ten (10) zones ranging from 1 to 10, where zone 1 represents the areas which will be under managed ecosystem such as National parks, sanctuaries, etc., zone 2 represents the areas that are expected to undergo least land use and land cover change and zone 10 represents the areas subjected to most probable land use and land cover change or the land use and land cover change hotspots.

The computed probable hotspot area with the type of zone of Darjeeling district in 2045 is presented in the Table 5.15. The total hotspot area is 1515.88 sq. km. which is 48.14% of the total geographical area of the district. The 12 administrative blocks where the hotspot areas will be occurring were identified and classified. It is observed that the block with the highest area under hotspot will be Gorubathan with 347.44 sq. km. which is followed by Darjeeling Pulbazar with hotspot area of 258.33 sq. km. and the least is found in Phansidewa with 1.69 sq. km. However, on analysis of hotspot based on the degree of land use and land cover change, Darjeeling Pulbazar with 145.66 sq. km. is the block which has most of the hotspot areas under zone 10 of the classification. Phansidewa block in fact has all its hotspot areas of 1.69 sq. km. under zone 10. The analysis of the other blocks more or less showed majority of the hotspot areas in the higher zones. The overall area under zone 10 of the hotspot areas is 819.38 sq. km. which is 54.05% of the total area under hotspot of land use and land cover change in the district.

Table 5.14: Land use and land cover hotspot area under different blocks in 2012

Block Name	Hotspot (Area_km^2)									
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**	**Zone 8**	**Zone 9**	**Zone 10**
DarjilingPulbazar	0.0924	87.6985	29.4449	4.0417	0.0141	0.0018	4.6534	0.0072	12.9911	135.0613
Gorubathan	111.0547	66.8611	32.9214	18.0786	17.1199	13.1565	32.0889	3.4216	3.0787	49.5176
JorbunglowSukiapokri	7.1231	23.1353	31.5040	0.6376	18.2562	0.6407	0.4621	0.0000	1.8529	62.5879
Kalimpong I	46.2315	37.0518	35.0448	15.7412	0.2707	10.5461	7.5141	8.7964	3.4008	37.1741
Kalimpong II	40.8042	16.5424	20.0896	6.0069	7.5094	4.1366	3.7961	4.2261	15.5620	36.7702
Kharibari	0.0000	2.0824	0.0323	0.2641	0.0000	0.0000	0.0000	0.0000	0.0000	5.1075
Kurseong	43.9931	5.0239	2.4074	23.9777	6.2019	10.7480	11.1463	0.9965	0.8103	83.1319
Mirik	6.6605	0.8297	1.1311	1.2753	0.8105	0.0000	0.0000	0.0000	0.0000	37.9533
Naxalbari	1.5648	1.1773	3.6263	0.2430	0.1435	1.4905	1.1368	0.3093	2.6646	15.9066
Phansidewa	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.5484	0.0516	0.0059	10.5558
RangliRangliot	11.5394	12.3422	1.0056	0.2176	0.0000	0.0000	3.9530	3.5415	0.5158	110.6791
Siliguri	9.7157	8.8385	14.5128	7.2154	0.1542	0.3684	0.0096	0.1148	0.0000	14.3011
Total (Area_km^2)	**278.7913**	**261.5831**	**171.7201**	**77.6991**	**50.4805**	**41.0886**	**65.3086**	**21.4652**	**40.8821**	**598.7464**

Table 5.15: Land use and land cover hotspot area under different blocks in 2045

Block Name	Hotspot (Area_km^2)									
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**	**Zone 8**	**Zone 9**	**Zone 10**
Darjeeling Pulbazar	0.0000	0.0000	0.0000	99.4680	1.0476	20.6208	0.0000	0.0000	0.2376	136.8432
Gorubathan	143.7264	7.7184	11.0700	11.5092	25.3512	0.0000	0.2664	0.0000	5.5440	142.2504
JorebunglowSukiapokri	4.7304	0.0288	0.0000	0.0000	6.8040	38.9376	0.0216	0.0000	0.0000	75.7764
Kalimpong I	53.5896	3.9996	9.3600	1.8144	12.6180	11.4732	8.7192	1.5480	20.1312	76.9176
Kalimpong II	46.1340	8.5392	0.0000	8.4060	4.9716	0.0000	6.8652	1.9476	0.1512	62.7876
Kharibari	0.0000	0.0000	0.0000	0.0000	0.3996	1.9800	0.0000	0.0000	0.0000	4.4028
Kurseong	10.8252	37.2168	0.0000	0.1368	0.1476	0.0000	0.9072	0.1152	0.0216	145.6596
Mirik	4.1760	3.0096	0.0000	0.0000	0.0000	0.0000	1.9080	0.0216	0.0000	32.5296
Naxalbari	0.7956	0.8064	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	13.2444
Phansidewa	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.6920
RangliRangliot	12.7872	0.0144	8.7372	0.0396	2.3832	0.0288	0.0000	0.0000	0.0000	119.7504
Siliguri	10.9368	0.4500	1.3716	7.0956	0.7632	0.0036	0.0000	11.7540	0.3168	7.5276
Total (Area_km^2)	**287.7012**	**61.7832**	**30.5388**	**128.4696**	**54.4860**	**73.0440**	**18.6876**	**15.3864**	**26.4024**	**819.3816**

5.5 Analysis of Vulnerability

5.5.1 Factors of vulnerability

The thirteen (13) factors which have a significant impact on the vulnerability of the study area includes; LULC, ecosystem-hotspot, population density, distance from road, elevation, slope, aspect, soil texture, soil depth, soil pH, precipitation, temperature minimum (tmin) and temperature maximum (tmax). The layers for the thirteen factors were prepared for the present scenario as well as for the future scenario in 2045. The layers are prepared and depicted separately in various categories of figures.

5.5.2 Weighting of factors

The weights for each of the factors is determined by comparing the relative importance of one factor against another factor developed by (Saaty, 1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). The rating ranges from "extremely less important" (1/9) to "extremely more important" (9). The rating is subjective and entirely depends on the analyst. In this study the researcher compares every pair and assigns the rating into the matrix as depicted in the following Table 4.4.

The weights derived from the pair wise comparison matrix and assigned to each of the suitability variables. Once the pair wise comparison was filled, a Consistency Ratio (CR) was calculated to identify inconsistencies and develop the best fit weights in the complete pair wise comparison matrix. CR is the procedure by which an index of consistency can be produced. It is argued that, a consistency ratio greater than 0.1 should be re-evaluated (Saaty, 1977). In this case, the CR was calculated to be 0.1.

Table 5.16: AHP Matrix- Vulnerability factors pair-wise relative importance

	Soil pH	Soil depth	Soil texture	Preci. (mm)	t min (degree)	t max (degree)	Aspect	Slope	Elevation (m)	Eql. distance	Pop. density	LULC	Hotspot
Soil pH	1	1/2	1/3	1/4	1/5	1/5	1/6	1/7	0.1429	1/8	1/8	1/8	1/9
Soil depth	2	1	1/2	1/3	1/4	1/4	1/5	1/3	1/3	1/8	1/7	1/6	1/9
Soil texture	3	2	1	1/3	1/14	1/5	1/5	1/5	1/6	1/7	1/7	1/8	1/9
Preci. (mm)	4	3	3	1	½	1/2	1/3	1/4	1/5	1/7	1/8	1/5	1/9
t min (degree)	5	4	4	2	1	1/2	1/3	1/4	1/3	1/5	1/7	1/4	1/9
t max (degree)	5	4	4	2	2	1	1/3	1/4	1/3	1/5	1/6	1/7	1/9
Aspect	6	5	5	3	3	3	1	1/3	1/4	1/6	1/8	1/7	1/9
Slope	7	3	5	4	4	4	3	1	1/2	1/5	1/3	1/4	1/9
Elevation (m)	7	3	6	5	3	3	4	2	1	1/5	1/3	1/4	1/9
Eql. distance	8	8	7	7	5	5	6	5	5	1	1/4	1/5	1/9
Pop. density	8	7	7	8	7	6	8	3	3	4	1	1/2	1/9
LULC	8	6	8	5	4	7	7	4	4	5	2	1	1/9
Hotspot	9	9	9	9	9	9	9	9	9	9	9	9	1

Table5.16: AHP Matrix- Vulnerability factors pair-wise relative importance (cont.) A^2& B^2

A2

	Soil pH	Soil depth	Soil texture	Preci. (mm)	t min (degree)	t max (degree)	Aspect	Slope	Elevation (m)	Eql. distance	Pop. density	LULC	Hotspot	Row sum	Normalized
Soil pH	13.00	9.33	9.42	6.86	5.63	5.58	5.34	3.52	3.30	2.69	1.86	1.69	0.48	68.71	0.01
Soil depth	19.68	13.00	13.54	9.78	7.92	7.90	7.50	4.71	4.21	3.29	2.34	2.10	0.74	96.71	0.01
Soil texture	21.89	14.49	13.00	9.08	7.38	7.24	6.72	4.75	4.45	3.36	2.50	2.34	0.98	98.19	0.01
Preci. (mm)	37.89	25.23	21.43	13.00	10.29	10.01	8.67	6.32	5.90	4.43	3.39	3.22	1.58	151.38	0.02
t min (degree)	52.33	35.02	29.98	17.38	13.00	12.61	11.11	8.18	7.58	5.48	4.17	4.07	2.11	203.01	0.02
t max (degree)	59.16	40.54	35.29	20.03	14.74	13.00	11.05	8.20	7.73	5.34	4.21	4.29	2.27	225.84	0.03
Aspect	87.56	61.82	54.85	29.30	22.56	18.37	13.00	9.72	9.40	6.38	5.25	5.51	3.11	326.84	0.04
Slope	119.77	86.43	82.57	46.23	37.23	31.65	21.38	13.00	12.05	8.72	6.51	6.63	3.70	475.88	0.05
Elevation (m)	133.27	92.93	91.57	53.07	43.48	39.40	27.25	15.28	13.00	9.07	7.10	7.08	3.98	536.48	0.06
Eql. distance	241.60	158.95	171.02	108.00	85.40	78.25	61.40	34.01	26.26	13.00	11.55	11.45	6.49	1007.38	0.11
Pop. density	275.00	202.00	202.17	131.17	103.10	94.10	76.63	47.79	43.08	20.65	13.00	12.69	7.06	1228.43	0.14
LULC	282.00	205.00	209.67	147.67	118.60	110.60	98.47	59.08	52.89	27.57	15.15	13.00	6.89	1346.59	0.15
Hotspot	585.00	427.50	466.50	350.25	280.80	285.30	284.10	159.84	146.34	112.52	52.98	39.17	13.00	3203.30	0.36

B2

	Soil pH	Soil depth	Soil texture	Preci. (mm)	t min (degree)	t max (degree)	Aspect	Slope	Elevation (m)	Eql. distance	Pop. density	LULC	Hotspot	Row sum	Normalized
Soil pH	4689.95	3270.74	3183.02	2010.54	1593.74	1474.92	1230.93	774.35	696.11	456.86	320.39	303.90	148.97	20154.4	0.01
Soil depth	6304.47	4396.85	4269.28	2699.93	2139.84	1984.10	1664.37	1050.41	947.09	629.15	439.56	415.90	201.86	27142.82	0.01
Soil texture	6496.07	4539.70	4439.21	2833.84	2249.60	2094.66	1770.76	1108.00	998.11	664.24	455.64	427.33	204.81	28281.96	0.01
Preci. (mm)	9223.30	6444.75	6313.91	4063.63	3229.24	3022.15	2581.46	1615.56	1458.04	982.95	668.79	623.20	292.12	40519.11	0.02
t min (degree)	11926.34	8331.62	8161.48	5263.81	4185.31	3922.98	3360.82	2105.06	1901.76	1290.27	876.81	815.66	379.29	52521.21	0.02
t max (degree)	12602.57	8797.61	8607.88	5570.28	4430.67	4164.20	3585.73	2251.88	2037.47	1391.96	945.03	877.30	403.99	55666.59	0.03
Aspect	16850.97	11744.34	11466.25	7457.27	5931.95	5599.54	4862.88	3068.47	2782.41	1921.25	1304.02	1207.38	547.72	74744.44	0.04
Slope	23603.91	16399.04	15869.48	10237.43	8126.24	7655.66	6630.08	4229.28	3842.84	2667.38	1840.73	1716.62	784.50	103603.2	0.05
Elevation (m)	26597.44	18478.57	17808.45	11434.29	9066.26	8524.43	7366.33	4720.11	4296.37	2987.42	2071.01	1937.26	889.78	116177.7	0.05
Eql. distance	49496.57	34386.78	32857.78	20872.16	16532.90	15480.22	13279.84	8583.91	7842.22	5491.56	3848.38	3622.69	1679.87	213974.9	0.10
Pop. density	62351.64	43255.10	41383.23	26103.63	20689.29	19304.16	16376.56	10550.11	9604.79	6708.48	4752.94	4495.86	2109.14	267685	0.13
LULC	71904.06	49860.93	47622.39	29763.21	23565.01	21872.28	18350.29	11829.78	10751.82	7459.46	5343.45	5087.50	2427.21	305837.4	0.14
Hotspot	194996.57	135166.68	129769.08	80501.38	63674.57	58650.13	48395.73	30966.65	27922.13	18793.09	13655.62	13117.30	6448.02	822056.9	0.39

Table 5.16: AHP Matrix- Vulnerability factors pair-wise relative importance (cont.)

Nor_A²	Nor_B²	Difference
0.007661398	0.009469	0.00181
0.010783011	0.012753	0.00197
0.010947466	0.013288	0.00234
0.01687908	0.019038	0.00216
0.022635438	0.024677	0.00204
0.025181213	0.026155	0.00097
0.036442204	0.035118	0.00132
0.053059794	0.048677	0.00438
0.059816238	0.054585	0.00523
0.112321581	0.100535	0.01179
0.136968327	0.12577	0.01120
0.150142117	0.143696	0.00645
0.357162132	0.386239	0.02908

Ranking of factor	Weight
Hotspot	0.02908
Eql. distance	0.01179
Pop. density	0.01120
LULC	0.00645
Elevation (m)	0.00523
Slope	0.00438
Soil texture	0.00234
Preci. (mm)	0.00216
t min (degree)	0.00204
Soil depth	0.00197
Soil pH	0.00181
Aspect	0.00132
t max (degree)	0.00097

5.5.3 Climatic data

The factors such as precipitation, temperature minimum (tmin) and temperature maximum (tmax) are prepared individually and depicted together in a single category of climatic variables in Figure 5.14-A. The temperature minimum shows a range of 2.80 - 22.91°C. The temperature maximum shows a range of 12.49 - 30.46°C and precipitation with a range of 1046 – 1636 mm matches with the ground condition of the study area.

5.5.4 Topographic data

The factors such as elevation, slope and aspect are prepared individually and depicted together in the category topographic variables in Figure 5.14-B. The elevation of the study area varies from 73 – 3354m. The slope varies from 0 – 67% and aspect is classified into flat and the other eight orientations.

5.5.5 Soil data

Soil with its variables such as soil pH, soil depth and soil texture are prepared and depicted in the category of soil variables in Figure 5.14-C. The soil pH varies from 4.5 – 7.5 with some marshy lands. The soil depth is classified into three major groups of moderate shallow to very deep, while soil texture is classified into three major groups of loamy to loamy skeletal.

5.5.6 Terrestrial data

The terrestrial data consists of LULC and hotspot layers which are prepared and depicted in the Figure 5.14-D. The LULC consists of sixteen classes and hotspot is of ten (10) zones of change level.

5.5.7 Social data

The population density and Euclidian distance of road of the study area are considered as social variables and their respective layers prepared and depicted in Figure 5.14-E. The population density is classified into five groups which range from very low density to very high density, while Euclidian distance of road is at 500m distance.

5.5.8 Ecological vulnerability and identification of critical ecosystem of the present scenario (2012)

The resultant output layer from the integration of various layers of factors of change from Figures 15.14-A to 5.14-E, gave the ecological vulnerability status of the study area for the present year 2012 which is depicted in Figure 5.15. The level of ecological vulnerability is classified into ten (10) zones with the managed areas under zone 1 to zone 10 with very high ecological vulnerability areas according to the different patterns of change in the study area. The ecological vulnerability zone with the highest grade i.e. zone 10 is identified as the critical ecosystem zone of the study area. The other lower zones defined as potential to heavy levels of ecological vulnerability.

The ecological vulnerable area of the district in 2012 is computed to be 1605.27 sq. km. which is 50.98% of the total geographical area of the district as depicted in Table 5.17. The vulnerable area is classified into zones and their current status in each block of the district is thoroughly analyzed. Gorubathan block is found to have the largest area with 346.44 sq. km. under different ecological vulnerability zones. However, the maximum area of 48.43 sq. km. under zone 10 of the ecological vulnerability area which is also considered to be critical ecosystem is found in Kalimpong I block. Kharibari block with an ecological vulnerability area of 7.52 sq. km. is the block with the least area under ecological vulnerability zone. The total area of 232.50 sq. km. in the district which falls in the zone 10 of ecological vulnerability area can be considered as the critical ecosystem.

5.5.9 Ecological vulnerability and identification of critical ecosystem of the future scenario (2045)

The ecological vulnerability and identification of critical ecosystem of the future scenario in 2045 is obtained from the integration of factors of change from Figures 5.16-A to 5.16-E, depicted in Figure 5.17. The Table 5.18 indicates the ecological vulnerability status in the district which is expected to occur over the years in 2045. The ecological vulnerable area of the district is 1516.17 sq. km. which is 48.15% of the total geographical area of the district. Even, in 2045 Gorubathan block is found to have the largest area with 348.06 sq. km. under different ecological vulnerability zones. However, Kalimpong I block with an area of 57.19 sq. km. is the block with the maximum area under zone 10 of the ecological vulnerability area which is also considered to be critical ecosystem. Phansidewa block with an area of 1.67 sq. km. is the block with the least area under ecological vulnerability zone. A total area of 200.68 sq. km. in the district which falls in the zone 10 of ecological vulnerability area can be considered as the critical ecosystem.

Table 5.17: Ecological vulnerability zone in different blocks in 2012

	Ecological Vulnerability (Area_km^2)									
Block Name	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**	**Zone 8**	**Zone 9**	**Zone 10**
Darjeeling Pulbazar	90.76	19.47	16.13	22.05	27.09	34.19	21.73	20.39	16.01	5.47
Gorubathan	40.24	23.80	21.71	29.22	28.87	34.21	35.31	48.07	49.77	35.23
JorebunglowSukiapokri	40.33	16.33	25.55	23.31	15.43	12.56	7.12	3.66	0.98	0.00
Kalimpong I	0.00	0.00	0.66	5.11	8.05	17.76	24.26	32.77	64.63	48.43
Kalimpong II	10.21	11.37	26.57	26.64	27.01	18.07	15.21	10.93	7.89	1.65
Kharibari	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.52
Kurseong	0.03	2.81	7.11	7.07	5.22	9.58	21.14	35.61	59.74	40.08
Mirik	0.00	0.00	0.00	0.08	1.80	4.91	7.87	11.67	13.93	8.57
Naxalbari	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	28.21
Phansidewa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.15
RangliRangliot	1.63	5.76	6.65	15.71	12.27	17.19	29.36	33.62	17.24	4.32
Siliguri	0.00	0.00	0.00	0.00	0.00	0.00	0.40	3.78	9.07	41.87
Total	**183.21**	**79.53**	**104.37**	**129.19**	**125.73**	**148.47**	**162.41**	**200.50**	**239.35**	**232.50**

Table 5.18: Ecological vulnerability zone in different blocks in 2045

Block Name	Ecological Vulnerability (Area_km^2)									
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**	**Zone 8**	**Zone 9**	**Zone 10**
Darjeeling Pulbazar	95.00	18.48	14.85	17.63	22.14	30.83	18.74	21.42	14.43	5.07
Gorubathan	40.52	24.68	21.53	32.90	30.49	34.94	32.74	53.96	47.24	29.06
JorebunglowSukiapokri	38.30	12.88	19.46	17.53	12.63	13.85	7.52	3.28	0.35	0.00
Kalimpong I	0.00	0.00	0.65	4.63	7.33	14.81	22.97	31.39	61.05	57.19
Kalimpong II	9.93	11.53	25.65	25.07	27.42	17.76	11.04	7.57	2.39	1.31
Kharibari	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.75
Kurseong	0.00	2.44	5.71	5.27	5.20	11.69	22.03	39.29	59.18	44.34
Mirik	0.00	0.00	0.00	0.00	1.07	3.14	5.65	8.91	13.29	9.47
Naxalbari	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	14.80
Phansidewa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67
RangliRangliot	2.56	6.15	6.81	15.23	11.24	19.00	28.27	32.13	17.81	4.47
Siliguri	0.00	0.00	0.00	0.00	0.00	0.00	0.43	3.88	9.52	26.54
Total (Area_km^2)	**186.31**	**76.16**	**94.66**	**118.27**	**117.53**	**146.02**	**149.40**	**201.82**	**225.33**	**200.68**

5.5.10 Ecological vulnerability with respect to biological richness

The ecological vulnerability class with respect to biological richness of the study area indicates the amount of different zones of biological richness in each ecological vulnerability class as depicted in Table 5.19.

Table 5.19: Area of biological richness VS ecological vulnerability class in 2012

Vulnerability level	Biological Richness Zones (Area in km^2)			
	Low	Medium	High	Very High
1	9.240192	5.185152	24.929856	157.260672
2	0.340416	2.817792	8.980416	47.835648
3	0.631872	6.773184	16.556544	43.89984
4	0.637632	4.612032	12.630528	55.760832
5	0.728064	4.7232	5.117184	48.249216
6	0.908928	5.382144	4.359744	42.2064
7	0.945792	9.107136	18.975744	37.934784
8	1.252224	21.832128	74.168064	52.94304
9	1.498176	41.727168	142.49376	26.585856
10	0.352512	36.231552	39.777984	0.710208
Grand Total	**16.535808**	**138.391488**	**347.989824**	**513.386496**

The entire study area contains 1016.30 sq. km. of biological richness area. It falls under four biological richness zones such as low, medium, high and very high. The table indicates the maximum area under very high biological richness zone with 513.39 sq. km. of the total geographical area of the study area. The figures in the table presents that in the ecological vulnerability zone 10 about 0.71 sq. km. of very high biological richness zone is observed which can be considered as the most critical ecosystem of the study area in respect to biological diversity.

CHAPTER-6

DISCUSSION

6.1 Overview of land use and land cover change classification

Landscapes may be interpreted as a mosaic of land use and land cover change forms in continuous change (Skole, 1994; Bennett et al., 2006), a transformation that in many instances results in processes of cover loss or regeneration. Deforestation is the most drastic process of degradation among possible changes of land cover. The progress and development of accurate land use and land cover classifications has been a subject of active research in the past four decades, since the launched of the first earth observation satellite in the early 1970s. Excellent progress in improving land use and land cover classification has been made, including incorporation of multiple sources of remote-sensing data (e.g. optical sensor data, radar, light detection and ranging (lidar)) and/or ancillary data (e.g. digital elevation model (DEM), population density), development of advanced classification algorithms (e.g. neural network, support vector machine, random forest decision tree), and application of expert knowledge for post-processing (Lu and Weng, 2007; Lu, Batistella, et al., 2012). However, classification still remain a complex procedure, the results of which affected invariably by many factors such as the characteristics of the study area, selected data sources (e.g. remote-sensing data, ancillary data, ground truth data), classification algorithms, and the analyst's experience (Lu and Weng, 2007). Previous research has emphasized much on the application of multisource remote sensing data and advanced classification algorithm, but misclassification often occurred due to the complex biophysical environments, resulting in similar spectral or radiometric data, and due to the constraints of spectral, spatial, and radiometric resolutions in remote sensing data per se.

In the Darjeeling Himalaya's it is found that no matter what remote-sensing data or classification algorithms were used, there were still some misclassifications that could not be automatically separated from the remote-sensing data. Incorporation of human knowledge during the classification procedure is necessary to improve land use and land cover classification. Therefore, the hierarchical-based method that combined automatic classification and manual editing has been proved to be valuable to provide reliable land use and land cover classification (Lu, Hetrick, et al., 2012).

Post-processing of the classification image has been regarded as an effective method to further improve classification accuracy. Ancillary data, such as DEM, are often used by relating expert knowledge of land use and land cover distribution to topographic factors (e.g. elevation, slope, aspect) (Lu and Weng, 2007). The key is to develop the expert rules that can be used to correct the misclassification. This study provides an alternative to conduct the post-processing by establishing some reasoning knowledge based on the multi-temporal classification results. This is especially valuable when good-quality ancillary data are not available, such as in the eastern Himalaya. Since a variety of sensor data with different spatial and spectral resolutions are available, more research should be focused on the combined use of the different source data or on the modeling of multi-scale remote sensing data to improve land use and land cover classification.

6.2 Land use and land cover change analysis and accuracy

Detail information on land use and land cover classes making changes, by how much and the proportion gained in return is the main advantage of the post classification change detection method used in the study. The change detection yielded land use and land cover maps showing the spatial distribution of change in the classes (Figure 5.2) and a change matrix (Table 5.3 to 5.7) indicating the proportions of specific land use and land covers taking part in the changes. The Darjeeling district landscape has experienced complex land use and land cover changes resulting from increased human activities over the 35-year period under study. Land use and land cover changes have compositional and structural implications on the landscape.

The classified images of 1977, 1985, 1997, 2005 and 2012 were key tools in the monitoring of land use and land cover changes in the Darjeeling district and also within the identified hotspots and critical ecosystems. Image classification is never a complete process when the accuracy of the output land use and land cover change map is unknown. The quality of classification is judged by its accuracy. The 85.39% overall accuracy recorded for classification of the 2012 LISS III image into sixteen major classes of the study area was in conformity with the 85% standard noted in Campbell (2002). Further analysis with kappa statistic revealed that only 84% of the whole classification was in agreement with the reference data used for the assessment leaving the remaining 16% to chance. Kappa at this level is considered to be good. The overall accuracy recorded for classification of the other images of 1977, 1985, 1997 and 2005 were found to be lower than the standard. The analysis of these images with kappa statistic are however good. The lower accuracy in the classified images of 1977, 1985, 1997 and 2005 are due to inherent errors in the field points collected in 2012 to assess the classification of images taken in mentioned four time periods. It is worth noting that a good accuracy result is as good as the training area and reference data (Lillesand and Kiefer, 1994).

Significant seasonal differences and its subsequent effect on the nature of vegetation in the study area could have little or no role in images since almost all the images were taken in the dry season.

6.3 Prediction of future land use and land cover using CA_Markov modeling

On a methodological level, this study provides an integrated approach with a detailed multi-temporal analysis of the land use and land cover change process, useful in evaluating the current land use and land cover dynamic in the region. In the present study future scenarios of land use and land cover change developed using a Markovian model with annualized transition probability matrices, which allows comparing information from different time periods. These scenarios only take into account the history of land use and land cover change. Information regarding other variables which drive changes may be incorporated in more sophisticated models in order to improve the future prediction, enabling researchers to outline normative scenarios assessing varying dynamics according to specific conditions. Markovian models are useful for exploratory analysis and for depicting contrasting scenarios. They have been used in many analyses of land use and land cover change; for example, Geoghegan et al. (2001) used a Markovian model to explore future land use and land cover change patterns in the Yucatan Peninsula. However, Markovian models are not spatial-explicit and assume that transition probabilities are time homogeneous. More detailed spatial explicit land use and land cover models may be used in future analysis to get a better understanding of the causes, locations and pathways of land use and land cover dynamics (Veldkamp and Verburg, 2004;Verburg and Veldkamp, 2005). For example, multi-agents models linked to GIS (Brown et al., 2005) may improve understanding about household decisions and exogenous drivers linked to land use and land cover change processes (Verburg and Veldkamp, 2005). In tropical countries, mainly in South East Asia, the socio economic factors most related to deforestation are expansion of the agricultural frontier and population increase. However, the relative importance of each of these factors varies for different regions (Agrawal, 1995; Bawa and Dayanandan, 1997). It has also been established that building roads and other communications systems increases the rate of deforestation (Sader et al., 1994; Mas et al., 1996; Mertens and Lambin, 2000).

The data and tendencies which are obtained in this study are useful for understanding land use and land cover change patterns in the study region. Important future steps for this analysis are to identify the proximal variables and driving forces of change which determine land use and land cover change.

6.4 Analysis of ecosystem hotspot

Monitoring dynamic processes of land use and land cover changes in tropical regions are better understood at localized scales (Lambin and Ehrlich, 1997). Land use and land cover changes within the Darjeeling district have been dynamic spatially and temporally over the 35 years under study. The hotspot analysis facilitated the identification of areas within the district that have undergone high levels of land use and land cover changes. The thresholds set at various stages of the identification procedure resulted in ten different classes of hotspots. The satellite image and spatial analysis based method adopted for the identification of hotspots in the Darjeeling district proved to have more advantages. The method allowed the reduction of large satellite data set for easy computation and zooming into specific areas for detailed analysis and comparison.

The computed total hotspot areas of Darjeeling district in 2012 is 1607. 76 sq. km. which is 51.06% of the total geographical area of the district. The hotspot analysis shows that the district is under extreme pressure of land use and land cover change due to various factors. The main areas of change of hotspot, which is zone 10 are mostly concentrated in the north-western part of the district with some sporadic patches distributed in the eastern and southern parts of the district. This shows that the areas are under intensive land uses with the geometric progression in population and tea plantations as the leading factors. Until and unless there is some remedial measures in place at the earliest, the survival of the existing natural ecosystem is in great peril.

The computed probable hotspot areas of Darjeeling in 2045 are 1515.88 sq. km. which is 48.14% of the total geographical area of the district. The analysis of the hotspot in the district shows that almost the whole of the hotspot falls under zone 10. It can be presume that in 2045 there will be high demand for land due to gigantic population growth and massive economic activities. This will indirectly leads to utilization of remaining natural ecosystems to extreme uses as there is no other feasible alternative to meet the huge demand. The scenario presents a frightening state which calls for meticulous planning and management of the last surviving natural ecosystem in the district.

6.5 Analysis of ecosystem vulnerability

6.5.1 Factors of vulnerability

The land use land cover gives the idea which classes are dominating larger areal extent and in what manner it is gaining or losing its dominance. Hotspot is an aggregate of change factors which indicates the areas which is expected to experience the most land use and land cover change at the particular instance of time (Roy and Srivastava, 2012). Population density has a profound impact on the natural ecosystem with higher the density more colossal the exploitation of the ecosystem. The proximity to roads provides easy accessibility which accelerates the rate of exploitation of the natural ecosystem. Almost every land based activities preferred the flat or gradient slope over steep and rugged terrain. It is also observed that land utility is rather more in lower elevation than in higher elevation. Type and physiological requirements of many crops depends on the aspect which determined cropping activities. Soil depth defines the root space and the volume of soil from where the plants fulfill their water and nutrient demands (Kosmas et. al., 1999). An important feature of a soil is that it changes with depth. Soil texture (e.g. loam, sandy loam or clay) refers to the proportion of sand, silt and clay sized particles that make up the mineral fraction of the soil. Texture is important because it influences the amount of water that the soil can hold, the rate of water movement through the soil as well as its workability and fertility. Soil pH affects plant growth, as it determines the availability of plant nutrients in the soil. Climate is the most important dominating factor influencing the suitability of a crop to a particular region. More than 50 per cent of variation of crops is determined by climate. The most important climatic factors that influence growth, development and yield of crops are solar radiation, temperature and rainfall (Agritech Portal, TNAU).

6.5.2 Ecological vulnerability and identification of critical ecosystem

According to Smit and Wandel (2006) and Adger (2006), vulnerability concept is interrelated with adaptation, adaptive capacity, resilience, sensitivity and exposure. For the present analysis, the main concern is with vulnerability and exposure and assume that the other aspect *ceteris paribus*. The degraded areas are no longer a threat to conservation, but the more serious threat is the possibility of natural areas converted into degraded areas. The conservation action therefore should look for the future challenges and the next opportunities for conservation, which is also supported by Jarvis et al. (2010). Ecological vulnerability information gives a clear picture of what and where the critical ecosystem of Darjeeling district occurs that faces serious threat at present as well as in the future.

The output layer of ecological vulnerability status of the blocks in the district indicates the trend in which land use and land cover change on account of intermittent effects of various factors acting on it. When the district was first taken over by the British administration in 1835, the entire hill portion was almost entirely under forest (Bengal District Gazetteer, 2011). The ecological vulnerability zones are identified only in the natural areas and as such it is found entirely in the upper region of the district. Though the district has good forest areas it is found to be scattered sporadically. With the introduction of commercial tea cultivation in the district in 1856 there was rapid development of tea gardens throughout the district. Commercial tea production has been the mainstay of livelihoods and economy in the Darjeeling district for over past 150 years. The environmental degradation of this region initially began with the cultivation of tea on high slopes covering about 18,000 hectares of land (O'Malley, 1907; Chaudhuri, 1978; Starkel and Basu, 2000). The expansion of tea plantations from just one tea estate in 1856, 39 in 1866, 113 in 1874 and 186 by 1905 apparently led to large-scale forest clearing, resulting in landslides, soil erosion, loss of wildlife and biodiversity (O'Malley, 1907; Starkel and Basu, 2000). With the gradual increase in population, unemployment in tea plantations multiplied, which compelled people to search for alternative livelihoods by often, tapping forest products, encroaching forest and slope land; thereby, further damaging the local ecology and degrading the environment (Bhadra, 1992). In addition, the unchecked deforestation, faulty land-use practices, settlement of burgeoning population on mountain slopes, unregulated construction of roads and encroachment of forest lands led to radical transformation of the geo-ecological conditions in the Darjeeling. The job uncertainty and potential loss of livelihood in the tea plantations is leading to a new phenomenon of out-migration to urban centres, resulting in construction of new buildings on slopes; thereby creating space shortage, land pressure, water scarcity and drainage problems in the region (Sarkar and Lama, 1986).

The analysis of the ecological vulnerability areas in the district in 2012 presents a lucid effect of anthropogenic activities on the natural environment. The areas which are in close proximity to critical ecological zones are found to be more or less concentrated in the periphery of settlements and roads which afford easy accessibility to natural resources and its rampant exploitation. The inference is drawn from the Kalimpong I block with an area of 48.43 sq. km. which is the highest in the district, as Kalimpong I is the block with the best road connectivity and massive development in the district. Topographical features like slope, elevation and aspect also have a major impact on the utility of the landscape. The critical ecological areas are found in majority of the areas adjoining to lower reaches and river valleys in the district. It is very vivid from the analysis of the output layer of ecological vulnerability, the lowest zones are found in areas with the least impact of anthropogenic activities as in reserved forests and areas situated far from settlements, roads and rugged terrain. The analysis of the ecological vulnerability areas in the district in 2045 also follows the same trend as in 2012. It is presumed from the analysis that Kalimpong I block with an area of 57.19 sq. km. will be the block with the highest critical ecological areas in the district. The influence of population growth and economic developmental activities continues to play a major havoc in the diminishing of the remaining natural ecosystems in the district.

The present study also attempted to predict the trend of land use and land cover change in the district in the near future in 2045. It is found that agriculture class with 593.71 sq. km. will be the major class with the largest geographical area inspite of it showing a decreasing trend compared to 2012. This trend indicates a shift in the economic activities of the people from agriculture to other occupations due to better skill acquirement. It is also possible that the growing population increased pressure on agriculture land to be converted to settlement. Tea class with 564.22 sq. km. will be one of the most probable major class which is showing a continuous increasing trend. Though the employment problem in tea plantations may persist, it will continue to expand with increasing demand for tea and will remain one of the main economic activities in the district. It is interesting to observe that the natural forest shows a declined in temperate forests classes whereas, there is an increased in sub-tropical and mixed forests classes. The reason for this can be ascribe to increase in temperature and regeneration capability of the tropical species compared to temperate species.

A comparative analysis of the ecological vulnerability zone with respect to biological richness of the study area was done. It is found that almost the entire biological richness area falls under different ecological vulnerability zones. From this observation it can be assumed that the areas which have high biological diversity tend to be the most vulnerable or critical to factor of change. The critical ecosystems are on the verge of complete annihilation unless there is an immediate conservation and management intervention.

This study was conducted in the framework of planning support system (PSS), because this study aims at providing geo-information instruments that can be used specifically by planners to undertake their professional responsibilities in a better way (Geneletti, 2008). The most important goal of ecological vulnerability assessment is to provide assistance to the authority and practitioners (Li et al., 2009). By doing ecological vulnerability assessment, conservation organizations can get clear image about “what will become threatened in the next several years” (Jarvis et al., 2010). Reducing vulnerability of environment can be more effective if it is supported by other strategies and plans at various level authorities (Smit and Wandel, 2006).

CHAPTER-7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

This study has used geospatial techniques to model and analyze critical ecosystem in Darjeeling district. The integration of satellite remote sensing, GIS, and Markov modeling provides improved understanding of the complex dynamic processes underlying land use/cover change. It allows a means of analyzing and identifying ecological vulnerability areas which are in the critical state at present, as well as more reliable projections and more realistic scenarios of future changes.

It is pertinent to say that ecological vulnerability status of the study area was increasing with time although at different magnitude. The increase was a function of the intensification of human activities year after year. Although human activities appear to be dominant, climate variability and change also plays a role. The extent of the impacts of human and climatic forces on the land use and land cover changes are however complex and not clear. The critical ecological zones are found in the areas adjacent to settlements and roads where most of the human activities are concentrated. The major factors that led to the magnification of ecological vulnerability in the district were human activities namely expansion of tea plantations and tourist infrastructure development.

Ecological vulnerability assessment provides a means of adding value due to ecosystem and land use change scenarios in terms of in between producer, taxpayers, service provider and users. This is the type of information for example that can be of interest to policy makers and society at large, and can help influence future development pathways. By extension, more detailed land use scenarios provide the opportunity to explore more detailed indicators of vulnerability provided the scenarios are constructed to a consistent framework.

7.2 Recommendations

The studies on critical ecosystem modeling and analysis in future can be improved and systematic if the following recommendations are suitably adopted.

1. There should be easy availability of sufficient high resolution images of the study area. The images of various seasons and in high resolution provide ease and better interpretation of the area under study.

2. There should be frequent field visit with sufficient GCPs to validate the interpretation of the various temporal images.

3. The data on climate, soil, socio economic, etc. should be collected from the ground and should be easily accessible in a common portal. This enhances better modeling and analysis and save time and resources enormously.

4. Tourism should be managed within the carrying capacity and limits of each ecosystem and site. Safeguards for the most ecologically sensitive areas by limiting on numbers of visitors and their impacts.

5. Checking the population overgrowth. Removal of poverty - giving special attention to the people at the bottom dependent on forest for their livelihood.

6. Publicity and information to educate all citizens about the environment destruction and protection. Expand the activities of local people involved in environment protection and restoration.

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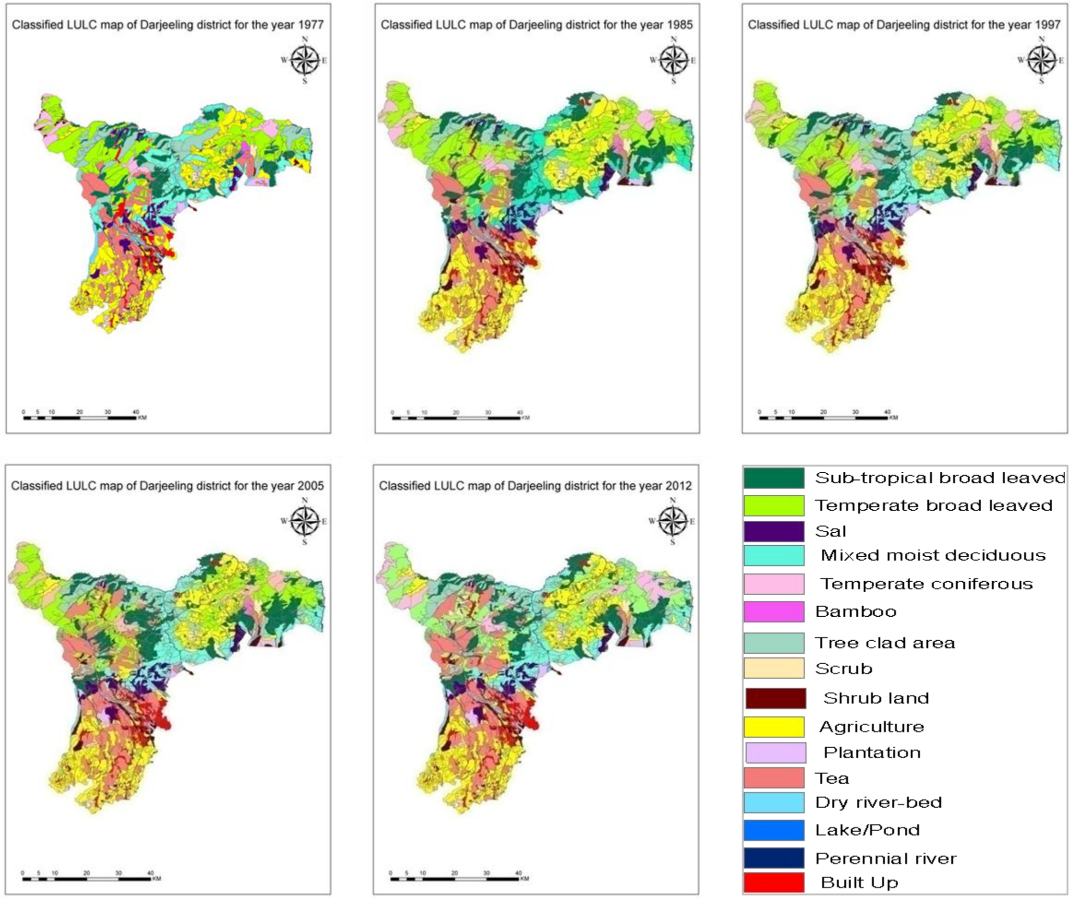


Fig. 5.1: Maps of land use and land cover for various time periods

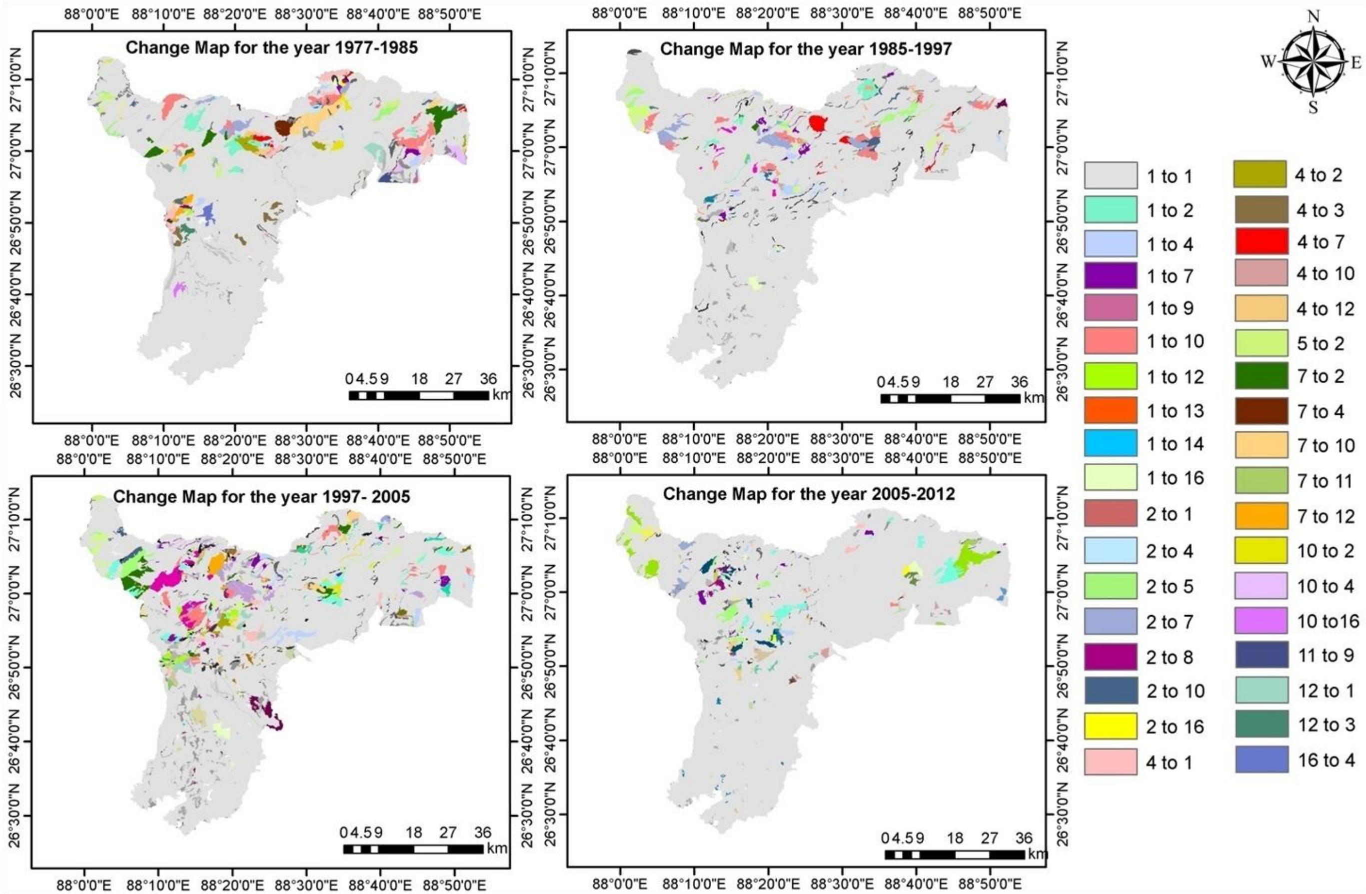


Fig. 5.2: Change maps of land use cover for various time periods

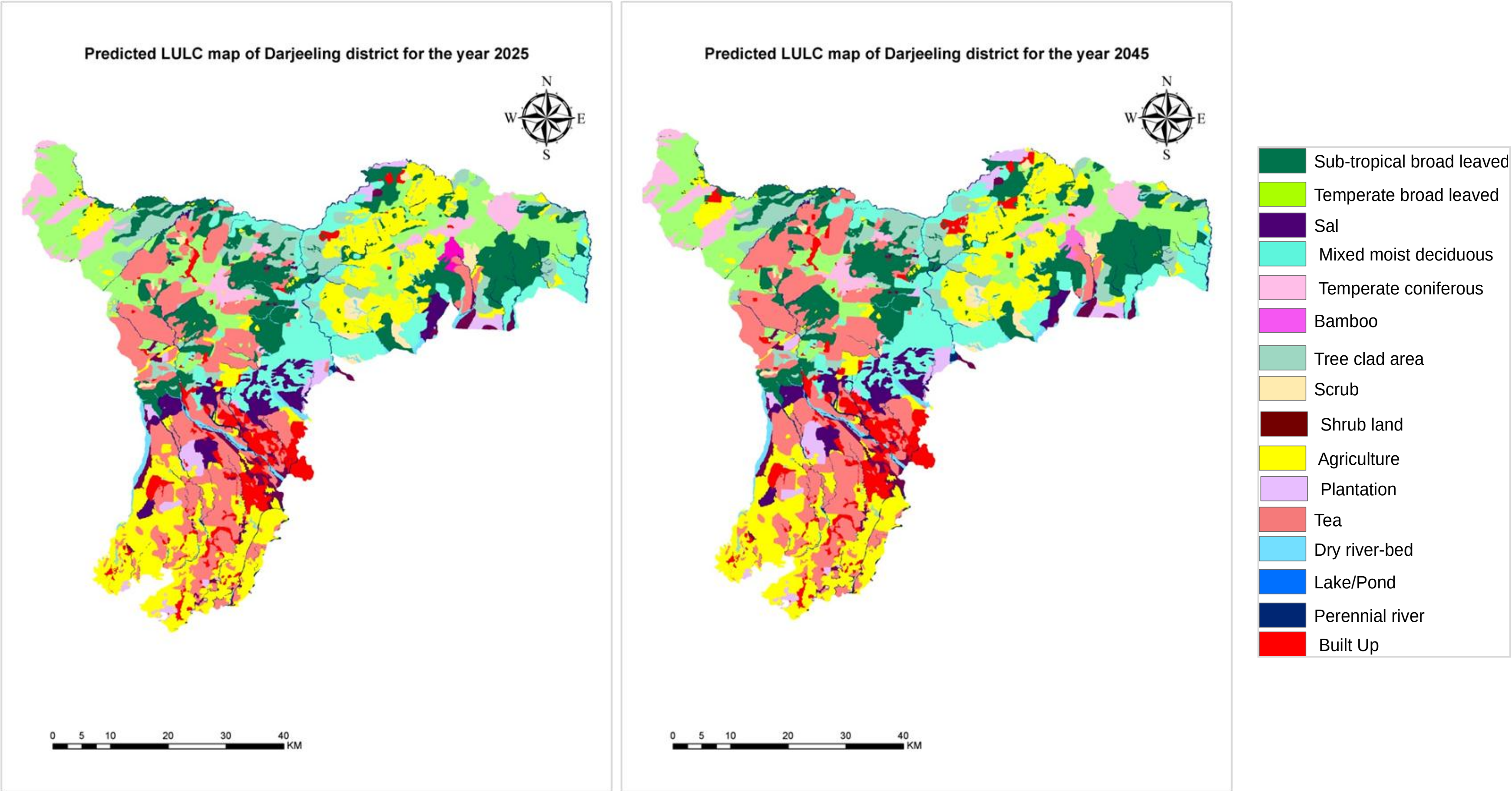


Fig. 5.3: Maps of predicted land use and land cover for the year 2025 & 2045

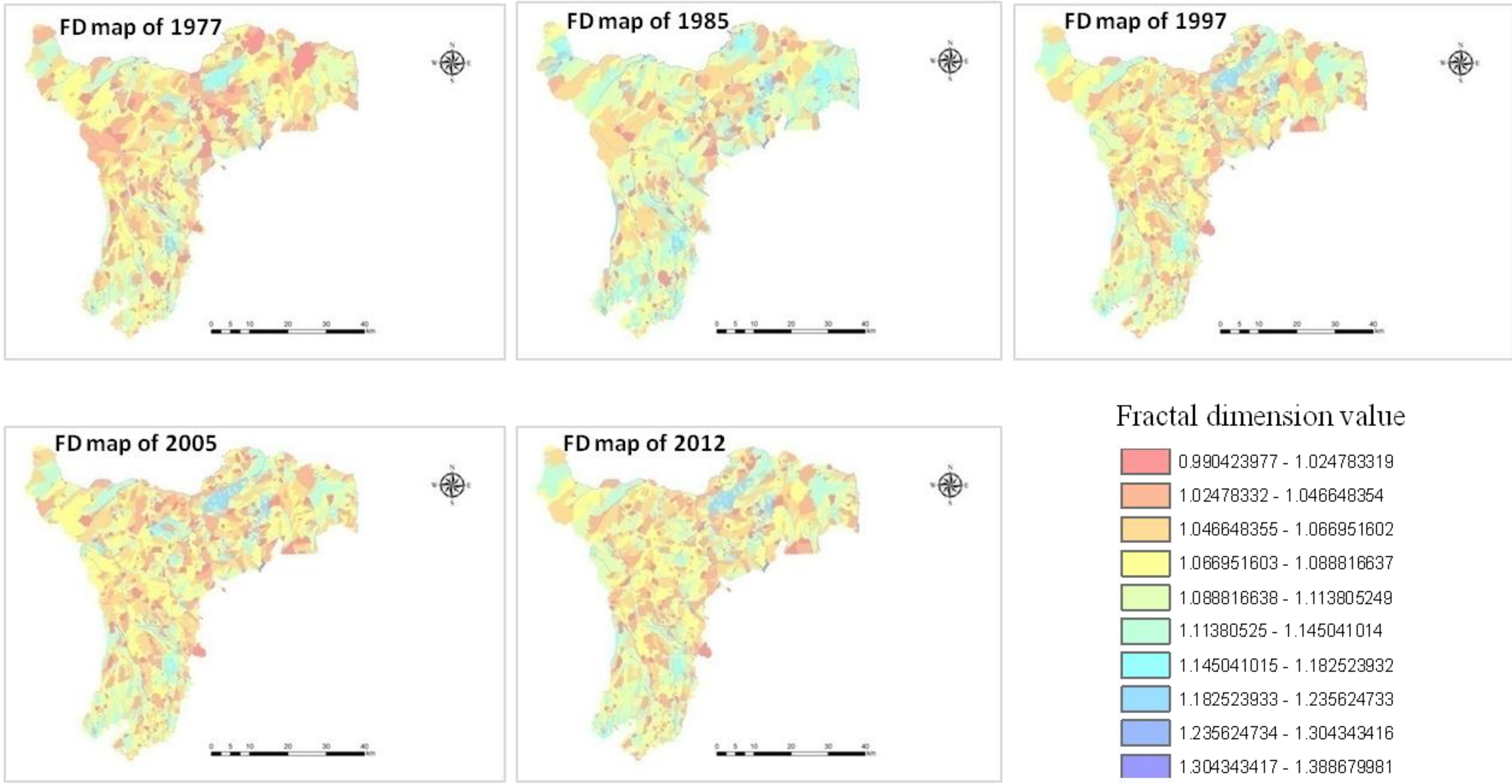


Fig. 5.4: Maps of fractal dimension for the various time periods

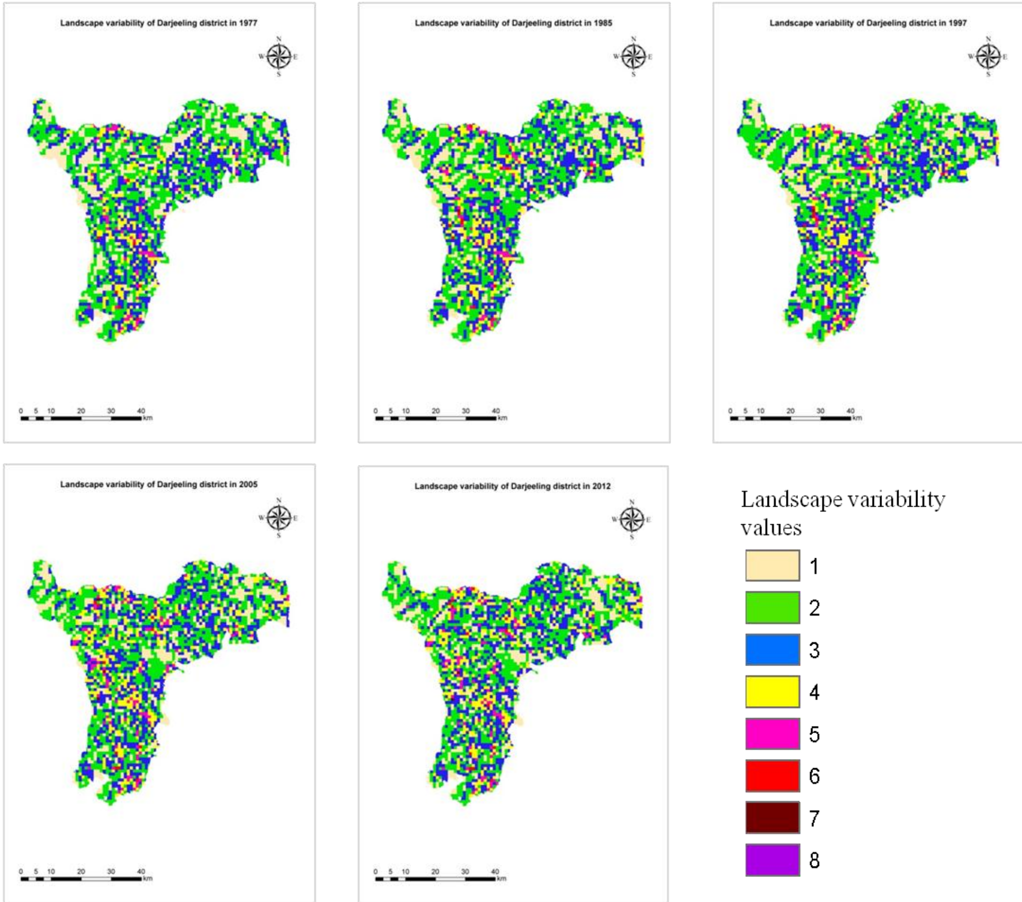


Fig. 5.5: Maps of landscape variability for the various time periods

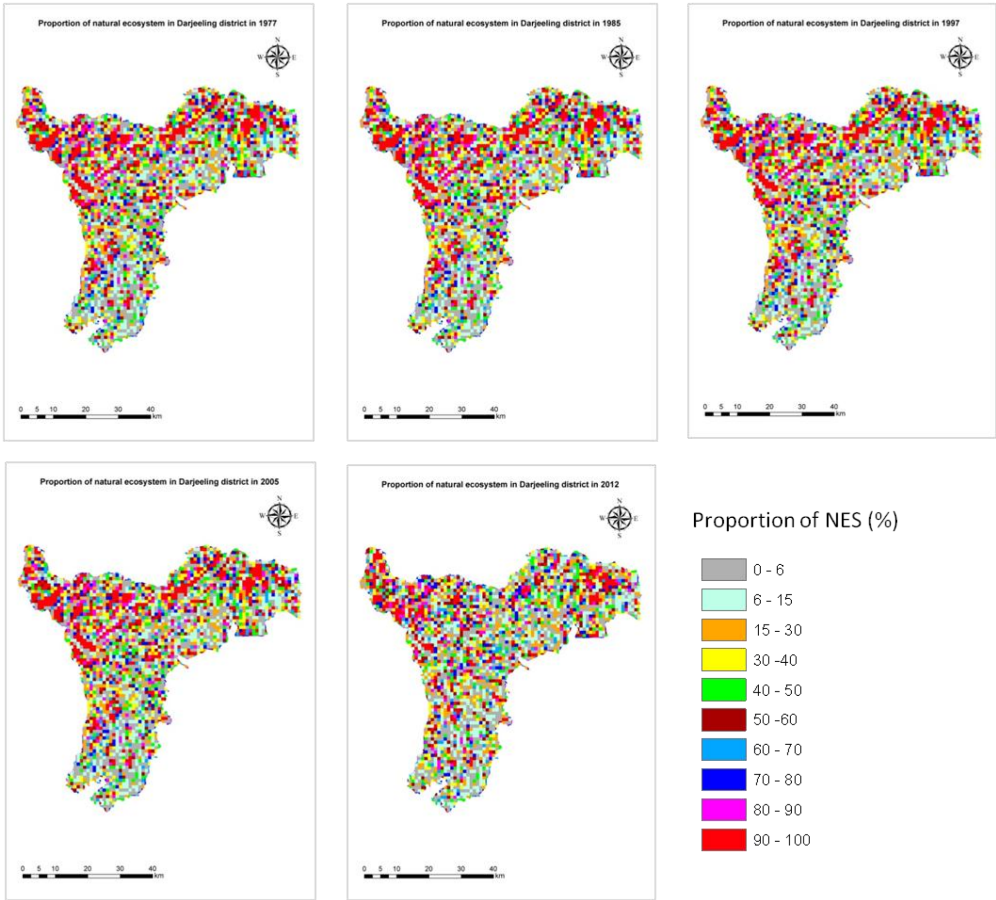


Fig. 5.6: Maps of proportion of natural ecosystem for the various time periods

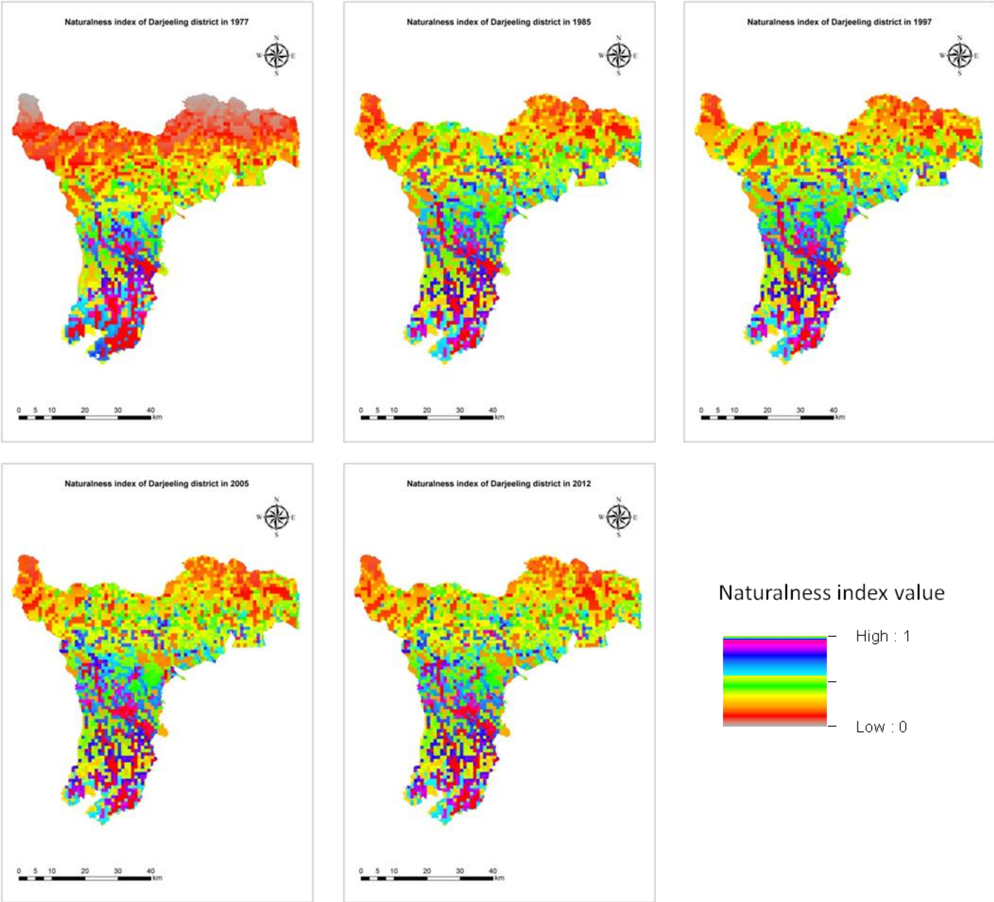


Fig. 5.7: Maps of naturalness index for the various time periods

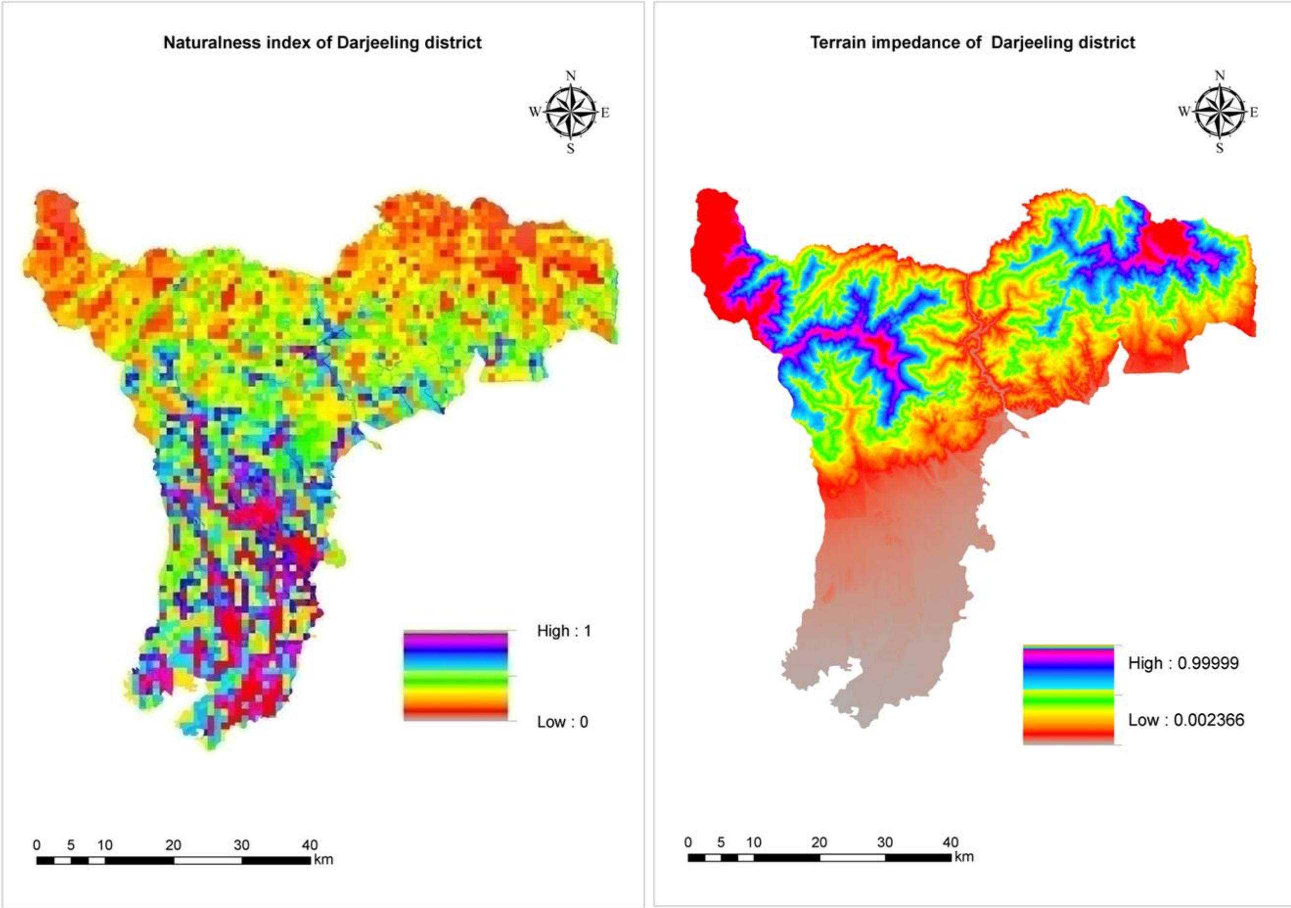


Fig. 5.8-A: Maps of naturalness index and terrain impedance

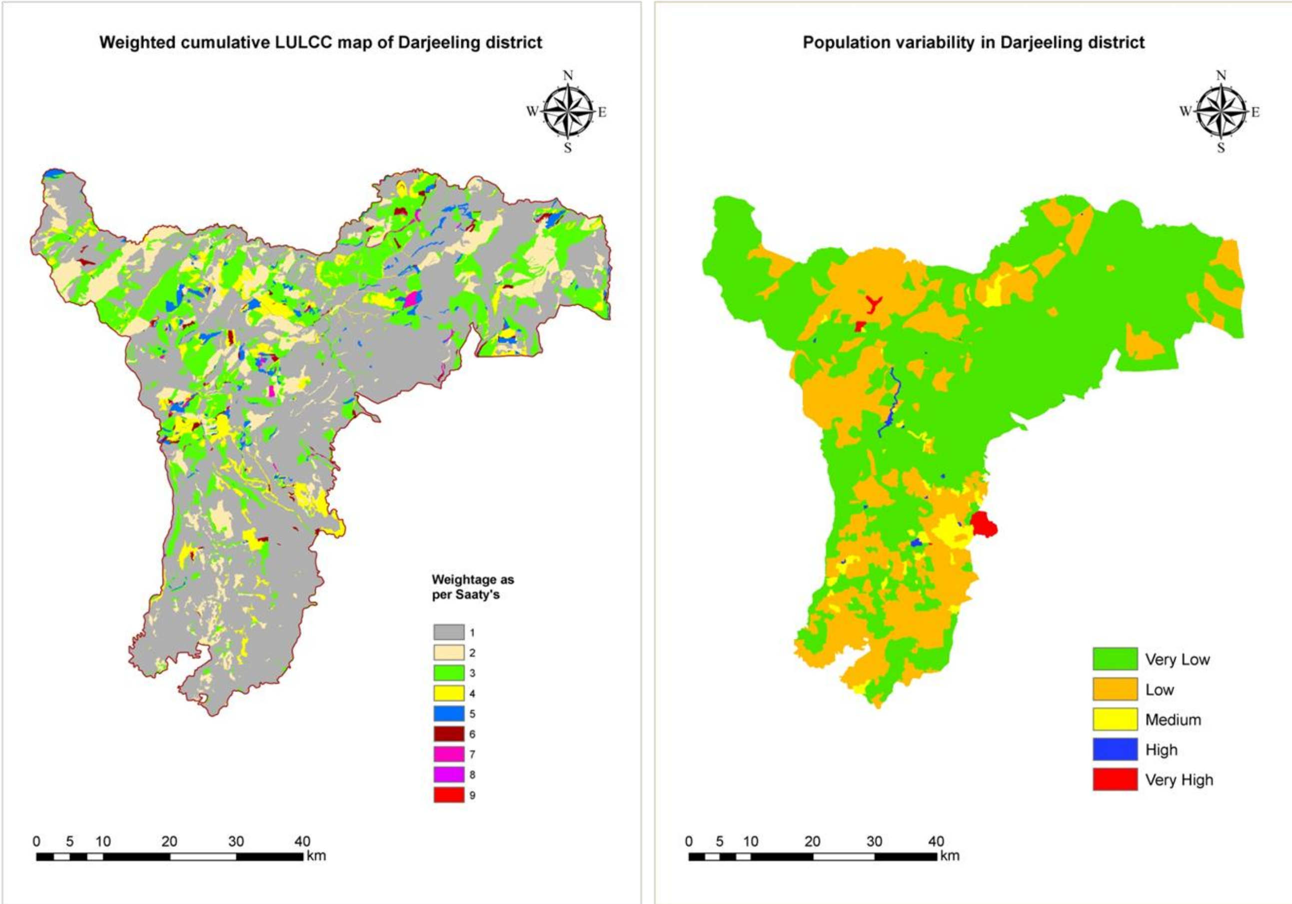


Fig. 5.8-B: Maps of weighted LULCC map and population variability

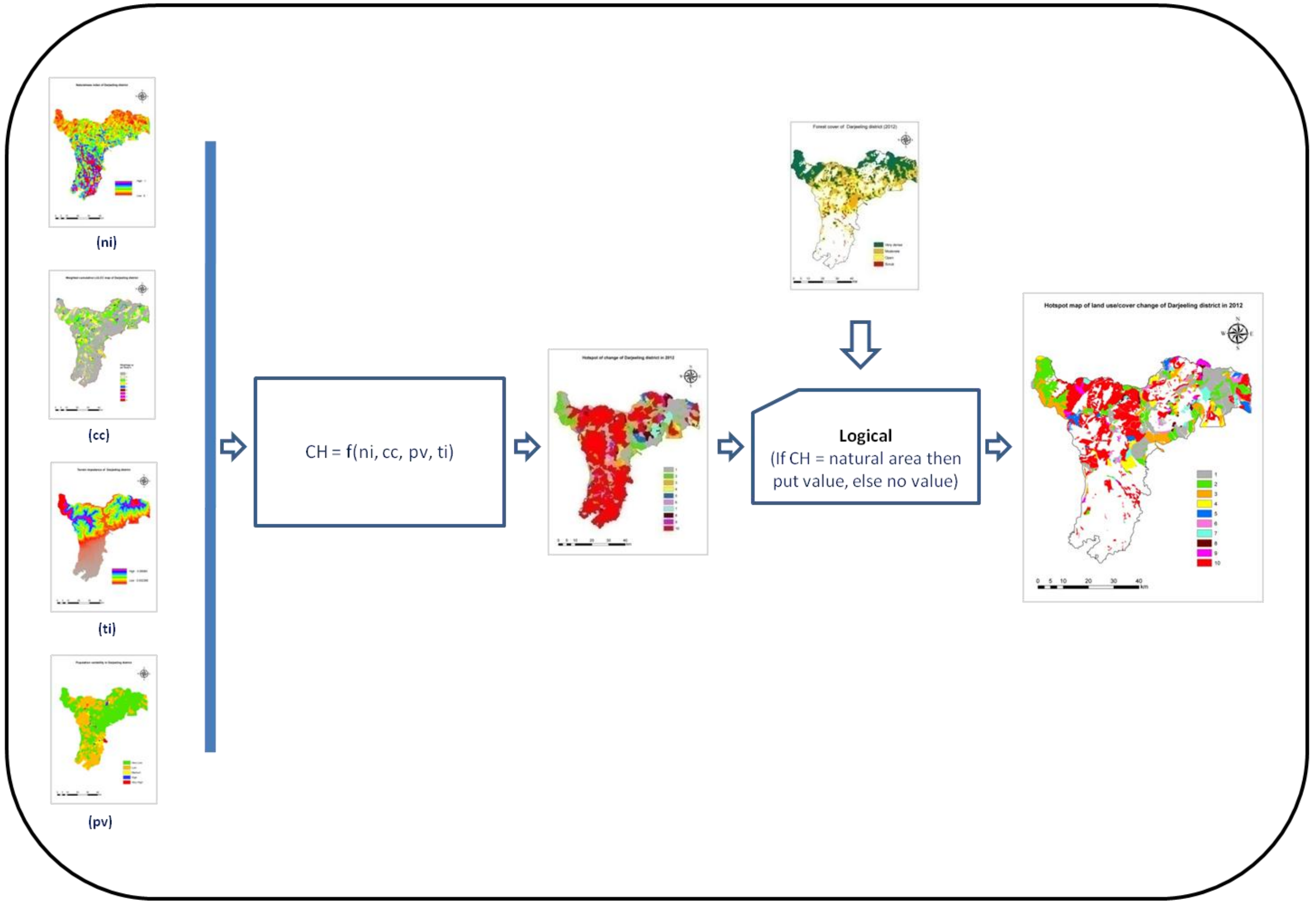


Fig. 5.9: Flow diagram for land use and land cover change Hotspot model

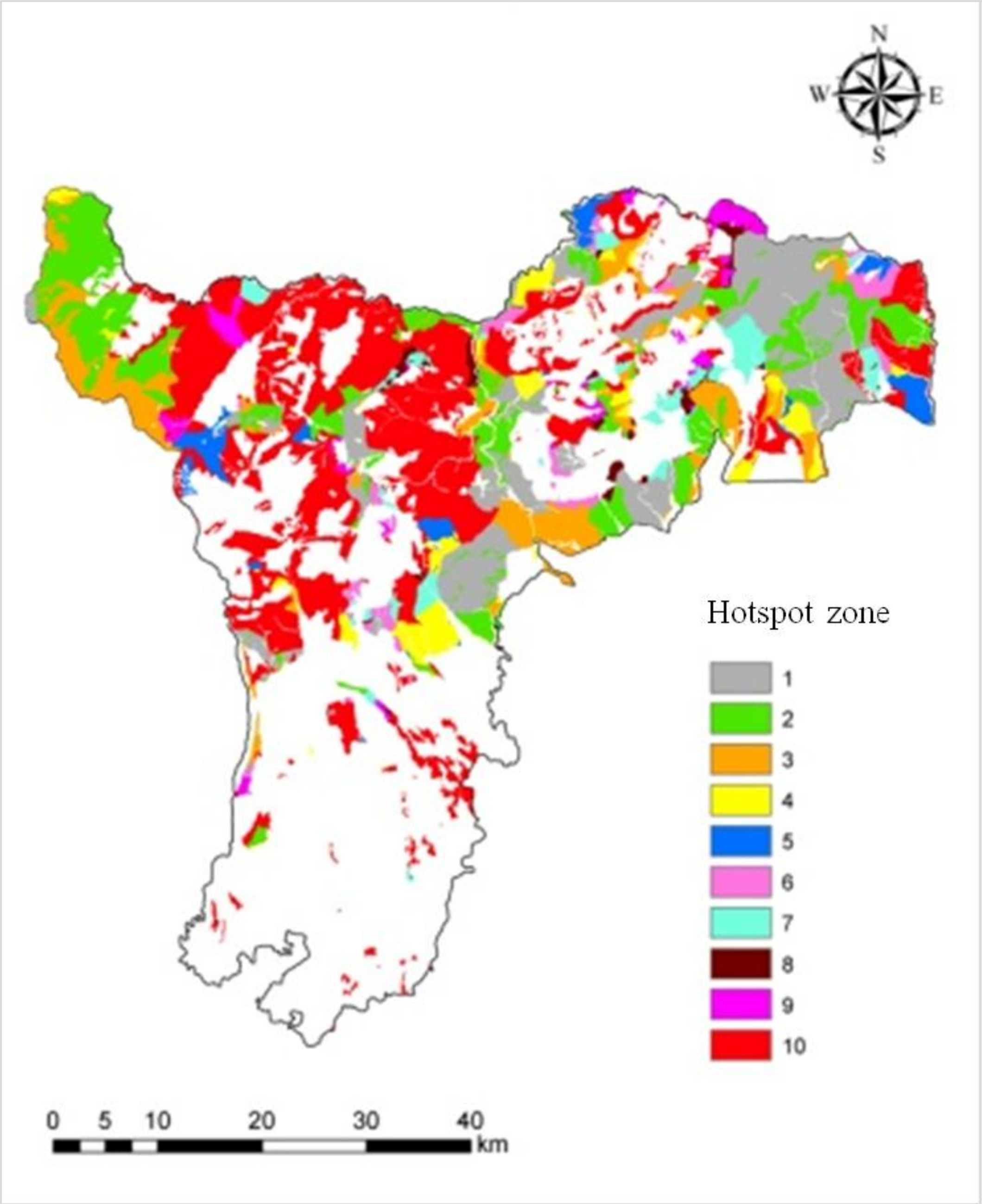
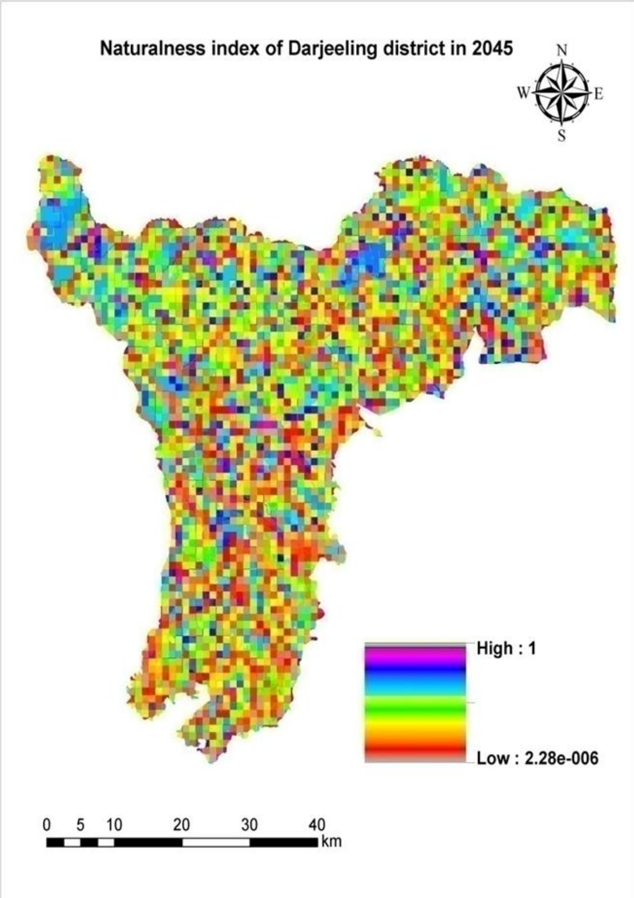


Fig. 5.10: Maps of hotspot of land use and land cover change in 2012



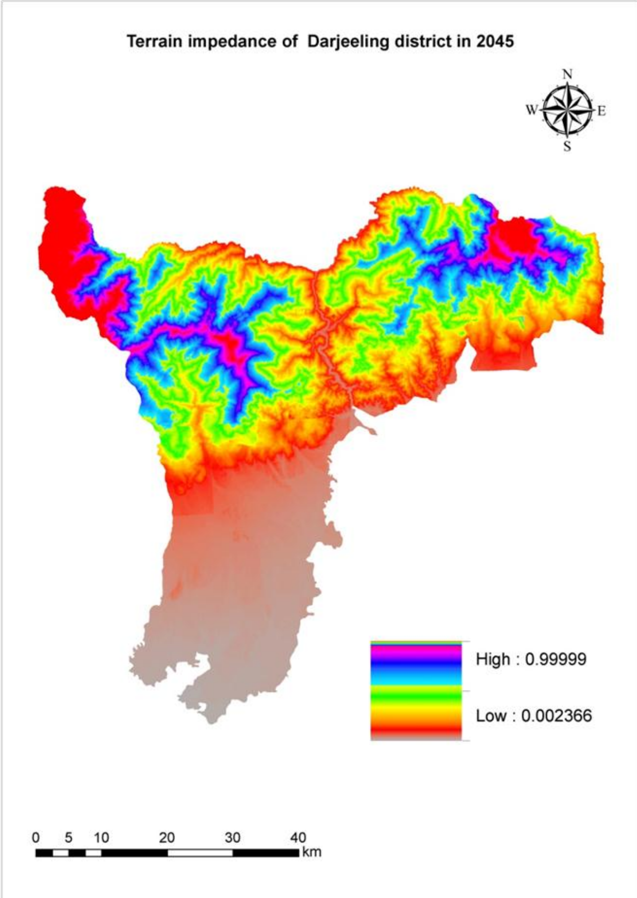
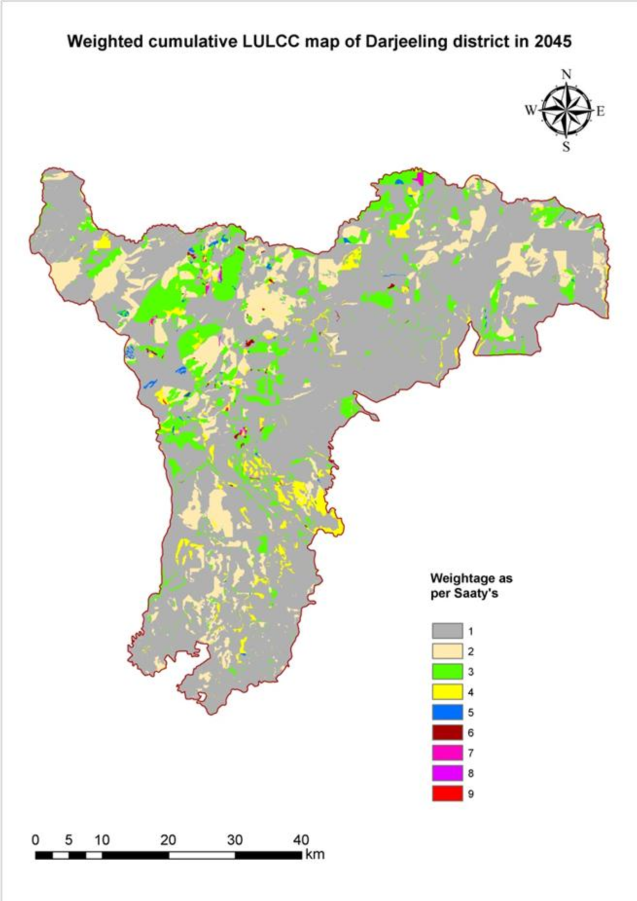


Fig. 5.11-A: Maps of naturalness index and terrain impedance in 2045



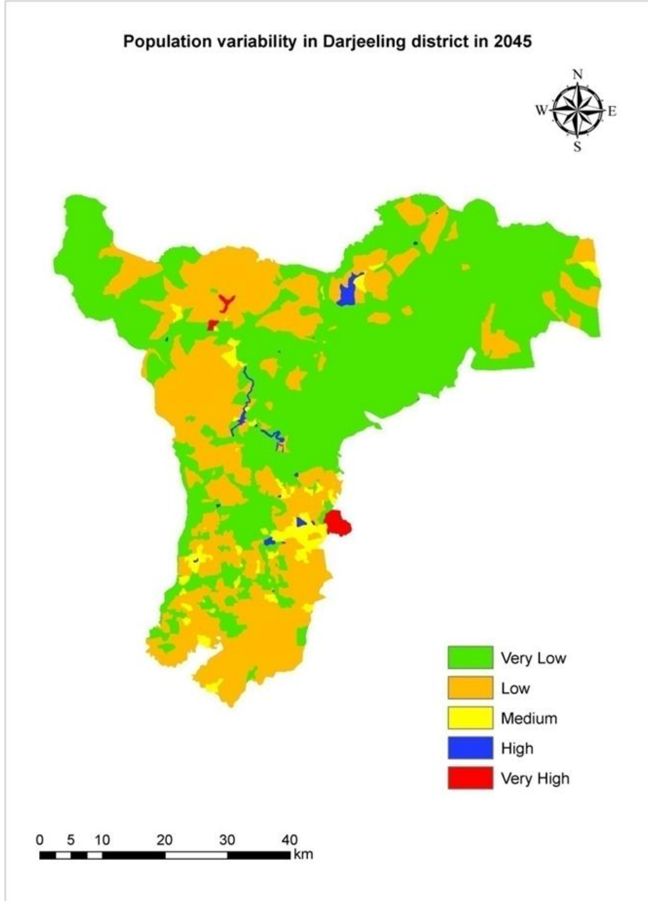


Fig. 5.11-B: Maps of weighted LULCC map and population variability in 2045

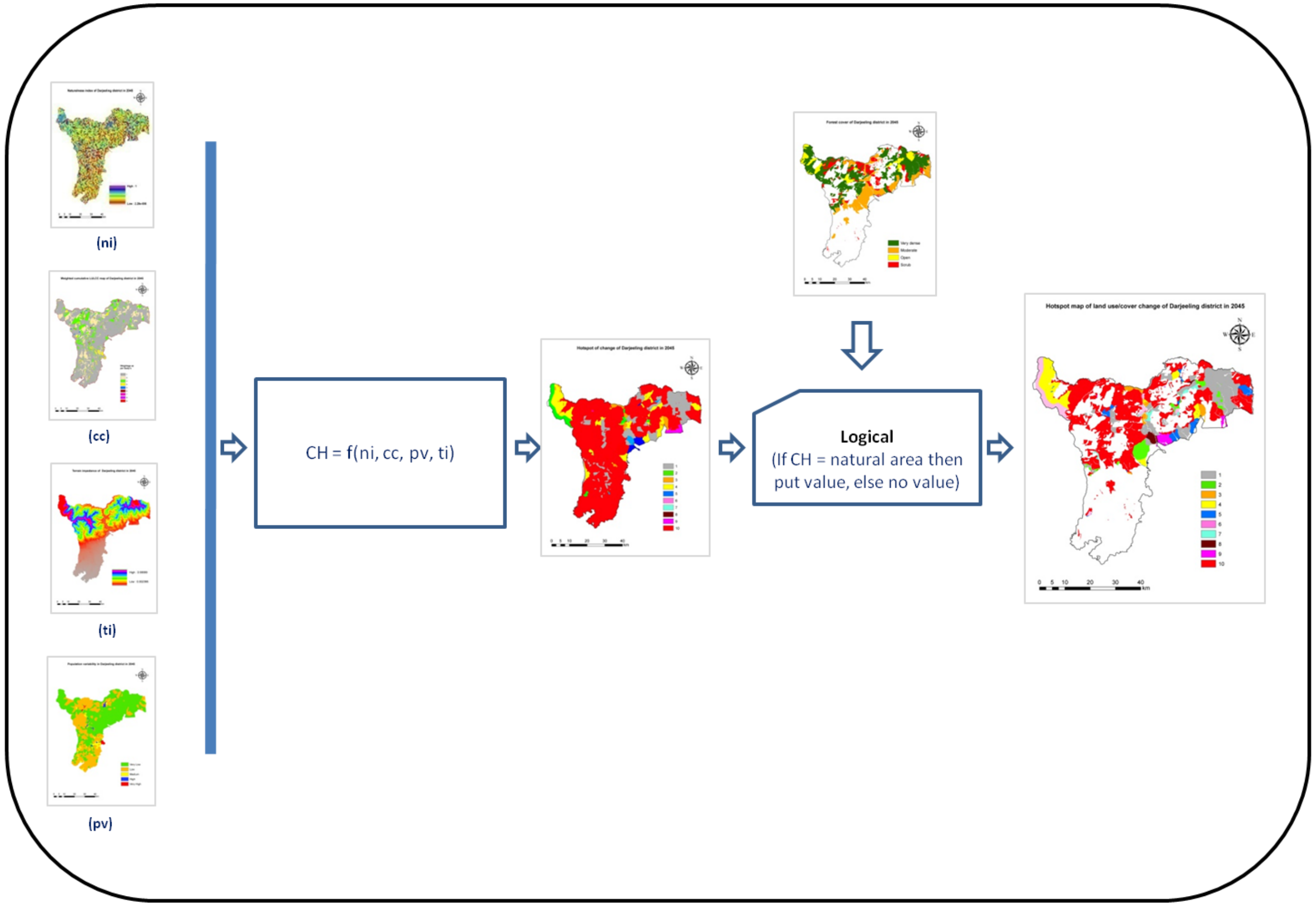


Fig. 5.12: Flow diagram for land use and land cover change Hotspot model in 2045

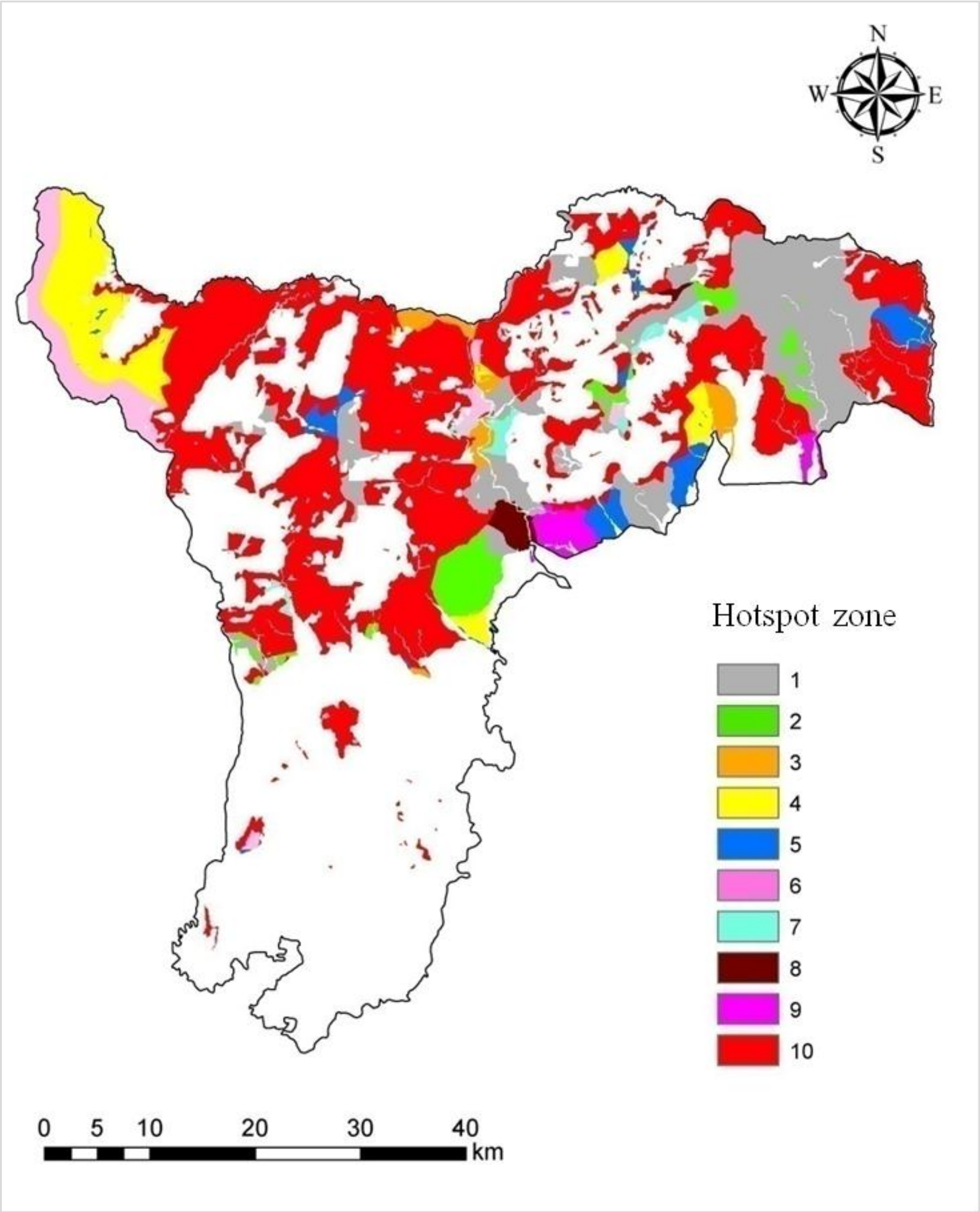


Fig. 5.13: Maps of hotspot of land use and land cover change in 2045

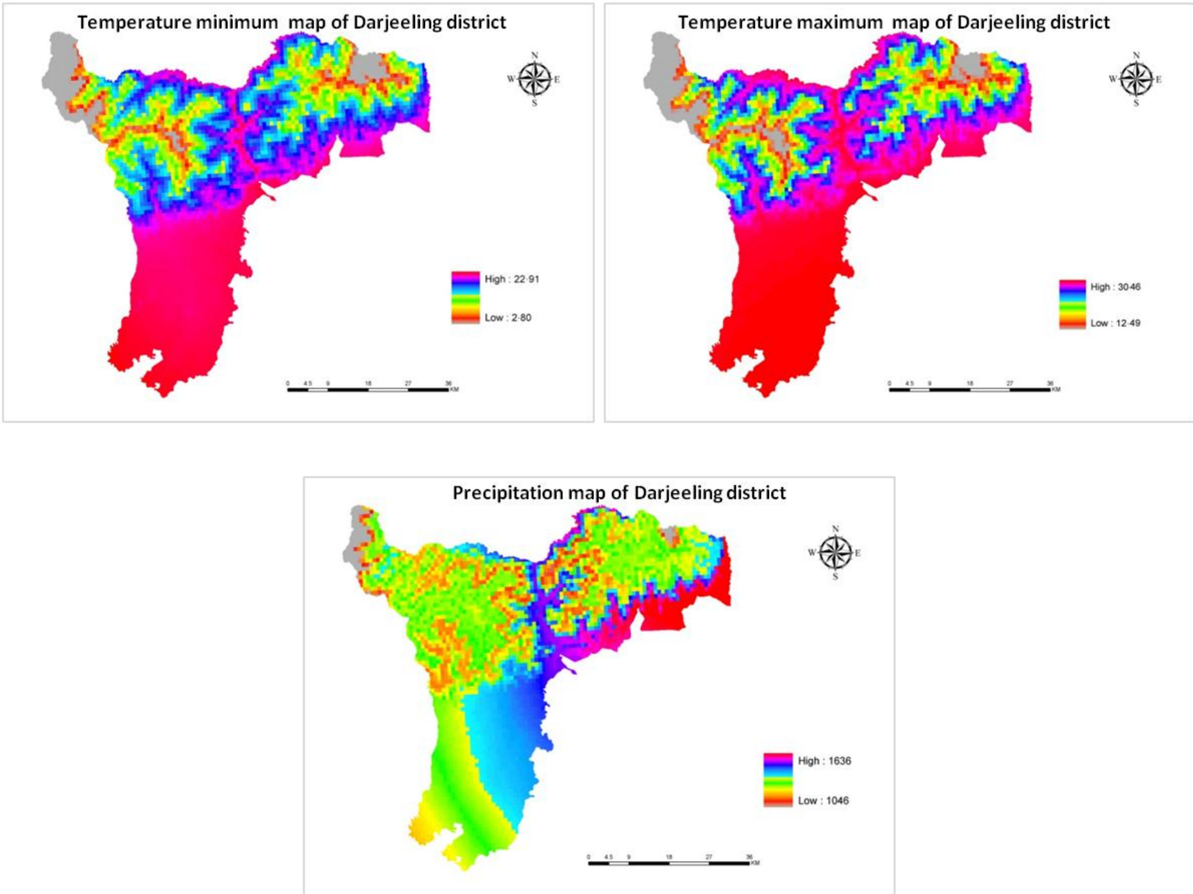


Fig. 5.14-A: Maps of climatic variables in 2012

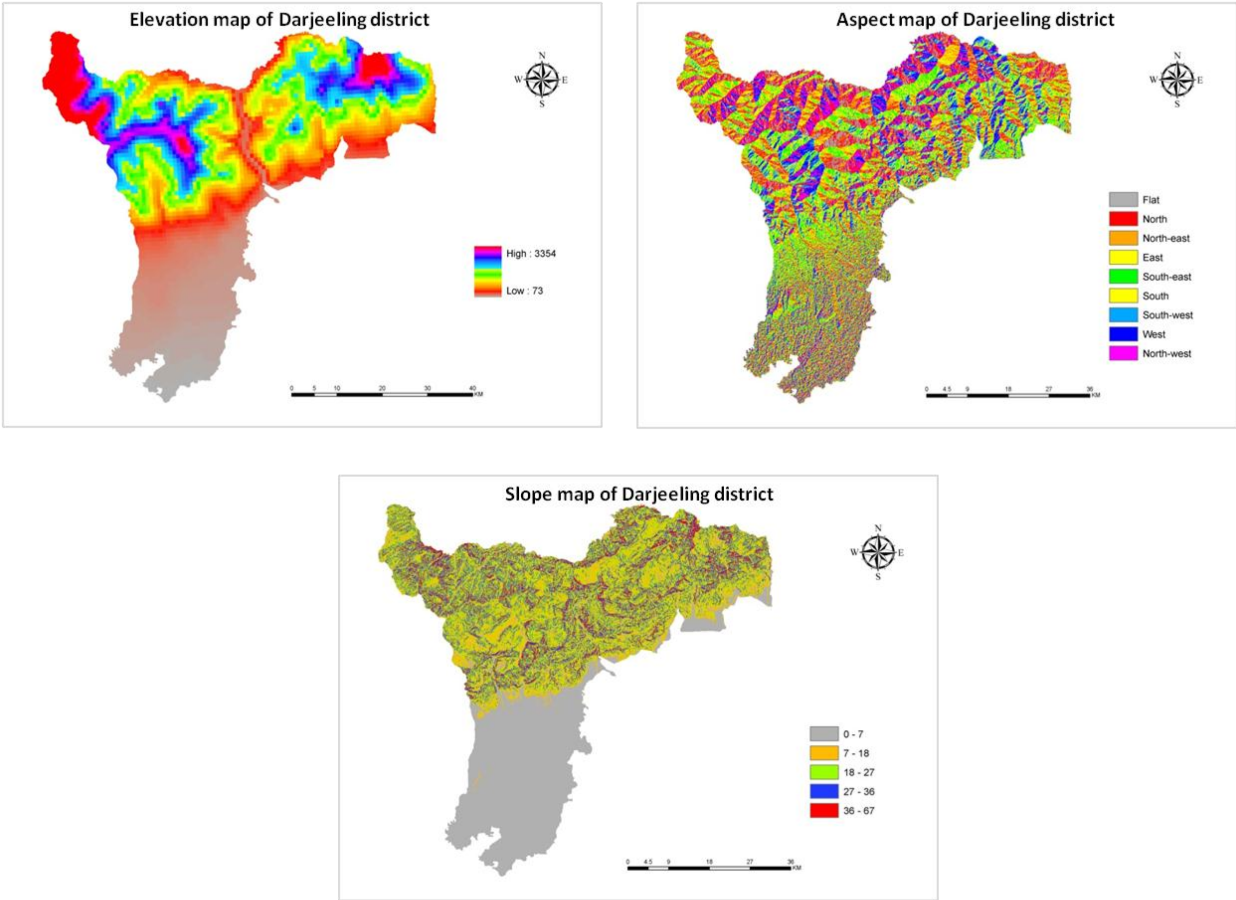
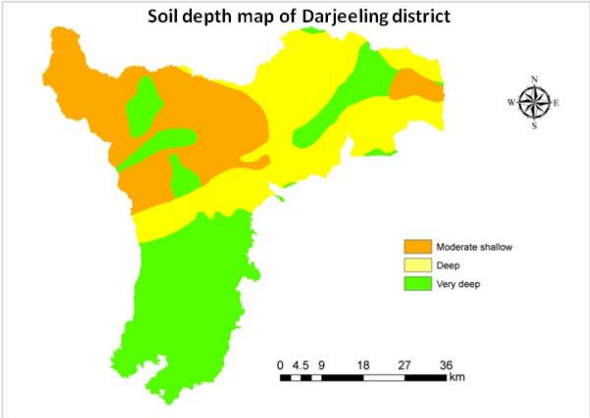
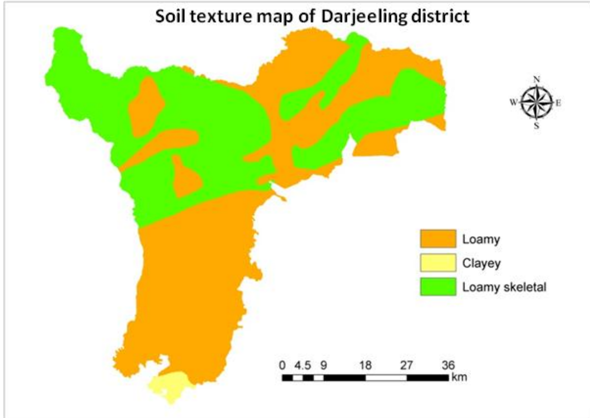


Fig. 5.14-B: Maps of topographic variables in 2012





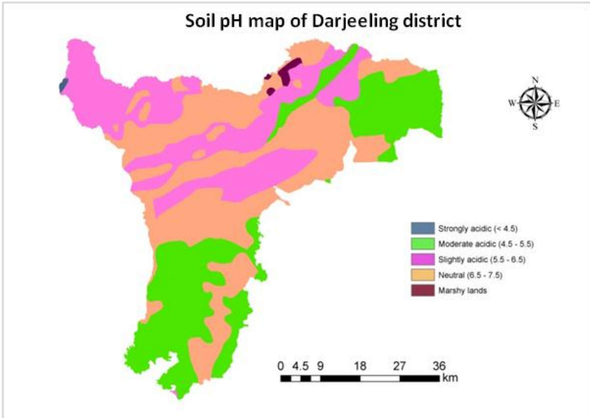
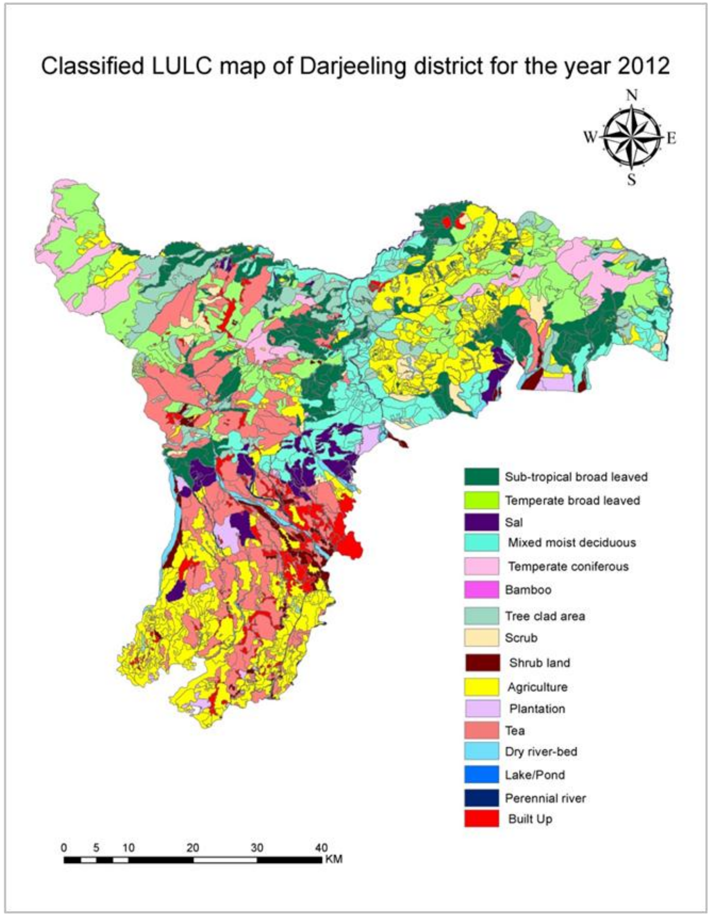


Fig. 5.14-C: Maps of soil variables in 2012



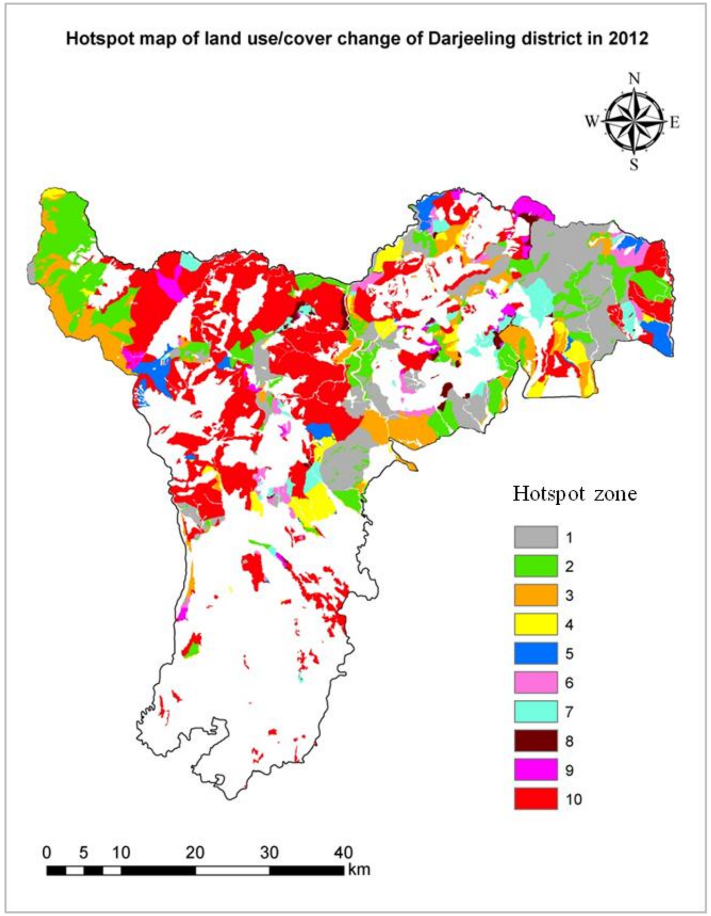
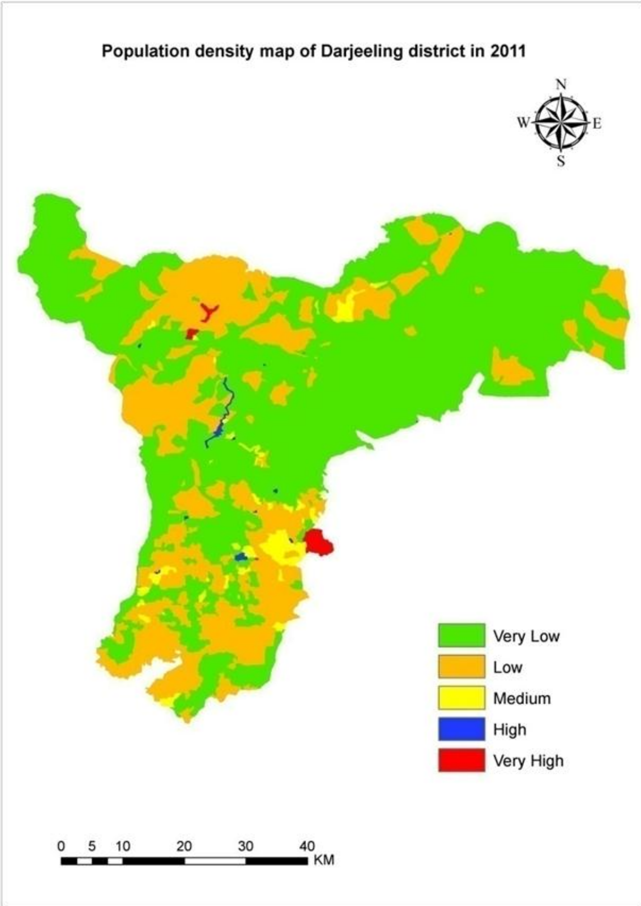


Fig. 5.14-D: Maps of terrestrial variables in 2012



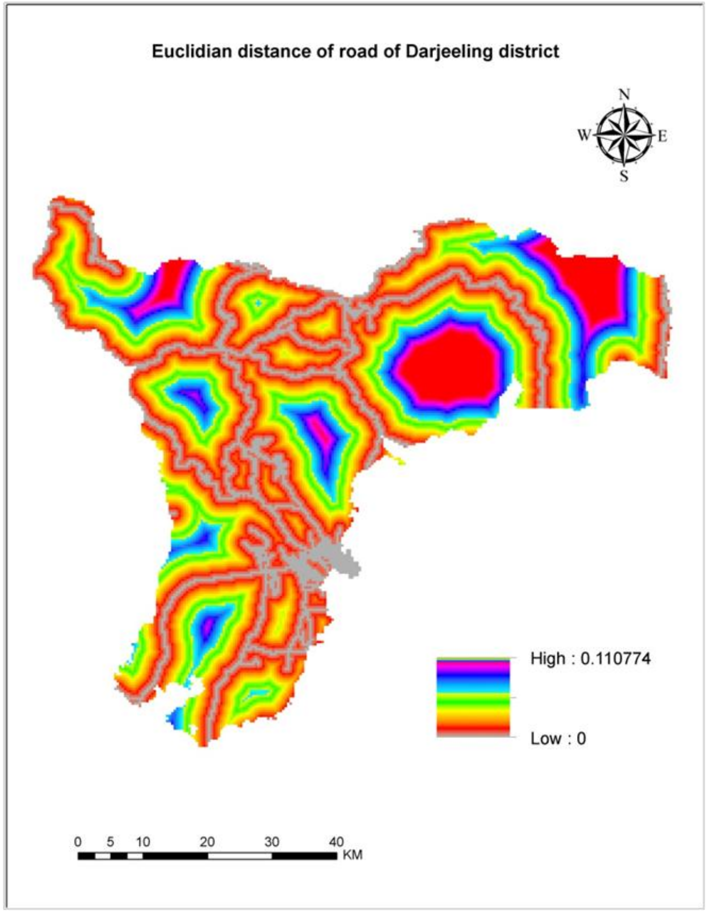


Fig. 5.14-E: Maps of social variables in 2012

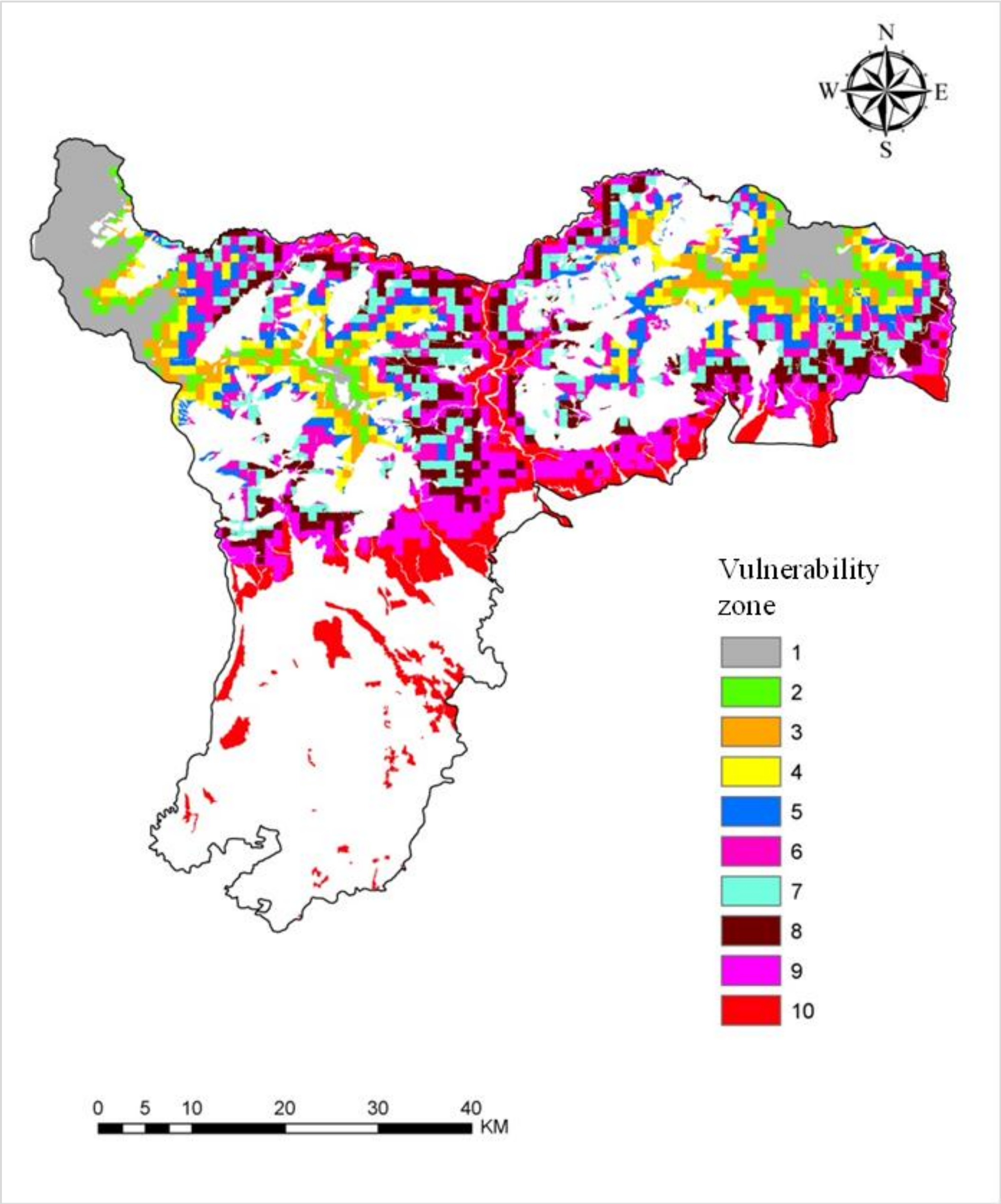


Fig. 5.15: Maps of vulnerability of land use and land cover change in 2012

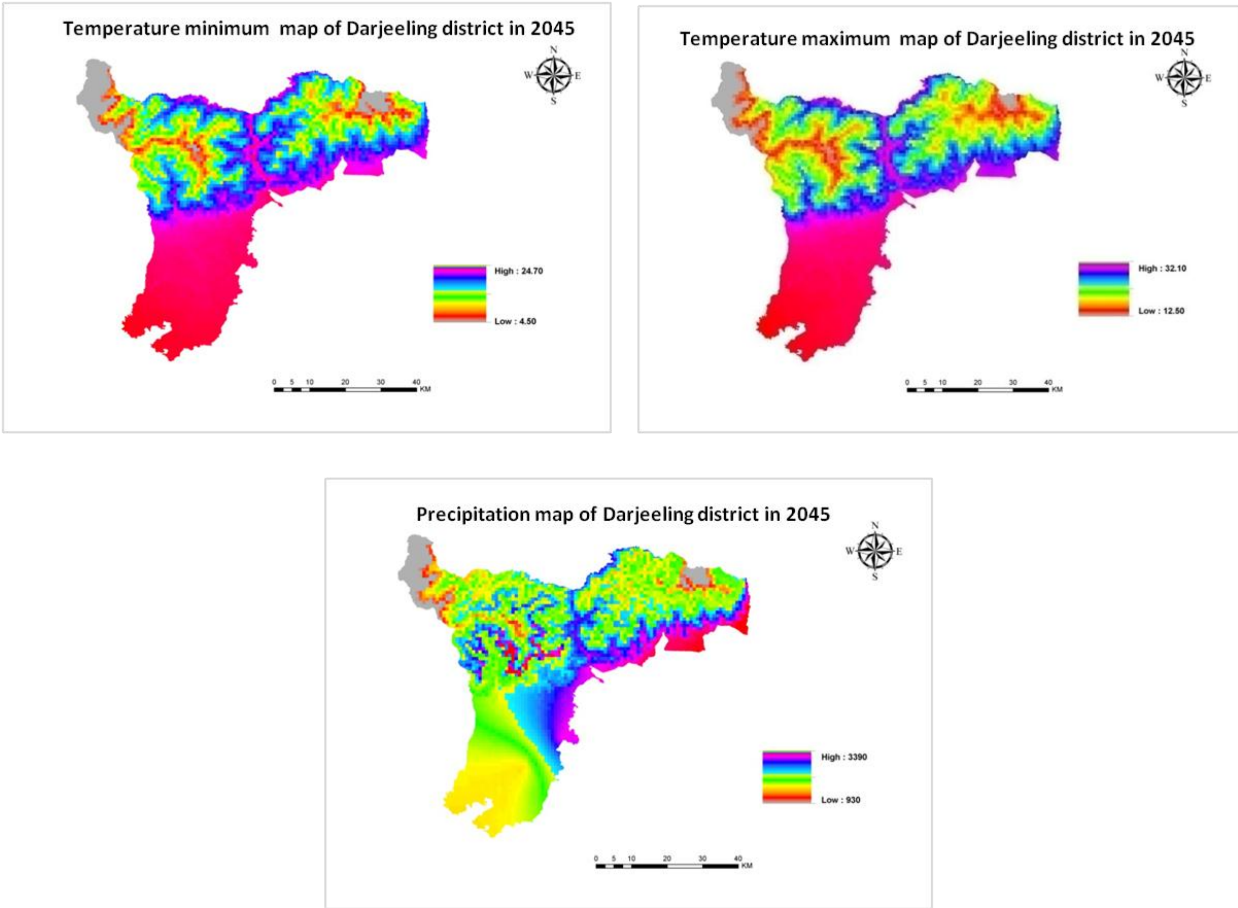
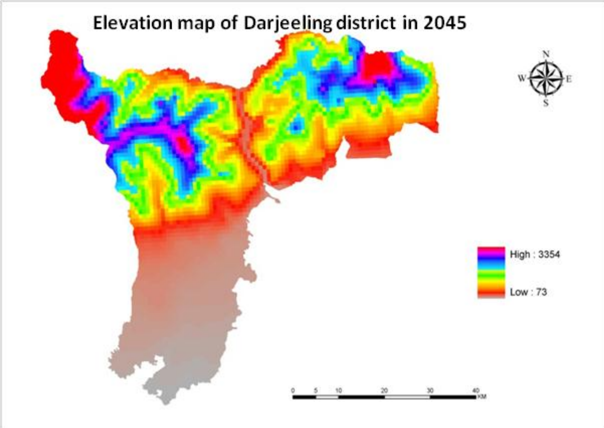
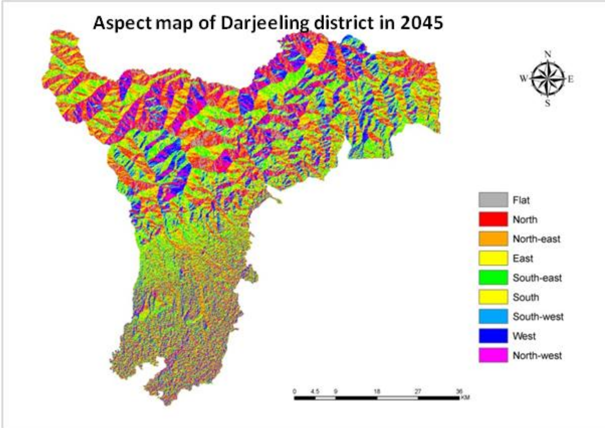


Fig. 5.16-A : Maps of climatic variables in 2045





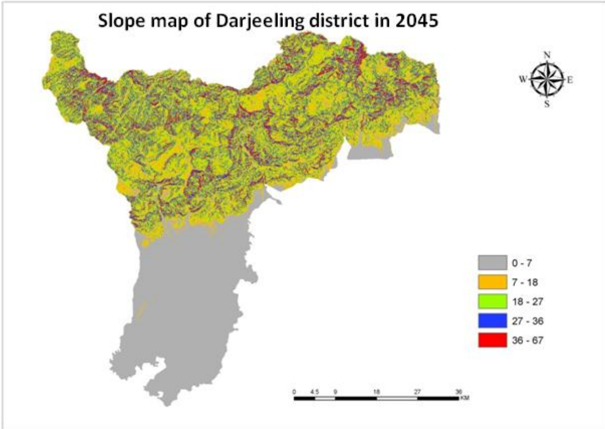


Fig. 5.16-B: Maps of topographic variables in 2045

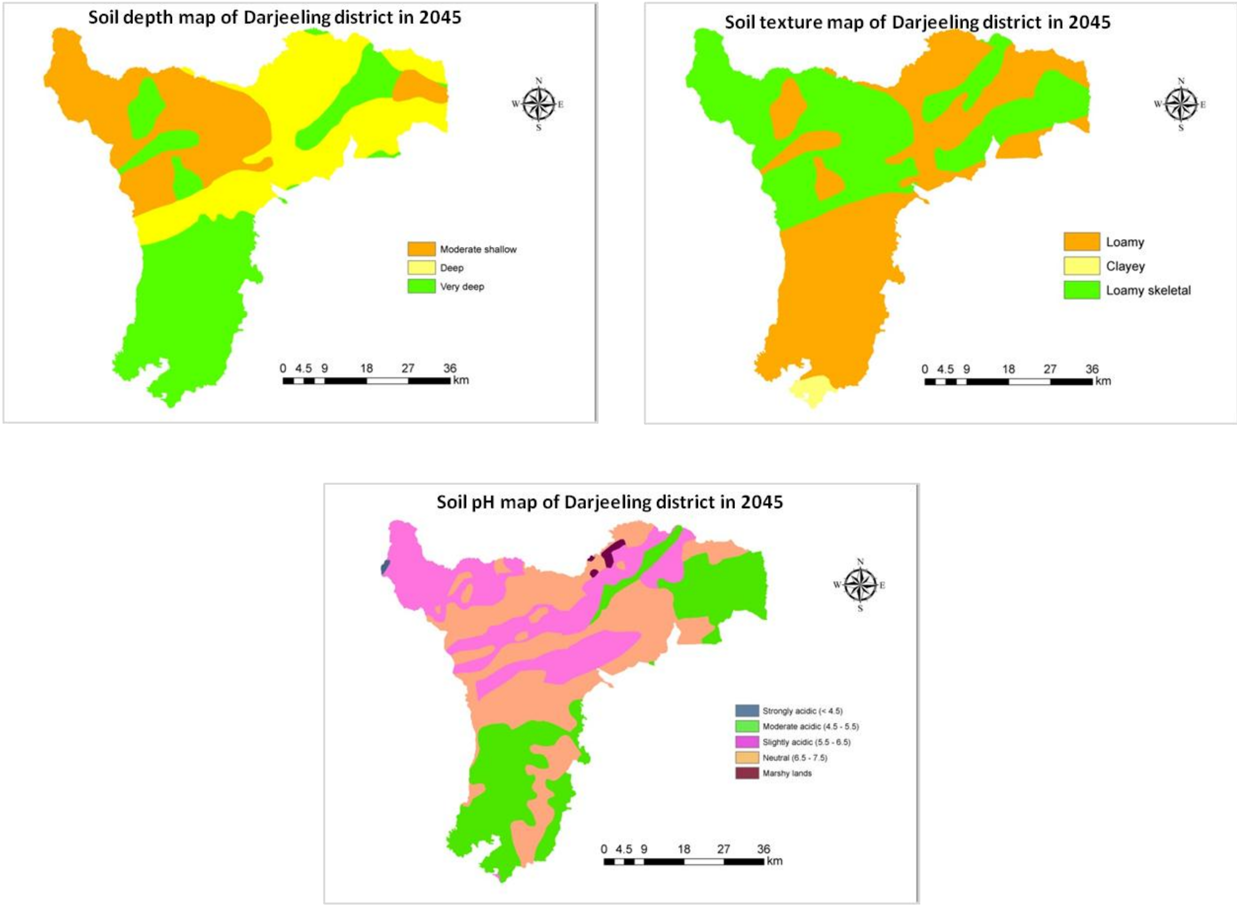
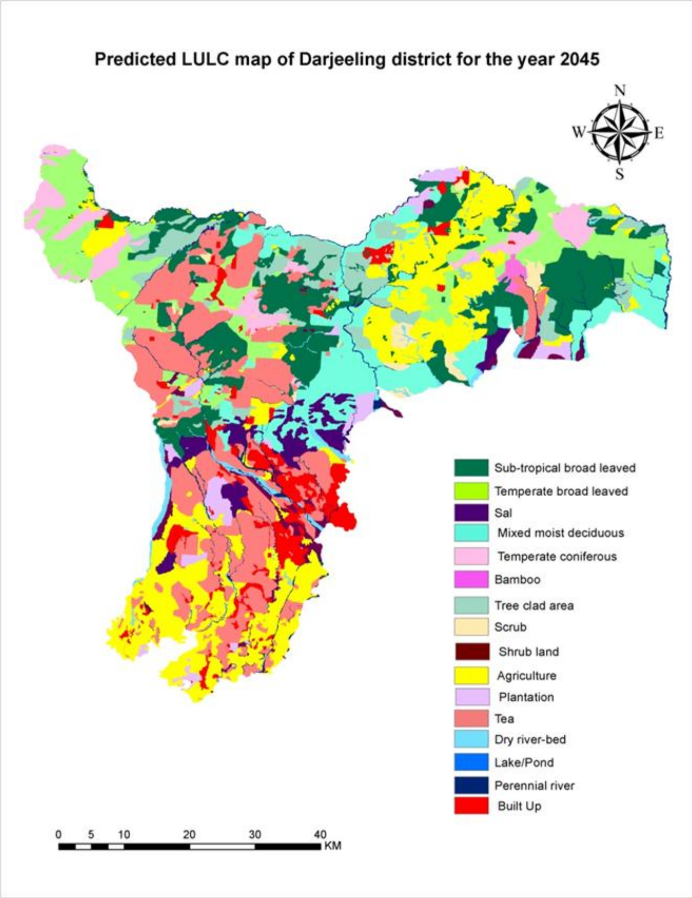


Fig. 5.16-C: Maps of soil variables in 2045



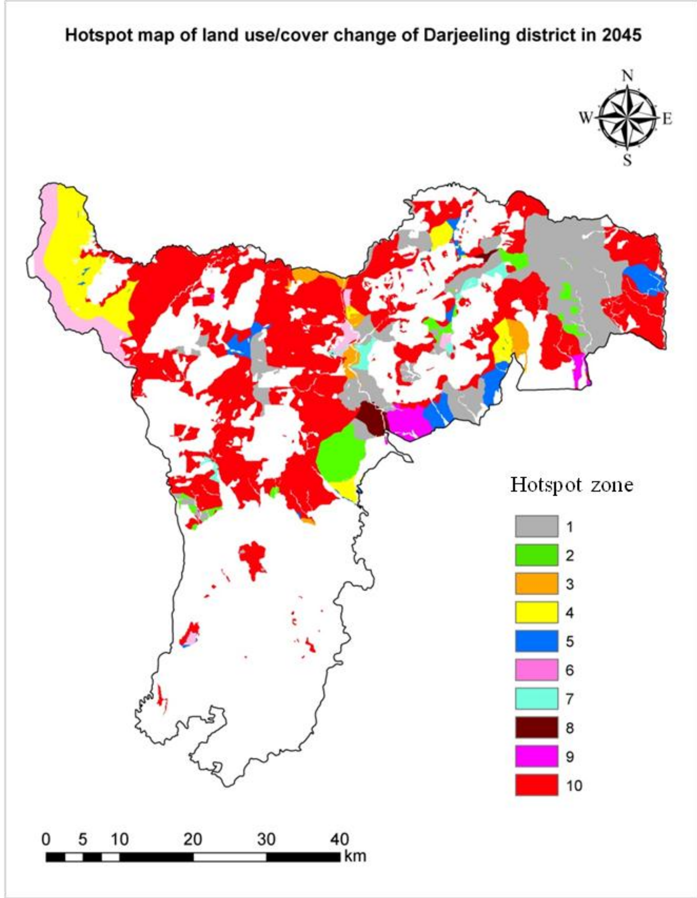


Fig .5.16-D: Maps of terrestrial variables in 2045

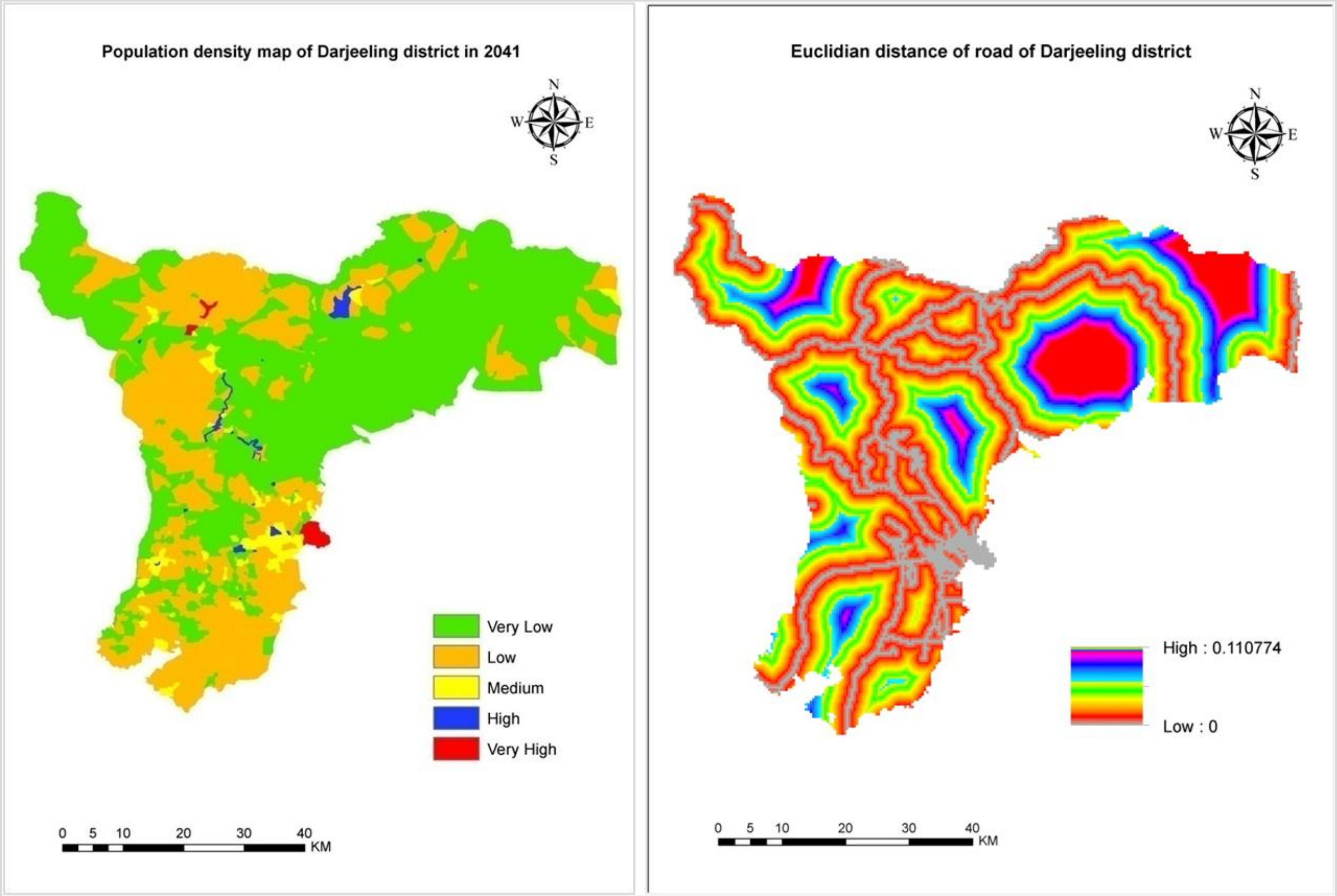


Fig. 5.16-E: Maps of social variables in 2045

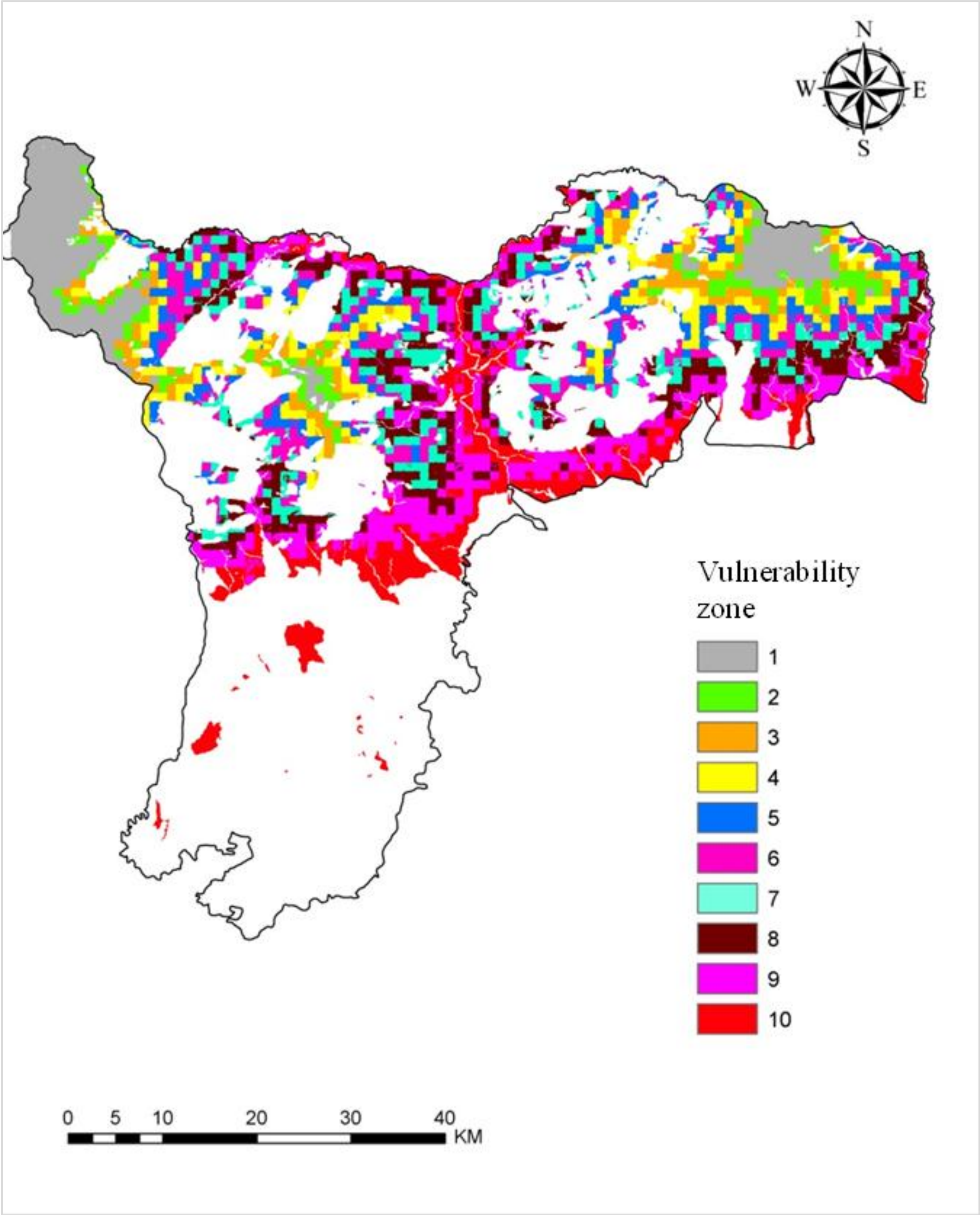


Fig. 5.17: Maps of vulnerability of land use and land cover change in 2045