ANALYSIS OF FOREST CANOPY DENSITY AND FACTORS AFFECTING IT USING RS AND GIS TECHNIQUES

(A CASE STUDY FROM CHITWAN DISTRICT OF NEPAL)

BY

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Menaka Panta

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ABSTRACT

Forest canopy density is a dynamic process determined by various natural and anthropogenic factors. It changes over time within the same forest type and over different locations in the same forest area, a landscape. Therefore detection of spatial and temporal change in canopy density and analyse the affecting factors of those changes is a useful and measurable indicator for sustainable management of forest resources in large areas. This is the major objective of this study. The study area is the Chitwan district, Nepal. In the study, TM images of 1988, 1992 and 2001 are used to assess spatial and temporal changes in the forest canopy. Secondary data are used to assess and analyse the factors that cause these changes. FCD Mapper (Semi- expert system) which computes remote sensing reflectance values of the Vegetation, Bare soil, and Thermal and Shadow indices was used as the main software tool.

The study found that the total forest canopy area decreased by 3.3 % from 1988 to 1992 and increased by 9.2 % from 1992 to 2001. Loss of canopy density mainly occurred at the edge of forest and around the new settlement during 1992-2001. The forest canopy density slightly loss in lower density canopy classes, whereas rest of other higher density classes have increasing steadily in the year 2001 in comparison with 1988.

The study found that some biophysical and anthropogenic factors (distance to settlement and river, fire and path) had a statistically significant influence on canopy density change. Other factors also influenced canopy density change but did not show a statistically significant relation. However, anthropogenic interference (e.g. stumps and debarking) did not give sharp view about the spatial distribution of canopy whether its effect was contributed or not. Different results were observed in two different sites. Interestingly, coppicing was considered as a canopy increasing factor rather than disturbances in this analysis. Change in population did not show any relation in this analysis.

It can be concluded from this research that understanding of factors affecting canopy density is quite complex phenomenon unless detail analysis of surrounding environment. Hence, it is better to carry out comprehensive analysis with other additional biophysical, anthropogenic, social, institutional factors for proper approach of their effect on canopy density.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FLOW CHARTS

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

FAO:	**Food and Agriculture Organization**
DFRS:	**Department of Forest Research and Survey**
RS:	**Remote sensing**
GIS:	**Geographic Information System**
ILWIS:	**Integrated Land and Water Information System**
ISA:	**International Society of Arboriculture**
FCD:	**Forest Canopy Density**
TM:	**Thematic Mapper**
HMG:	**His Majesty's Government of Nepal**
ITTO:	**International Tropical Timber Organization**
AVI:	**Advanced Vegetation Index**
BI:	**Bare Soil Index**
TI:	**Thermal Index**
SI:	**Shadow Index**
ITC:	**International Institute for Geo-Information Sciences and Earth Observation**
CBS:	**Central Bureau of Statistics**
HH:	**Household**
CF:	**Community Forestry**
FCC:	**False Colour Composite**
PM:	**Professional Master**
CC:	**Canopy cover**
TT:	**Total tree number**
MHT:	**Mean height of tree**
MDBH:	**Mean diameter breast height**
MPFS:	**Master Plan for the Forestry Sector**
Govt.:	**Government**
DF:	**Department of Forest**
NF:	**National Forest**
NTFP:	**Non Timber Forest Products**
IGA:	**Income Generation Activities**
TROF:	**Tree Resources Outside the Forest**
NDVI:	**Normalised Difference Vegetation Index**
SAVI:	**Soil Adjusted Vegetation Index**
DADO:	**District Agriculture Development Office**
DFO:	**District Forest Office**
VDC:	**Village Development Committee**
LHF:	**Leasehold forestry**

1 INTRODUCTION

1.1 General Background

"The canopy cover (the green mantle of forest) is the topmost layer of vegetation, which provides shelter for all that resides beneath it. The canopy filters the sunlight, softens the rain, and blocks the wind so that younger, tenderer life may thrive. In turn, the roots of the trees draw nutrients and moisture from the soil and organic material on the forest floor, conveying it up to the green canopy and keeping it lush and growing" (Lund, 2002). Forest canopy refer to the proportion of the ground covered by the vertical projection on to it of the over all vegetation canopy (Howard, 1991). The forest canopies provide habitats for many animals' species (Meer, 1995). Forest canopy is essential to environmental and economic health, providing additional cooling, increasing property values, improving air/water quality, and contributing to a more beautiful, friendlier, and liveable community (Morrow *et al.*, 2001).

Forest area and its changes is an important and, supposedly easily measurable indicator for sustainable management of natural resources in larger areas (Kleinn, 2001). Forest Canopy density is a major factor in assessing forest status and is an important indicator of possible management interventions. Importantly forest canopy can be used to understand and measure the forest condition efficiently from satellite images (Urquizo *et al.*, 1998). Understanding of forest canopy density is essential to analyse the actual status of forest, which is one of the important indicators to be used for the forest resources and management (Urquizo, 1998). Furthermore, forest management practices, like extraction of major and minor forest products from the forest and further implementation of interventions could be referred partly based on forest canopy density. Additionally, information on forest canopy, which is directly or indirectly related to the severe problem caused by soil erosion, water resources degradation, biodiversity loss, and climate change density is needed by forest manager.

Forest canopy density may be determined various factors. On one hand, high population pressures cause deforestation, forest degradation and increasing demand of agriculture lands ultimately reduces forest coverage of an entire area. Sustainable management and conservation program under suitable environment, on the other hand, promotes forest coverage (FAO, 2001). Rikimaru (1996) found that in Asia pacific region there were so many on- going initiatives that were seek to find to bring about a positive change in forest canopy under different innovations program like joint forest management, community forestry, family and/or group agroforestry, village woodlots. The forest canopy of tropical forest influence by infrastructure railways, roads, electricity power line, and channels together with quarrying, mining (Longman & Jenik, 1974). Similarly, it can be observe that around big towns and in the neighbourhood of industrial centres, forest canopies vanish very quickly. While scale and intensity of disturbances negatively affect on canopy density. The negative effects may impact the local ecosystem, the regional environment or even the global biosphere (Boerboom & Wiersum, 1983).

Canopy density is a dynamic process. Many studies done in different rain forests all over the world it becomes clear that forest canopies are regularly opened by fall of trees or big branches. Although, this creates gaps in the forest canopy, new vegetation starts to develop which eventually closes the gap. Consequently, the forest canopy also is a mosaic of patches of different canopy height and structure (Meer, 1995). On a larger scale, major catastrophes such as landslides, ecological succession, invasion of exotic species volcanic eruptions, fire and hurricanes may severely disturb large part of forest (FAO, 2001), while on a smaller time and spatial scale, canopy gap may affect the canopy density in particular (van der Meer, 1995). Gaps form from the death or displacement of a tree crown with an area or exceeding the area occupied by an average co-dominant tree crown in the surrounding forest. Van der Meer (1995) noticed that the effect of canopy gap and light availability on seedling performance determines the canopy density. Similarly, the nature of the species light / shade demander, leading favourable environment to germinate their seed and growth development of seedlings also affects to the forest canopy density in particular forest. The anthropogenic interventions in the natural forest reduce the number of trees per unit area and canopy closure. The population pressure, political instability, economic development activities are the major factors contributing to deforestation and forest degradation which could potentially affect forest canopy (Hussin & Sha, 1996). Some other activities like fire, illicit felling, fuel wood and fodder collection, grazing, encroachments, charcoal burning, logging / timber extraction, debarking, coppicing and girdling all are human interferences may affect the forest canopy density. In a case study from Asian regions (Northern Laos, the Siwalik Hills of Nepal, and several areas in China and Indonesian Kalimantan) Geist & Lambin (2001) found that the impact of forest fires and its frequency significantly contribute to the tropical deforestation which eventual affect the canopy density of tropical forest . Apart from these micro environmental factors such as light conditions, soil moisture and nutrients of their habitat controls plant distribution (Uemura, 1992). Chabot & Hicks (1982), Chapin & Shaver (1985) quoted by Uemura (1992) further stated that the availability of light conditions in any habitats ecologically and physiologically highly influences the plant in photosynthetic activity, formation of leaf (number), lifespan of leaf, timing of leaf emergence and shedding. That all are possible factors, which controls the distribution and growth of plants, hence it could be ultimately affect the canopy density in particular.

However, canopy density could differ within the same forest type and over different locations in a landscape. “Canopy disturbance is not a random process because certain areas are persistently more frequently disturbed than other areas” (van der Meer, 1995). Forest canopy density expressing the stocking status and constitutes the single major stand physiognomic characteristics of the forest (in terms of species composition/ forest type, crown closure, orientation of leaf surface, contains of chlorophyll pigment in leaf, number of stand, basal area, canopy dominant species) can affect canopy density (Roy, 1999). Further, van deer Meer (1995) revealed that the preferred forest management system of different tropical rain forests of the world (Selective cutting, clear- cut and strip cut) which noticeably leading on formation of canopy gap. These canopy gaps essentially determine the canopy density in particular forest.

It is therefore important to analyse the determining factors of canopy density change on a smaller and local scale before proceed the intervention. It is worthwhile to identify the area in which intervention strategy could be implemented. Furthermore, one should make sure that how fast a canopy density is

changing over time and space. The other important aspect is to investigate the specific reasons of canopy density change (increases or decreases) and determining factors directly related to canopy density. It could be helpful to take action or pay attention in area prioritisation process.

Forest canopy density can be detected either by ground survey or using remote sensing (RS) techniques. Followed by ground survey, the canopy closure, number of trees per unit area and basal area are always taken as parameters to measure density (Roy, 1999). However, ground survey cannot be easily carried out for the larger area. Digital image analysis techniques have the potential to provide precise estimation of canopy density. But, the conventional image classification methods need extensive fieldwork for collection of ground truth for training and accuracy assessment. The costs and effort associated with those methods can be relatively high unless good managerial aspects are already on hand (ISA, 2001). To overcome these problems, one of an efficient way could be Forest Canopy Density (FCD) Mapper, a semi-expert system proposed by (Rikimaru, 2000).

The FCD Mapper, which has been based on biophysical indices, is one of the useful tools to detect and estimate the canopy density over large area in a time and cost effective way (Rikimaru, 1996). Curran (1980), Malila *et a*l., (1981), McCloy & Hall (1991) quoted by Roy (1999) stated that biophysical vegetation indices have capacities to handling variations either due to vegetation background influences or atmospheric disturbances in a scene, or variation due to by sensor itself. Therefore, it reduces the effect of bias and assist in the extraction of significant features of a specified ground object. These indices also help in categorising mixed pixel effectively. The approach has been tested and already implemented in some part of the world e.g. the evergreen forests in the islands of Luzon (Philippines) and Sumatra (Indonesia); monsoon subtropical deciduous forests in Ching-Mai (Thailand) and Terai forest (Nepal) with an overall accuracy of about 90% (Rikimaru, 2000).

1.2 Forest Canopy and its dynamics in Nepalese context

Nepal is a one of the developing country where forest and tree resources are the main fundamental elements that contribute to livelihood (Shrestha, 1999). Nepal has been practicing community forest management programme since mid 1970's. Accordingly other forest management, awareness, development of infrastructure (by means of to support forest management activities), alternative energy sources availability has been leading towards restoration of forests (MPFS, 1988). But, annual loss of forest (deforestation and forest degradation) has been increasing than its expansion rate at an average annually by 0.4% since 1995 and most of these are happening in the Terai regions. The main factors are excessive forest product extraction, infrastructures development, expansion of agriculture land, constrains in implementation of government's forest policy, lacking of inter institutional coordination, demographic and economic factor, traditional use of firewood, culture, poverty and so on (EFEA, 1999).

Nepal's gross forest area has decreased by 1348000 ha and the forest area has been converted to shrub land by 869300 ha in between 1979-94 (DFRS, 1999b). Moreover, the area of forest in 1990 was 4683,000 ha and in 2000 it remained 3900,000 ha. Similarly, change in forest area between 1990-2000 was -78,000 ha annually and the annual rate of change was -1.8%.(FAO, 2001). The most serious decrease has taken place in the low land, which is known as Terai. In this region about 18% of woody vegetation has changed into other land use classes in between 1979-91(DFRS, 1999a). Be-

cause of the flat landscape, most of the areas are accessible and potential for both agriculture and forestry. Since the major source of national revenue come from the extensive and easily accessible Terai forests, therefore relatively well developed forestry infrastructure and accessible markets are concentrated there with few personnel posted to hill areas (Hobley, 1996). Paudel (2000) mentioned that most of the hilly districts of Nepal has highly emphasized and implemented community forestry programme through Forest Department with sufficiently financial and technical supports from many NGOs and international donor agencies and is claimed to be successful programme in this moment. Terai forest on the other hand is still in primal stage for the development of community forestry program. In contrast to the extensive body of knowledge on community forestry in the hills, very few CF program has been launched and success in the Terai (Chakraborty, 1997).

The Terai lands of Nepal have been facing problems from deforestation and encroachment in the forest since last 40 years with migrating population from hilly areas (MPFS, 1988). Poudel (2002) has reported that deforestation is still major problem in Terai and Siwalik range which is leading by high degree of poverty caused rapid population growth. Terai forest consists of valuable Sal *(Shorea robusta)* tree species, which is by its physical and mechanical properties said to be one of the most durable timber species than the others (Stainton, 1972). Therefore, these forests have high commercial value. Moreover, people living in the Terai are highly depend on forests for the energy sources and agricultural needs having access to forest products and services (Shrestha, 1999). Many evidence found in literatures about Terai forest of Nepal mentioned by many people, working NGOs and INGOs. Terai forests are highly influence by human interference such as firing, fuel wood and fodder collection, grazing, encroachments, charcoal burning, illicit felling / timber extraction, debarking, path, coppicing and girdling (IUCN, 1991). It is also clearly shown below in the Figures 1, 2, 3, 4, and 5.

Rapid population growth on the other hand, causes demand of agriculture land for food production and forest products also manifest massive destruction of Terai valuable forest (FAO, 1997). With these factors, the forest of Terai vulnerably shrinks as comparison with hills. It is consciously leading to canopy degradation, deforestation and its threaten to the future generations. However, Messerschmidt (1990), Stone (1990), Fisher (1991), and Gilmour (1991) quoted by (Fox, 1993) illustrated that there is a lot of examples of successful conservation, rehabilitation, plantation and active forest management in some parts, hence their efforts essentially contributed in forest of Nepal. Similarly, the findings of other forestry sector projects have shown that there has been a remarkable increase in trees growing on the private agriculture lands, which compensates for some of the loss of trees in government forests. Further, in some community-managed forests, forest area or forest quality has been also remarkably increasing (DFRS, 1999). Further, Gilmour & Nurse (1991), Carter & Gilmour (1989), Carter (1992) quoted by Hobley (1996) stated that although in some parts of Nepal crown densities may be decreasing, though not in all. Moreover, the actual area of land cover by forests doesn't seem to have changed significantly. In fact, some areas have increases forest cover more than previous.

Figure 1-1. Illicit felling inside the forest (Top left)
Figure 1-2. Debarking effect inside the forest (Top right)
Figure 1-3. Bushes and non-woody vegetation after fire (Middle left)
Figure 1-4. Making path inside the forest (Middle Right)
Figure 1-5. Grazing effect inside the forest (Below)

1.3 Problem statement

"Forest of one type or another cover nearly a third of the world's land area. They are distributed unevenly and their resources value varies widely " (Lillesand *et al*., 1987). Forests are known to be one of the most important renewable natural resource. Most of cases socio-economic and socio-political reasons in developing countries of South East Asia has faced one of most serious degradation of forest in the tropical world (Roy, 1999).

Knowledge of forest types, including the canopy density classes is necessary for scientific forest management. Remote sensing techniques as a tool satellite imagery provides a mean to obtain a synoptic view of forest and their condition on real time basis (Lillesand T. M & Kiefer R.W 1987). Satellite remote sensing data has been importantly substantial and extensively used to map forests of tropics where up to date data about spatial distribution is necessarily for organizations and are absent or lacking (Roy, 1999). Similarly, knowledge of forest species composition (types of forest) is an integral part of natural resource management and ecology. Therefore the integration of remotely sensed data coupled with digital geographical data could be time and cost-effective method of forest mapping and proper planning of resource in natural resource management (Gartner & Genderen, 1996). Remote sensing techniques have ability to grasps up data rapidly and inexpensively over large geographic regions. Further, it is comprehensively useful for conservation biologists and environmentalists for mapping natural resources, monitor and document the local, regional and global consequences of acute and chronic changes in environment (Wilkie & Finn, 1996). Remote sensing thus one of fundamentally very important technique which can provide the knowledge essential for developing strategies of intervention program to mitigate adverse impacts on natural resource.

Digital remote sensing provides timely information which is potential data updating sources to GIS. Remotely sensed data integration with GIS model is very useful for studies of natural resources phenomena with respect to various environmental/ biophysical factors. However, in developing countries uses of remotely sensed data is still limited in GIS land and natural resources management applications (Zhou, 1991).

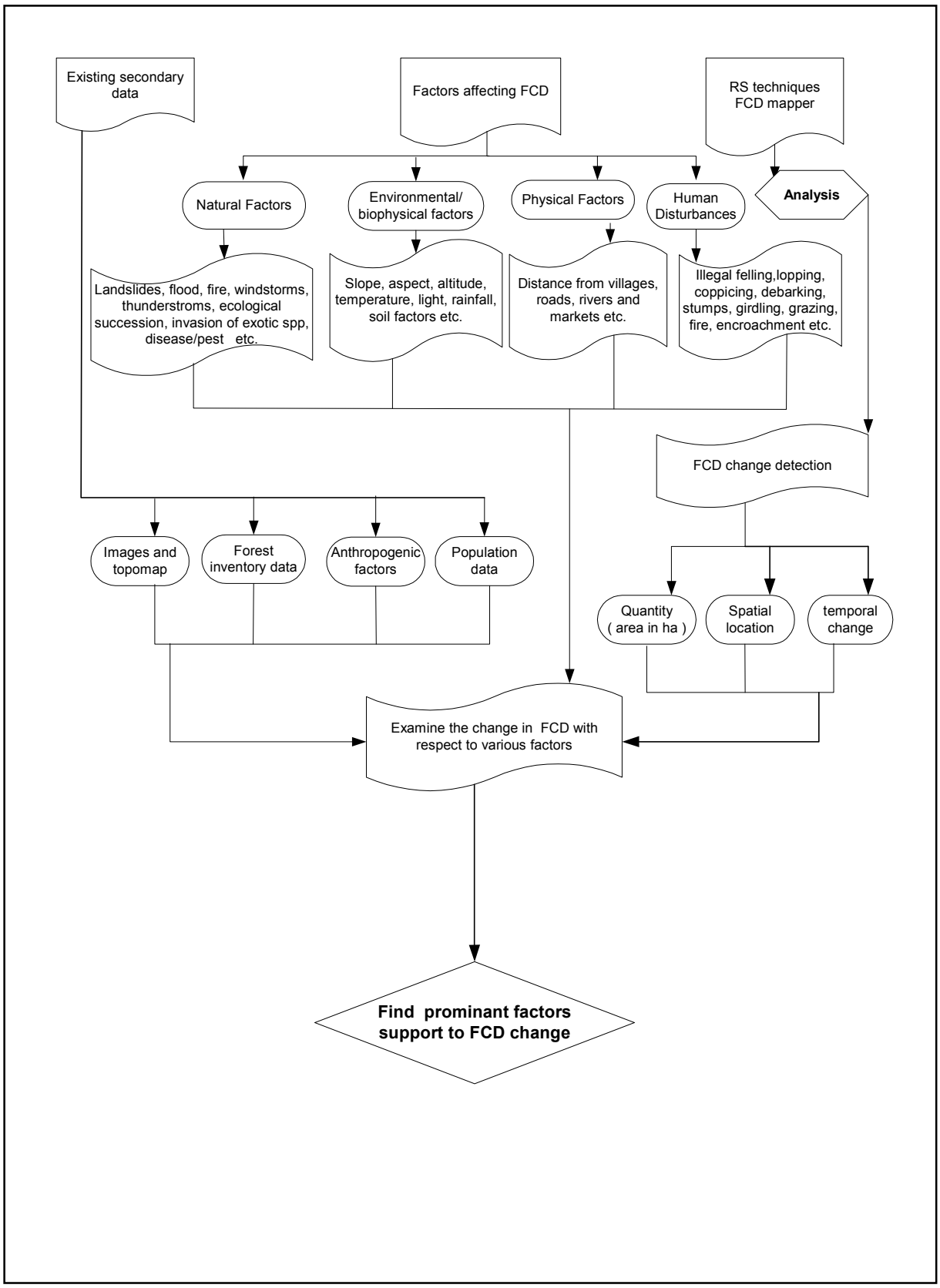
Though, many studies have been done on forest canopy and its dynamics, afforestation, deforestation and forest degradation in the different part of the world, few have been carried out in Nepal. Furthermore, most of previous studies have been focused on forest cover change (deforestation and forest degradation) and canopy density change. (Nepal, 1999) analysed temporal change in forest cover in Chitwan district of Nepal using multispectral satellite imagery and ancillary data. Maharjan (2001) and Kothandapani (2001) analysed canopy density changes and forest degradation using FCD Mapper (Semi- expert system). Similarly, Requene (2000) analysed forest cover change using GIS and RS techniques. Kaphley (1999) compared the standing tree volume in various classes of national forest in Chitwan district. Mujuni (1999) accessed forest cover change using GIS and RS techniques and related socio-economic aspects in the same area. Furthermore, based on forest structure data (dbh, volume and species composition), DFRS (1999) conducted a forest inventory in some Terai districts of Nepal including Chitwan and analysed forest cover changes between 1979-94. However, none of these studies analysed the factors of those changes. It is interesting to note that, the studies on analyse

of canopy density change (increases or decreases) and factors affecting it on a local level are in its primitive stage.

The use of remote sensing, along with secondary data integrated in a GIS, for calculation of forest canopy density is in its infancy. Normally, field data are used to support image classification and to verify results of the analysis of remote sensing imagery. Accordingly, during fieldwork, detailed information is collected by direct observation of the real world, interview with villagers/people based on primary sources. This primary information is usually collected by sampling from pre image classification and topographic maps, either by systematic sampling or using randomly generated coordinates of sample locations.

In this research, it was not possible to conduct a fieldwork in Nepal because of presently unrest and insecure situation. In this situation existing secondary data could be helpful to carried out analysis if the nature of the data able to meet researcher goal. Moreover, the use of existing secondary data purposely cost and time effective for the organization unless large investment already in one hand for same data collection. The important consideration and challenge is can secondary data adequately help to provide information, and, if yes, to what extent and with what limitations?

Rikimaru (1996) found that consideration of secondary sources of data for integrated approach with GIS techniques is very useful and important in land and natural resource management. It is helpful to rehabilitate, scientific management of degraded forest areas in sustainable way in natural resource management. However, an important consideration of using secondary data is the purpose of the study and level of information that is needed for the planning and decision making for implementation of possible intervention strategies. Consequently, this research also examines the possibility of using secondary data, which were previously collected from Nepal. Based on existing secondary data, this study focuses on spatial and temporal change of canopy density with respect to various environmental / biophysical (roads, settlements, and river, canopy dominant species), human population and their disturbances (stumps, lopping, grazing, girdling, firing, coppicing, path, animals dropping, and debarking) on the local level. For the distance from settlement to forest, settled area out side the forest is considered in this analysis. Though canopy density could be affected by other biophysical and socio-economic factors, because of data limitation only the human disturbances such as felling, lopping, stumps, grazing, coppicing, fire, debarking and girdling, biophysical factors species composition, distance road, river and settlement, and population were considered in this analysis. Moreover, most of the study area covers flat more or less 300m from sea level so slope, aspect and altituditional factors do not play role and influence the canopy density.



Flow chart 1-1. Logical flow of problem statement

1.4 General objective

The main aim of this study is to:

- detect spatial and temporal change in canopy density and
- analyse the affecting factors of those changes using ancillary data.

1.5 Specific objectives

The specific objectives are:

- To map the spatial locations and determine amount of canopy density change from 1988 to 2001.
- To identify and analyse the possible biophysical/ environmental and anthropogenic factors affecting forest canopy density.
- Analyse the relation between population change and forest canopy density.
- To examine the extent to which existing data can provide the information needed to meet the above objectives.

1.6 Research questions

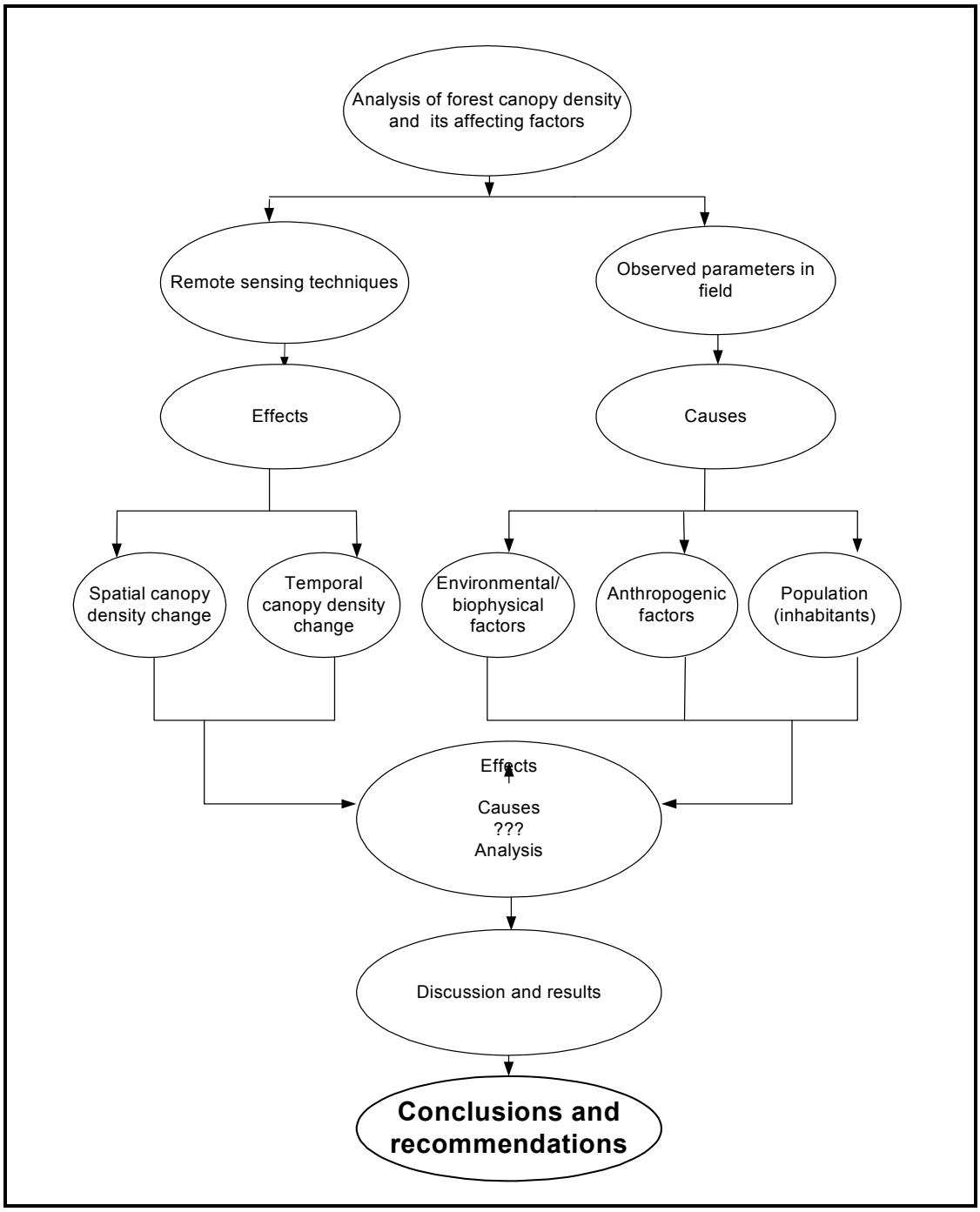
- Is there any relationship between environmental/biophysical (canopy dominant species, distance from river, road, and settlement) factors and forest canopy density change?
- Is there any relationship between effects of anthropogenic factors (human interference) and forest canopy density?
- Has population an effect on forest canopy density?
- Are the secondary data adequate to help the answers the above research questions?

1.7 Organization of the thesis

The remainder of this thesis consists of four chapters and appendices. Chapter two introduces the study area, materials and methods. Chapter three present the analysis and results. Chapter four Presents discussion and chapter five for specific and general conclusions based on all the previous chapters. Appendices relate to analytical statistical data tables.

1.8 Conceptual approach

The conceptual approach of this analysis (Flow chart 1-2) starts with forest canopy density and factors affecting it, which could be responsible for change. Remote sensing techniques are reliable tool to analyse forest canopy density. It has potential in detecting both spatial as well as temporal change in terms of location and area. An empirical data (field observations) on the other hand, have been used to analyse the factors leading to canopy density change. A combination of remotely sensed techniques and ground truth survey analysis may be helpful to understand the impact of factors on canopy density change. It could be further helpful to the planner for implementation of possible intervention strategies in forest management of Nepal.



Flow chart 1-2. Logical flow of conceptual framework

2 STUDY AREA, METHODS AND MATERIALS

2.1 Study Area

Nepal, a rich treasure of 76 forest type is located in the latitudes of 26°22′ N and 30°27′ N, and longitudes of 80° 04′ E and 88° 12′ E. It extends from low land (Terai, 59 m) from south to high Himalayan region (8848m) in the north (Stainton, 1972). Nepal is divided into five administrative regions, 14 zones and 75 districts. Chitwan district is one of them. A southwest part of Chitwan district was selected as the study area (83°54'45" and 84°48'15" East longitude and 27°21'45"and 27°52'30" North latitude). It is about 150 km far from capital Kathmandu.

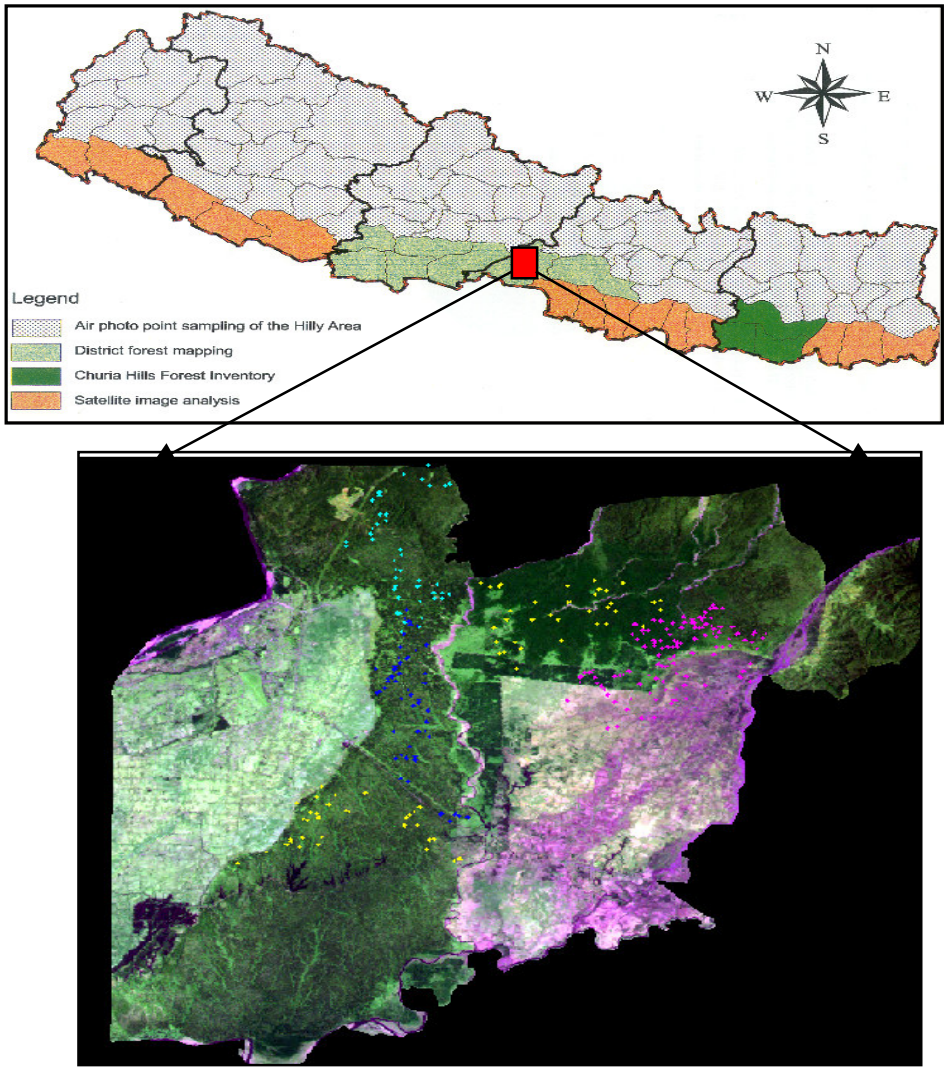


Figure 2-1. Landsat TM 1992 (FCC351) showing study sites. Cyan shows: data collected in 1998, Blue: 1999, Magenta: 2000 and Yellow: 2001. For detail see Figure 3.12 also.

2.1.1 Topography:

Based on the literature, the study area is an inner Terai valley, which lies between Siwalik Mountain in the South and Mahabharat range in the North, covering area of approximately 2230 sq. km. The Chitwan district is almost a flat valley slope slightly towards the South. The altitude ranges from 244m to 1945 m.s.l.

2.1.2 Climate

Chitwan has a diverse climate and rainfall over its landscapes due to elevation and land configurations. It has tropical to sub-tropical climate and the average annual rainfall is 1510 mm. It is characteristically hot and wet during summers and cold and dry in the winters. The average maximum and minimum temperature is 37°C and 8°C respectively.

2.1.3 Drainage

Some rivers are perennial and some are seasonal in this district. Narayani (which flows in the west, also separates Chitwan from Nawalparasi district) and Rapti are the two big rivers, and Lother, Rue and Karra are the small rivers in this district.

2.1.4 Geology and Soil

Geologically, the district can be divided in Mahabharat, Siwaliks and valley formations. The Mahabharat range mainly consists of pale green chlorite, derecite- phyllite. The Siwaliks range is composed of the Neogene coarne grained clastic rocks. The northern part of the valley has gravels, whereas the southern part is more flat with sand, clay and silt. Soils is in the valley are mainly sandy loam, however the southern parts border of the district are composed of coarse bedded sand stone, crystalline rocks, clays and conglomerates (ITC, 1998).

2.1.5 Forest resources

Mainly 3 forest types dominate the study area. They are Sal forest, mixed hardwood forest and reverine khair- sissoo forest. Sal (*Shorea robusta*) forest is pioneer and dominant forest species of this region characterized by Terai and hill sal. It has a high commercial value. It is one of the protected species of the natural forest. In most of the area it is associated with others species mainly Asna (*Terminalia tomentosa*), Saj (*Terminalia alata*), Jamun (*Eugenia jambolan*a), Banjhi (*Anogeissus latifolius*), Barro (*Terminalia bellerica),* Ramphal *(Dillenia pentagyna)* etc.

A combination of sal and broadleaved trees formed mixed hardwood forest. Some common species are Asna (*Terminalia tomentosa*), Karma *(Adina cordifolia), Albizzia odorettisima*, *Lagerstroemia parviflora*, Bhajhi (*Anogeissus latifolius*), Khair (*Acacia catechu*), Simal (*Bombax ceiba)*, Gutel (*Trewia nudiflora*), Bel (*Aegle marmelos*), Sindure (*Mallotus philippensis*), Kusum (*Schlichera oleosa*), etc. Khair (*Acacia catechu*)–Sisso (*Dalbergia sissoo*) is another major reverine forest type found in this district, which is predominated by Sisso. This association is only occur along the new alluvial soil deposition mainly due to flood, streams and rivers.

2.1.6 Forest management systems

In Chitwan district, the government has been implemented active forest management practice (proper conservation, protection and utilization) under Forestry Sector Management Master Plan of 1988. Some part of national forest has already been handed over to the local people under Community For-

estry Programme as per management plan. Besides these, the Department of forest implemented production as well as protection forest demarcation (National forest development programme), Leasehold forestry, and private forestry. However, Community Forestry Programme has poorly implemented in the Chitwan district in comparisons to other districts of Nepal (ITC, 2001a).

2.1.7 Land use

The total area of Chitwan district is 219454 ha out of which 112700 ha land is covered by forest, 1200 ha by shrub land, about 93200 ha by National Park and the rest is agriculture, riverbeds and water body (DFRS, 1999). As revealed data from Fieldwork report on Chitwan 1998, the forest area 58,507 ha was under the District Forest office (DFO), 4,801.81 ha of forest has been handed over to the local communities as accordance to operational forest management plans. 150 ha was covered by private forest, 28 ha have been handed over for local institution (Medical college), 91.2 ha have been handed over and 200 ha was on the process for Hill leasehold forest. Similarly, as revealed from field work report 2001 now the area of Leasehold and private forestry has been extended and handed over to the local communities 468 ha and 216 ha respectively. Further, 80295 ha and 5186 ha has been implemented under protection and production forest respectively.

2.1.8 Population and livelihood

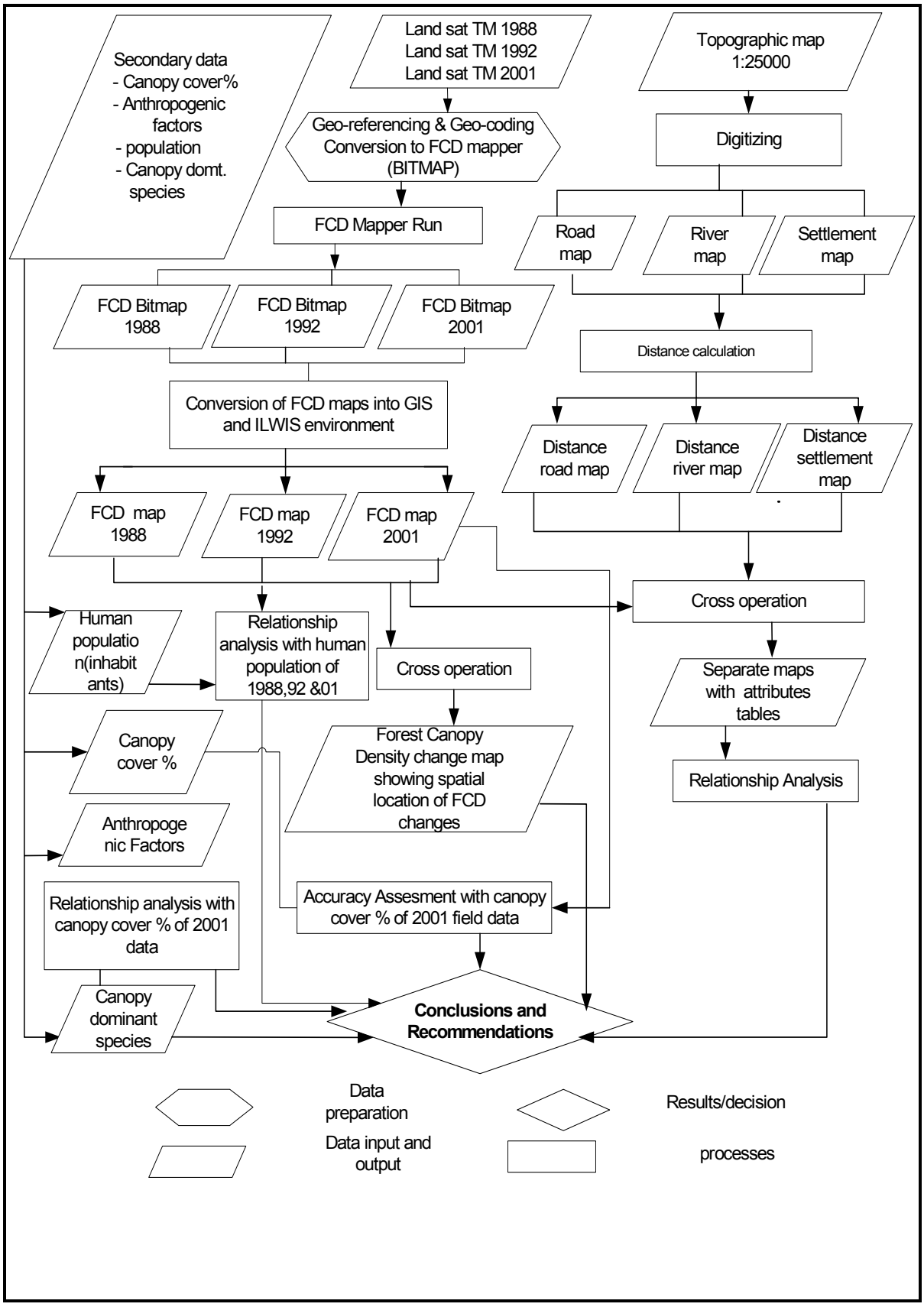
Based on 2001 population census (CBS, 2002) population of Chitwan district is 472048, out of which males are 235084 and females are 236964. The annual growth rate is 2.04% per annum. The agriculture land is 42800 ha. in the district where 53400 hh are involved in agricultural activities. The district having diverse in ethnicity and the population in villages is heterogeneous in character. Most of the people are depend on the subsistence agriculture, some of them are depends on daily wages labour and on forest for illegal cutting to earn for subsistence. Some people are businessman and service holders. The other sources of income in Chitwan district are Eco-tourism in Royal Chitwan National Park.

2.2 METHODS

The research is based on three main principles.

- Uses of Forest Canopy Density Mapper as Remote sensing technique/ tool to determine spatial and temporal detection of forest canopy density over the periods.
- Analysis of biophysical / environmental factors with respect to forest canopy density change using ancillary data.
- Analysis of field observation / disturbances data with respect to examine the spatial distribution of forest canopy density in the study area.

Analysis process is presented below (Flow chart 2-1) in the logical research framework.



Flow chart 2-1. Logical flow of research framework

2.2.1 Concept of Forest Canopy Density Mapping Model and Semi-Expert System

FCD Mapper (Semi- expert system) version 1.15 is a computer software package compatible with Windows. The FCD model requires less information of ground truth only sufficient to check accuracy assessment (Rikimaru & Miyatake, 1997). Furthermore, he recommended that it is one of useful tool for monitoring and management for the future with less ground truth survey. Because of fieldwork has not carried out and only was used previously collected data of the same area, it was prioritise to use and analyse FCD of over periods using available satellite data.

FCD Mapper contains the algorithms and formula to compute the satellite imagery based on four bio-physical indices. These indices are advanced vegetation index (AVI), Bare soil index (BI), Thermal index (TI) and shadow index (SI). Landsat TM satellite imagery data is used in FCD model. The Model is based on the growth phenomena of forest together with biophysical spectral response of the area.. It calculates forest canopy density in percentage (e.g. 10%, 20%, 30%, 40 % and so on as interval of 10%).

2.2.2 Characteristics of Four Indices

Forest Canopy Density Mapping Model is a combination of Vegetation, Bare Soil, Shadow and Thermal Indices. Figure 2.2 illustrates the relationship between forest condition and these indices. Vegetation and shadow parameters of a forest are strongly correlated with each other. An increment in vegetation increase shadow as well. Similarly, bare soil and temperature are also correlated as shown in the figure below. Vegetation Index response to all of vegetation items where as Shadow index directly related to the forest density. When forest density increases, tree vegetation makes more shadow beneath it which ultimately increases SI. Thermal Index increases as the vegetation quantity decreases. It reacts directly with temperature exposure from the bare lands. Bare Soil Index increases as the bare soil exposure degree of ground increase.

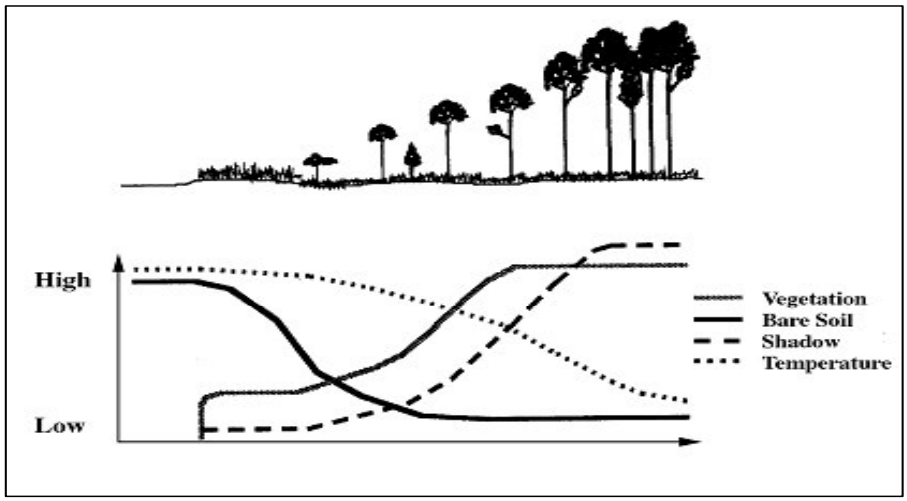


Figure 2-2. Characteristics of four indices for forest condition

	Hi- FCD	Low-FCD	Grass Land	Bare Land
AVI	Hi	Mid	Hi	Low
BI	Low	Low	Low	Hi
SI	Hi	Mid	Low	Low
TI	Low	Mid	Mid	Hi

Table 2-1. Combination characteristics of four indices

AVI	=Advanced Vegetation Index	Hi	=High
BI	=Bare Soil Index	Mid	=Middle
SI	=Shadow Index	FCD	=Forest Canopy Density
TH	=Thermal Index		

2.2.3 Obtaining of Four Indices

a. Advanced Vegetation index (AVI)

Normalised Difference Vegetation Index (NDVI) is unable to highlight subtle differences in canopy density. It has been found to improve by using power degree of the infrared response. The index thus calculated has been termed as advanced vegetation index (AVI). It has been more sensitive to forest density and physiognomic vegetation classes. AVI has been calculated using the following equation:

B1~ B7: TM Band 1~ 7 data

B43=B4-B3 after normalization of the data range.

CASE-a B 43 < 0 AVI= 0

CASE-b B 43 > 0 $AVI = ((B\,4 + 1) \times (256 - B3) \times B\,43)^{1/3}$

b. Bare Soil Index (BI)

The bare soil index (BI) is formulated with medium infrared information. The underlying logic of this approach is based on the high reciprocity between bare soil status and vegetation status. The bare soil areas, fallow lands, vegetation with marked background response are enhanced using this index. Similar to the concept of AVI, the bare soil index (BI) is a normalized index of the difference sums of two separating the vegetation with different background viz. completely bare, sparse canopy and dense canopy etc. By combining both vegetation and bare soil indices, one may assess the status of forestlands on a continuum ranging from high vegetation conditions to exposed soil conditions. BI has been calculated using equation:

$BI = ((B5+B3)-(B4+B1)) / ((B5+B3)+(B4+B1)) \times 100 + 100;\ 0 < BI < 200$

The range of BI is converted within 8 bits range

c. Shadow index (SI)

Forest is three-dimensional in its structure. To extract information on the forest structure from RS data, a combination of forest shadow itself and thermal information on the forest influenced by shadow can be utilised. The crown arrangement in the forest stand leads to shadow pattern affecting the spectral responses. The young even aged stands have low canopy shadow index (SI) compared to the mature forest stands. The later forest stands show flat and low spectral axis in comparison to that

of the open area. SI has been calculated using equation. The shadow index is formulated through extraction of the low radiance of visible bands.

$SI = ((256-B\ 1) \times (256-B\ 2) \times (256-B3))^{1/3}$

d. Thermal Index (TI)

Two factors account for the relatively cool temperature inside a forest. One is the shielding effect of the forest canopy, which blocks and absorbs energy from the sun. The other is evaporation from the leaf surface that mitigates warming. Formulation of the thermal index is based on these phenomenon. The source of thermal information is the thermal infrared band of TM data. The temperature calibration of the thermal infrared band into the value of ground temperature has been done using equation:

$L = L\ min + ((L\ max - L\ min)/255) \times Q$

Where:

L: value of radiance in thermal infrared

Q: digital record

L max: value of radiance = 1.500 mw/cm2/str (Q=0)

L min: value of radiance = 0.1238 mw/cm2/str (Q=255)

2.2.4 Data Compilation

This study is based on secondary data collected by former MSc and PM students during their successive fieldwork visit to Chitwan, Nepal. Data need for this research is available from Department of Natural Resource, ITC Enschede. The participants of the forestry for sustainable development, ITC had collected the secondary data and I have used in this study. The data, which were collected in 1998, 1999,2000 and 2001, covers most part of the study area. They were mostly focused on forest inventory (measurement of dbh, height of tree, total no. of tree, canopy dominant species in the plot and canopy cover %), Tree Resources Outsides the Forest (TROF) and socio- economic activities related to forest issues of the area. Although they were collected in four different years, the measurement parameters were more or less the same, however additional information were recorded in some year.

2.2.5 Geo - referencing of satellite imageries

Image and map processing:

Geometric correction of the images is very important step of the image processing. It is helpful to establish the relationship between row and column numbers with real world co-ordinates. Remotely sensed images in raw format contain no reference to the location. In order to integrate these data with other data in a GIS environment, it is necessary to correct and adapt them geometrically (ITC, 2001b). Landsat TM images of three different years 1988, 1992 and 2001 were used in this study. Landsat TM of 1988 was geo-referenced using Topographic map (1: 25000) 1994 and the accuracy was checked with Topo-sheets.In the process of geometric correction for Landsat TM image of 1988, Oct 12th eight points were identified and matched with points on the Topo-sheet obtained sigma = 0.221. Similarly, Landsat images of 1992 and 2001 were geo- referenced using image to-image registration method where 1988 image was taken as a master image. At the same time, using nearest neighbourhood method geo-coding of the images was performed.

Maps generation (Digitising):

Road, settlements, and river maps were digitised from Topographic map. Digitised maps were converted in the rasterised form using ILWIS software. GIS operation i.e. distance calculation function was used to produce distance maps of road, river and settlement as an output maps. These maps were used for further analysis, which has been mention in the data analysis part.

Creation of Subset (Study area) map:

Boundary map was digitised from topographic map of the study area, which covers all sample plots of 1998, 99,00 and 01. Segment boundary map was polygonised and rasterised. Finally, a subset maps were made from each band of three-year images using boundary map and map calculation function. These subsets were then exported in bitmap format (BMP) and were used in FCD Mapper.

Image format conversion:

FCD Mapper only supports BSQ, BIL and BMP format data. Furthermore, geo-referenced images were in raster format, hence it could not compatible for the FCD Mapper. All seven bands of Landsat images were converted to BMP format before proceed for FCD Mapper program.

Forest canopy density mapping using FCD Mapper:

FCD Mapper is used to calculate the forest canopy density class on the basis of FCD model. Using the FCD Mapper Software carried out FCD mapping. Accordingly, the entire mapping processes were followed based on FCD model (Rikimaru, 2000). Followed this model; all seven bands of the Landsat TM images of three different years (1988, 1992 and 2001) were used for the FCD mapping. The converted raster images of all seven bands do not offer header and record offset size. So in those parameters were set up as null value and 902 values were assigned for the record length and 768 for the end pixel. Correcting noise followed the procedure by choosing surface water and slope shadow. The images were cloud free hence cloud correction was not necessary to performed. Finally, images were normalized and NDVI was chosen in PCA option. Similarly TI (Thermal Index) was normalized. Furthermore, normal equation was chosen for generation of SI (Shadow Index) and gap detection was chosen to obtain ASI (Advanced Shadow Index).

The threshold values for different parameters were assigned as follows: 55 point for water set and 100 points for gap set. There was no any information about the black soil in the study area hence black soil correction was leaved as such. Similarly, 98 points for the vegetation set, 140 point for the Bare Soil set, 110 for minimum vegetation density and 120 for maximum vegetation density were considered as the threshold values for the VD calculation. After finalizing the setting of the threshold values, the software automatically starts to calculate VD. At the same time SSI (Scaled Shadow Index) was generated from VI-BI-SI indices. Accordingly to calculate the SSI, canopy density class 3 to 7 were selected from FC (Forest Cluster) table. Finally forest canopy density model was completed by the integration of VD and SSI. This integration resulted into the 11 forest canopy density classes with statistics. The detailed result has been summarized in result and analysis part.

Conversion of FCD maps into GIS or ILWIS environment:

As stated above, the FCD Mapper gives map of 11 classes of FCD and statistics by default. The area expressed in terms of hectare was based on grid system. The information was rather confusing because very few pixels were representing some of the classes that were not good enough for further

analysis. Therefore to over come this problem, following steps were pursued. The FCD map of 1988 was imported to the ILWIS environment via map. The imported FCD map was then geo-referenced and sub map was generated using same line (902) and column (768) numbers as before to remove extra information. The domain was changed from colour to image domain. Than the cross operation was done using the same FCD map twice. The class 1 to class 12 was assigned in a new domain. Reclassification operation was done and finally six classes map was obtained as a final map. Similar processes were followed for the other FCD maps. The classified FCD maps were then compatible for further spatial analysis in GIS.

2.2.6 Data Analysis:

Analysis of remote sensing Image data for change detection:

FCD Mapper software was used to produce forest canopy density map of year 1988,1992 and 2001. To analyse and detect the forest canopy density changes from 1988 to 2001 in terms of spatial location and total area, cross operation was performed between canopy density maps of different years. The cross operation between 1988 and 1992; 1992 and 2001; 1988 and 2001 were done. Finally, forest canopy density change map with three classes (negative change, positive change and no change) was calculated.

Relationship between biophysical factors and forest canopy density:

The relation between distance from road, settlements, and river with forest canopy density change is one of the questions of this analysis. These factors were analysed by using map interpolation. The road, river and settled area maps were digitised; rasterised, interpolated and a continuous distance map of each variable were generated. The canopy density map of 1988 and 2001 were crossed with each map (road, river and settled area). Finally, relation was analysed using map attributes and results were presented in tables and graphs. Furthermore, statistical relationship between forest canopy density change and the distance of three environmental/physical parameters (road, river and settled area) were analysed using Pearson correlation analysis technique. Similarly, forest structure (in the sense of relation between dbh, height of tree, and total number of trees, canopy dominant species and canopy cover percentage) was analysed using the same technique. All quantitative data measured in the sample plots which previously collected were tested by One-Sample Kolmogorov-Smirnov Test whether distribution of measured variables were normal or not. Based on the pattern of data distribution, different statistical methods of significant were carried out. Accordingly, Pearson correlation test was preferred for statistical significant test of biophysical factors. ANOVA test was preferred for species composition. The SPSS statistical software was used in this analysis.

Relationship between anthropogenic factors (human interference) and forest canopy density:

Some of the anthropogenic factors for instance, grazing, sign of fire, girdling, lopping, coppicing, stumps, debarking and path could spatially and temporally alter the forest canopy cover which has been already analysed in the region (Joshi, 2001). However, the effect of these anthropogenic factors (human interference) on forest canopy density has poorly been analysed. Analysis was done giving weight value to each disturbance parameter recorded as “Yes” for sign of disturbance and or “No” for those parameters where sign of disturbance was not traced out. The test of significance was performed using nonparametric test e.g., Kruskal-Wallis Test. Non-parametric techniques used with scores,

which are not exact in any numerical sense, but which effect are simply ranks. It can be used where the population may be not normally distributed in a certain way. It has also advantages because of its simplicity in computational way. The most usefulness and advantages of nonparametric test is it can be used or test for small sample plots (Siegel & Castellan, 1988).

Relationship between human population and forest canopy density:

Total canopy density occupying area (in terms of ha) of each year 1988, 1992 and 2001 and population number of corresponding years were considered to analyse the relationship between canopy density change and human population over the periods. In this study population of nine VDCs out of 38 (including two Municipalities) were taken due to data availability and constraint of other social information. Analysis was done between total population in 1988, 1992 and 2001 and total forest canopy density occupied area (in terms of ha) of 1988, 1992 and 2001. Furthermore, forest area in ha/person was also calculated. Excel spreadsheet was used and results were presented in graphic and tabular form.

2.3 MATERIALS

2.3.1 Satellite images

Landsat TM images of 1988 (Oct 12th), 1992 (May 7th) and 2001 (Oct 24th), which covers almost all part of the Chitwan valley (study area) were used for the analysis. All the seven bands (1-7) of Landsat TM were also required for the FCD Mapper.

2.3.2 Topographic map

Topographic maps of 1994 (1: 25000) of Chitwan district published by Survey Department of HMG of Nepal were used for georeferencing of Landsat TM images year 1988, 1992 and 2001.Similarly, six Topographic map (topo-sheet) having scale 1:25000 were used for digitising road, river and settled area maps for whole area.

2.3.3 Software

Following software were used in this study:

- FCD Mapper (Semi- expert system) version 1.15
- ILWIS version 3.1 was used for GIS operations and the spatial analysis for the change detection as well as to analyse responsible factors. It was also used for processing of remotely sensed data.
- Apart from these, Microsoft word, SPSS, Excel and Minitab were used for the data analysis, graphics, various statistical tests, correlation analysis and so on. Microsoft Word was used for the word processing. Similarly, Visio was used for flow diagrams. Scanner was also used for the scanning of Topo-sheets and images of the study area.

3 RESULTS

As has been mentioned in the previous chapter, mapping of forest canopy density using a biophysical approach is a simple and straightforward method. This method has been used by many researchers and has given different results. The main concept of the analysis is to calculate the percentage of forest canopy density based on satellite images. Most of the results from previous research claimed a high correlation between the reflectance properties and field measurement of canopy density, if the field measurement has been taken at the same time with the satellite overpass. In this analysis, however, the images and field measurements were collected at different time. This fact gave another challenge for this research: Can Landsat TM imagery of different season reasonably contribute to forest canopy density mapping over a relatively long period? To answer this question, the main activities of this approach are: (i) selection of existing data of study area from different types of data sets (ii) calculation of the FCD using different indices (AVI, BI, SI and TI) with different band combination of TM image. Another fact is that the canopy density is a dynamic phenomenon. Many biophysical and human disturbances alter canopy density significantly. Based on available data sets, some of these factors were analysed. The main questions were (iii) assessing the effect of distances from road, settlement and river and the spatial distribution of canopy density over a period of 13 years in Chitwan district (iv) assessing the effect of population (inhabitants) on canopy density (in terms of area) in 1988, 1992 and 2001; (v) assessing the effect of anthropogenic factors on canopy density; (vi) and assessing the effect of canopy dominant species on FCD. This chapter is structured following this sequence of activities.

3.1 Forest Canopy Density change detection:

In general, FCD Mapper gives eleven class from 0 to 10 of forest canopy density by default Some of these classes are representing a very few pixels which would not good enough for further analysis. So to overcome this problem, eleven classes are merged into six such as class0 (0%), class1 (1-20%), class2 (21-40%), class3 (41-60%), class4 (61-80%) and class5 (81-100%). The canopy density of each year and comparative analysis has been separately presented under the following sub headings.

3.1.1 Forest Canopy Density in 1988

Figure 3.1. and 3.2 shows that most of the study area is under canopy class 0 (non forest either area outside the forest or open land within the forest) having an area of about 4982 ha. However, about 4513 ha has been covered by canopy class4 (61-80%), whereas class1 (1-20%) has the least area of about 268 ha. Accordingly, about 905 ha have been occupied by class2 (21-40%), 2040 ha by class3 (41-60%) and 3056 ha by class5 (81-100%) respectively in 1988 (Appendix C, Table 16). The result of the forest canopy density is presented in Figure 3.2. The small area of canopy class1 (1-20%), class2 (21-40%) and class3 (41-60%) clearly suggests the limited degradation status of the forest in 1988.

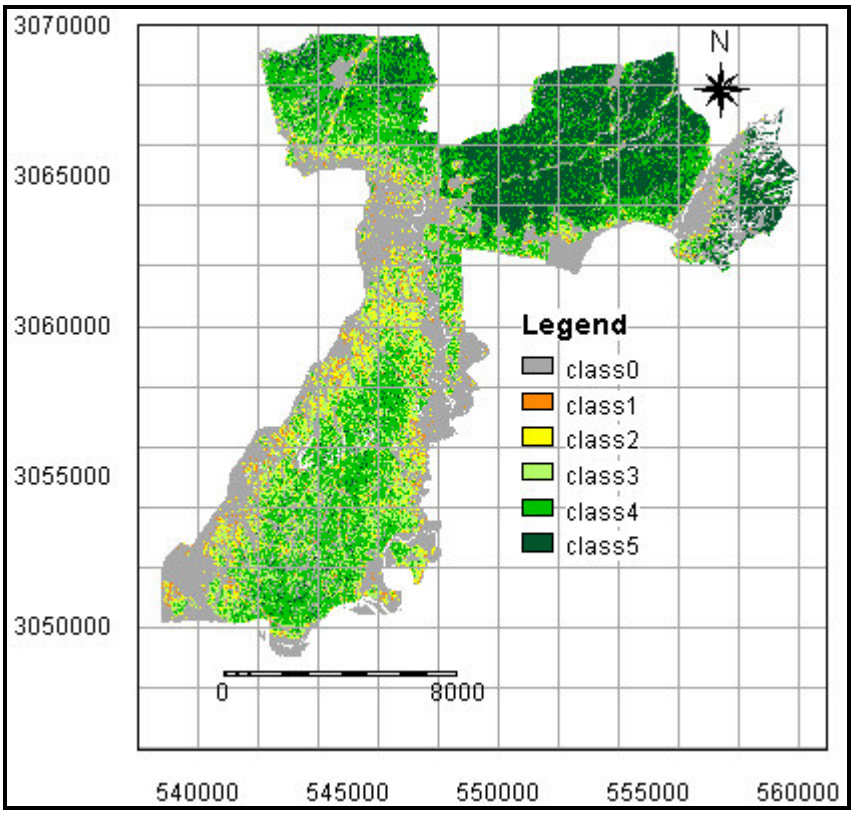


Figure 3-1. Forest Canopy Density Map of 1988

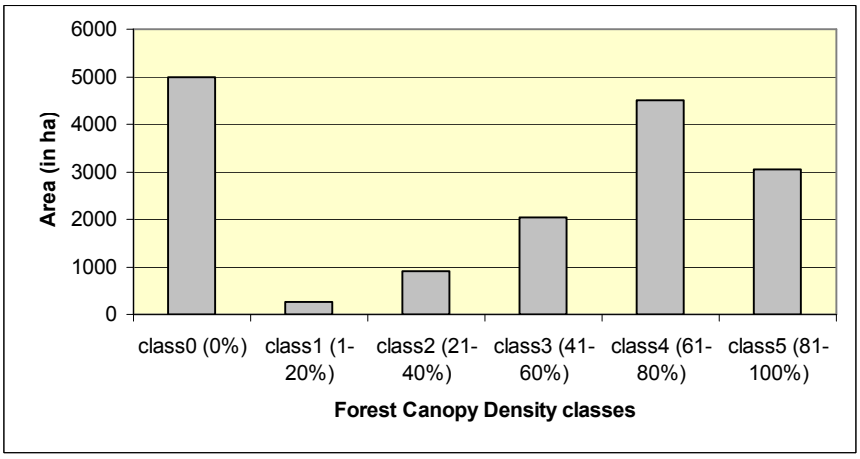


Figure 3-2. Forest Canopy Density class distribution in 1988

3.1.2 Forest Canopy Density in 1992

Figure 3.4. shows that non-canopy class has covered the largest area that is about 5666 ha in the year 1992 among all six classes. Figure 3.3 canopy density map clearly shows the spatial distribution of canopy density classes. Furthermore, canopy density in class1 (1-20%), class2 (21-40%) and class3 (41-60%) were increased by 362 ha, 1485 ha and 2961 ha respectively compared to 1988. Whereas class4 (61-80%) and class5 (81-100%) has decreases in comparison with 1988 from 4513 ha to 3328 ha and 3056 ha to 2295 ha respectively. There is a clear pattern of decreasing of canopy density by 26.3% in class4 (61-80%) and by 24.9% in class5 (81-100%) when compared with canopy density of

the year 1988 (Appendix C, Table 16). This suggests that forest degradation occurred in the period 1988-1992.

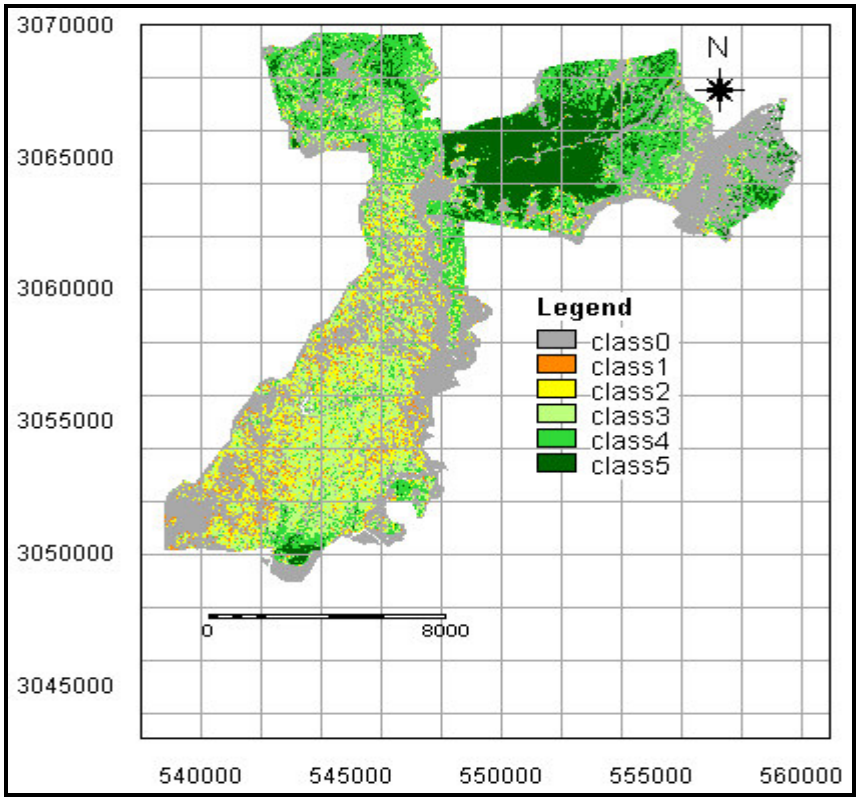


Figure 3-3. Forest Canopy Density Map of 1992

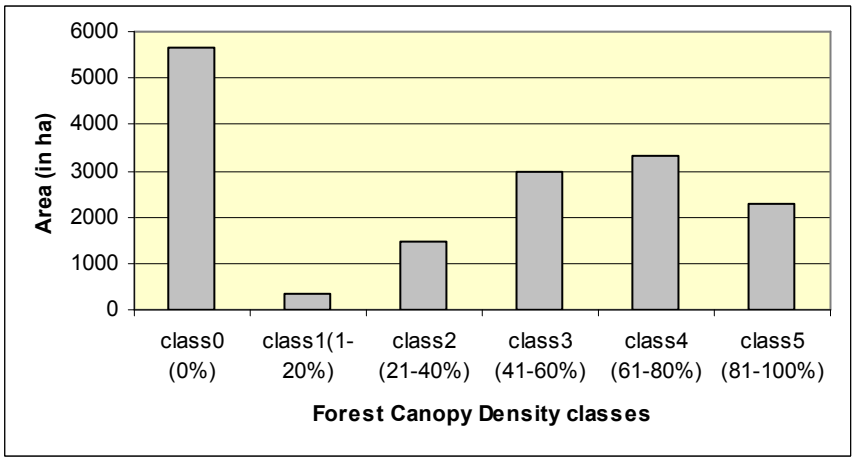


Figure 3-4. Forest Canopy Density class distribution in 1992

3.1.3 Forest Canopy Density in 2001

Figure 3.6 shows that about 4939 ha area was covered by FCD class4 (61-81%) whereas about 138 ha area was covered by class1 (1-20%) in 2001. Similarly FCD class2 (21- 40%) and class3 (41- 60%) decreased from 1485 ha to 853 ha (42.5 %) and 2961 ha to 2208 ha (25.4%) respectively. However, about 3242 ha area in class 5 (81 - 100%) was increased with in the three years (see Appendix C, Table 16 for more detail). On the basis of these figures, the process of degradation has been reversed over the past decade.

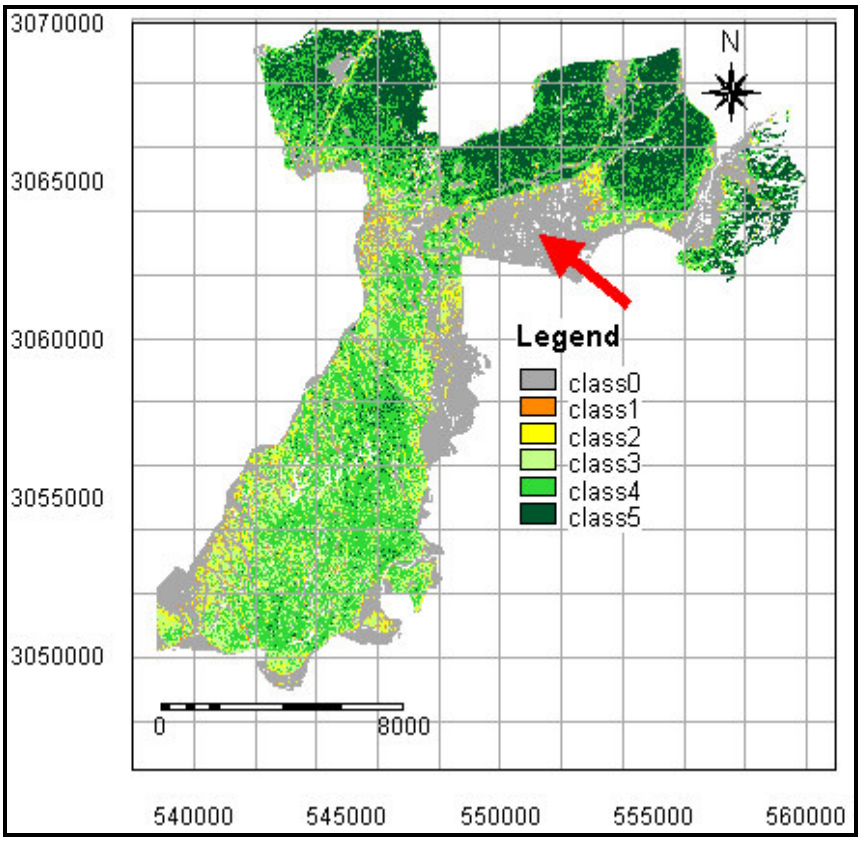


Figure 3-5. FCD of 2001 (Red arrow indicating a remarkable loss of forest canopy density somewhere between 1992 and 2001)

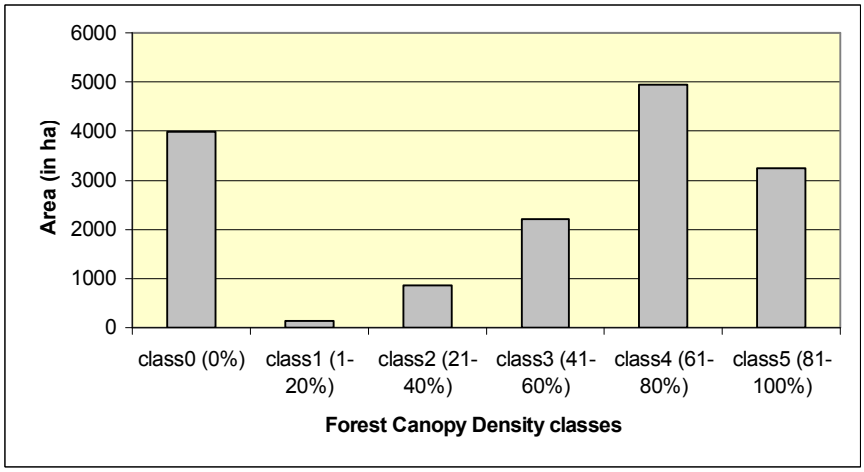


Figure 3-6. Forest Canopy Density class distribution in 2001

3.1.4 Comparative analysis of forest canopy density change from 1988 to 2001

The estimation of forest canopy density in the Figure 3.7 revealed that there had been major changes in the degraded canopy density class1 (1-20%) and class2 (21-40%) during the 1992, the differences in forest area cover being 61% and 42.5% respectively. Some areas have remained more or less the same with respect to canopy density classes, but some areas have shown dramatic increment in canopy density. A dramatic positive change is in the class4 (61-80%) and class5 (81-100%) (moving from

the 3328 to 4939 ha and 2295 to 3242 ha respectively) by 48.6% and 41.3% respectively has occurred during 1992 to 2001 (Appendix C, Table 17). Whereas some areas has decrease of canopy density mainly occurred at the edge of forest and around the new settlement during 1992-2001. It is interesting to note that there is no remarkable major change in canopy density classes between the years 1988 to 2001. The forest canopy density slightly loss in lower density canopy classes (class1 and class2), whereas rest of other higher density classes (class3, class4 and class5) have increasing steadily in the year 2001 in comparison with 1988. It also shows the change in forest condition is not dramatically observed in 2001 when compared with 1988.

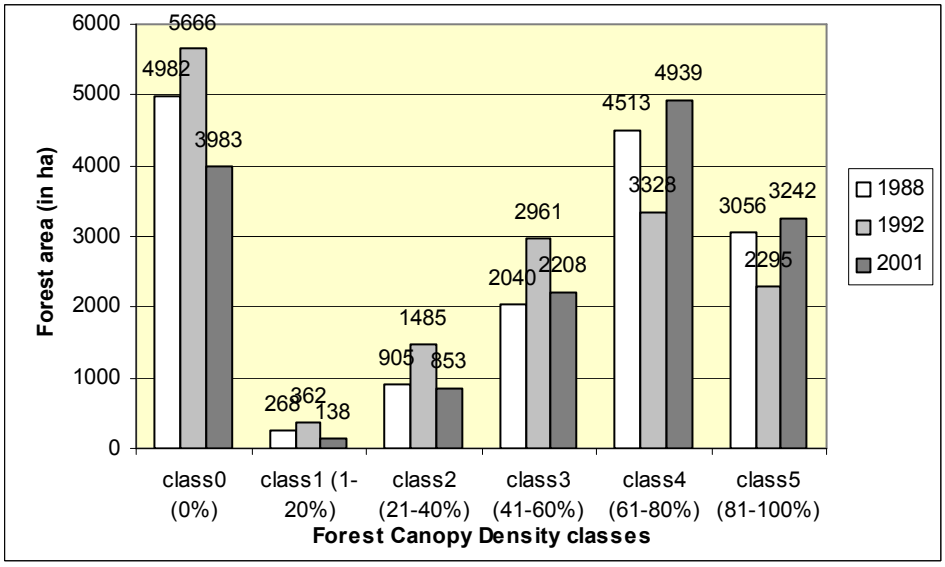


Figure 3-7. Forest Canopy Density Class distribution in 1988, 1992 and 2001

Degraded forest canopy class was the most dominant canopy cover. Figure 3.8 showed that there was a little (3.3%) change (decrease) in the overall area of forest cover from the 1988 to 1992, but the forest area was increased by 9.2% between 1992 and 2001. Whereas, only 5.5% was increased in between 1988 to 2001. Figure 3.9 canopy density change map from 1988 to 2001 also indicated that remarkably negative change in canopy density had clearly shown in government plan clear felled area and some area near to the settled area.

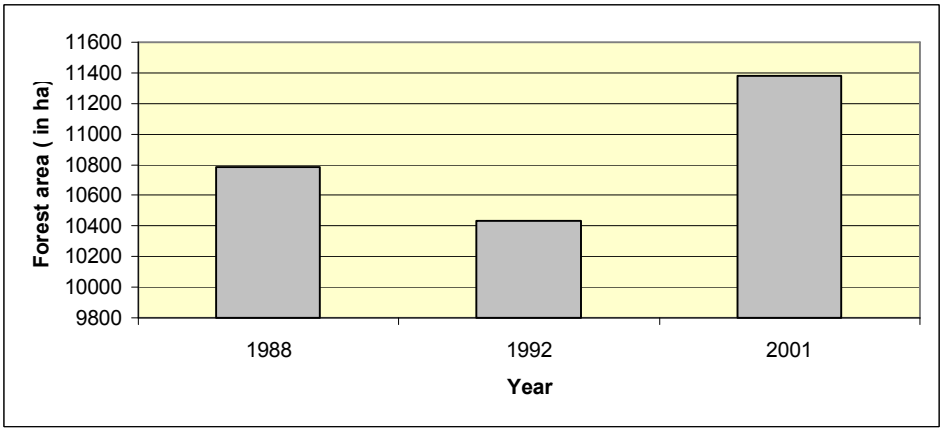


Figure 3-8. Graph shows the total forest cover area (in terms of FCD) in 1988, 1992 and 2001

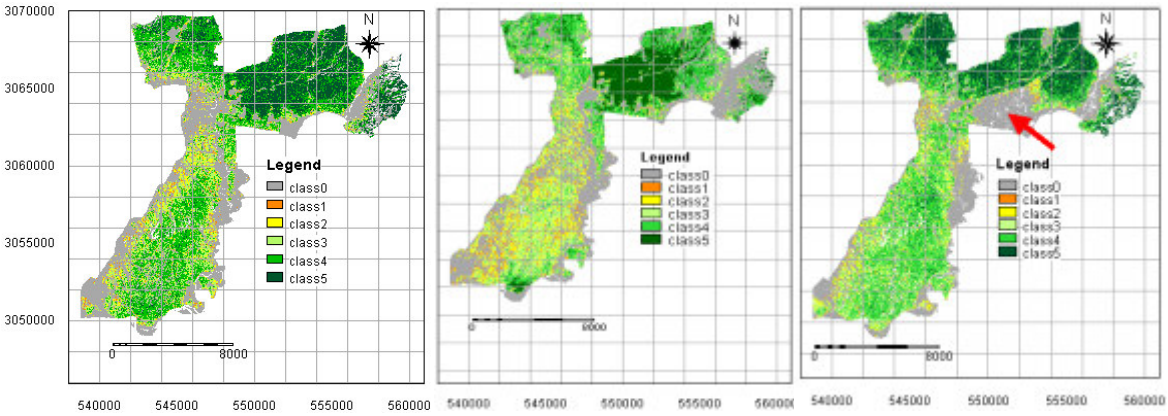


Figure 3-9. FCD maps 1988 (left), 1992 (middle) and 2001 (right) indicating spatial location of canopy density.

FCD map of 1988 (Left), 1992 (middle) and 2001 (right). These three time series maps derived from TM imagery shows forest cover well enough to identify not only the canopy density class but also the spatial location (red arrow on the right map showing clear felled area between 1992 to 2001) where and to what extent the canopy density has been changed (Figure 3.10 for further detail).

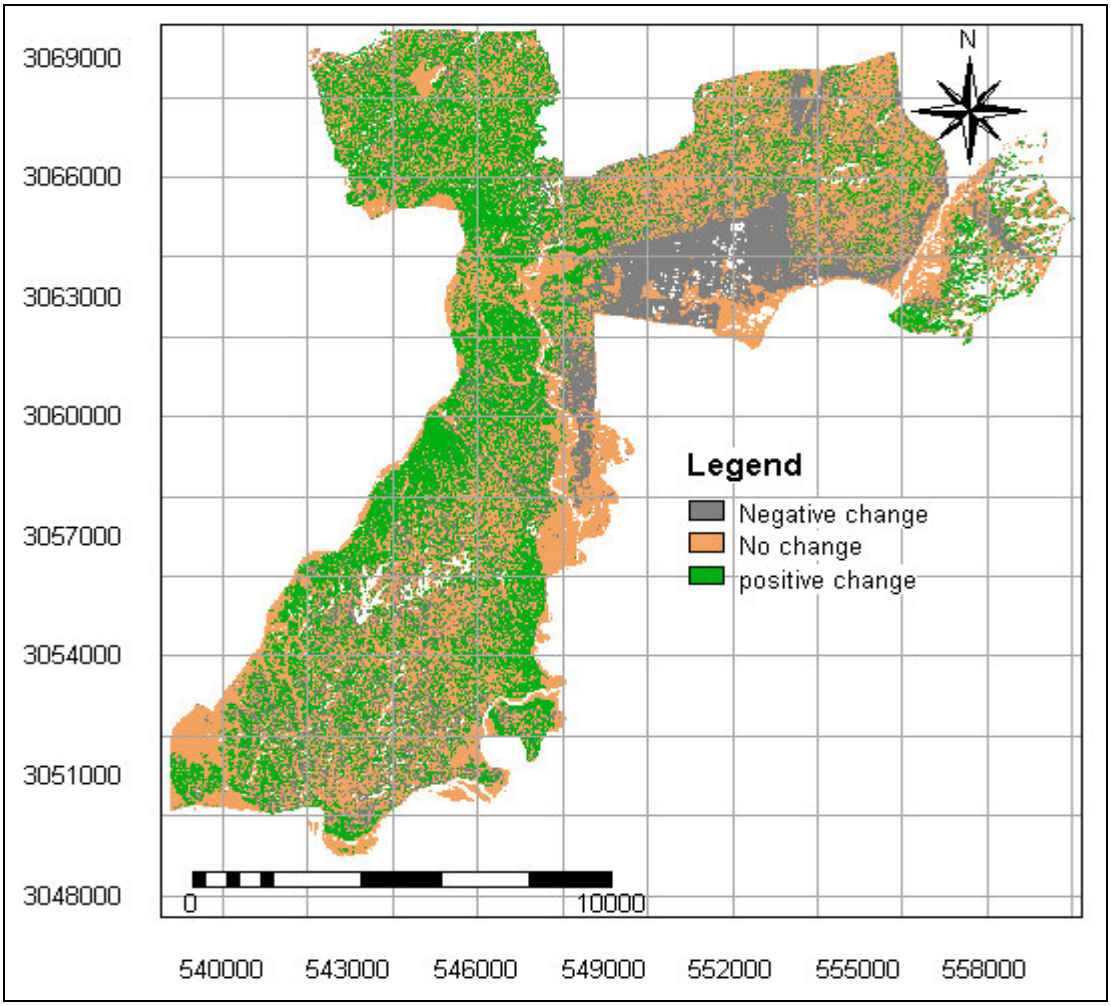


Figure 3-10. Forest Canopy Density change map. Change from 1988-2001 in the study area

3.2 Forest Canopy Density and Accuracy Assessment

The classification accuracy has been evaluated using data recorded from sixty-nine different sample plots in 2001 (see Figure 3.12). The sample point (n=69) has been distributed in the different forest canopy class. The per pixel forest canopy density value have been analysed, on the basis of the comparative results of the statistical analysis and FCD Mapper classifier. The FCD Mapper calculates canopy density percentage (intervals of 10 %) in eleven classes (by default) from class 0 (no canopy) to class 10 (100 % canopy). However, the field data were collected as three canopy classes (e.g. non forest, open forest and closed forest). Therefore eleven canopy classes were merged into three canopy classes for this analysis. Accuracy assessment was carried out using field sample point of 2001 and crossed with FCD map of 2001 (Figure 3.11). The results (at 95% confidence limit) indicate that the overall mapping accuracy has been 71 %. The forest canopy density was calculated in terms of area in hectare. The accuracy map and matrix is shown in Figure 3.11 and Appendix C, Table 19.

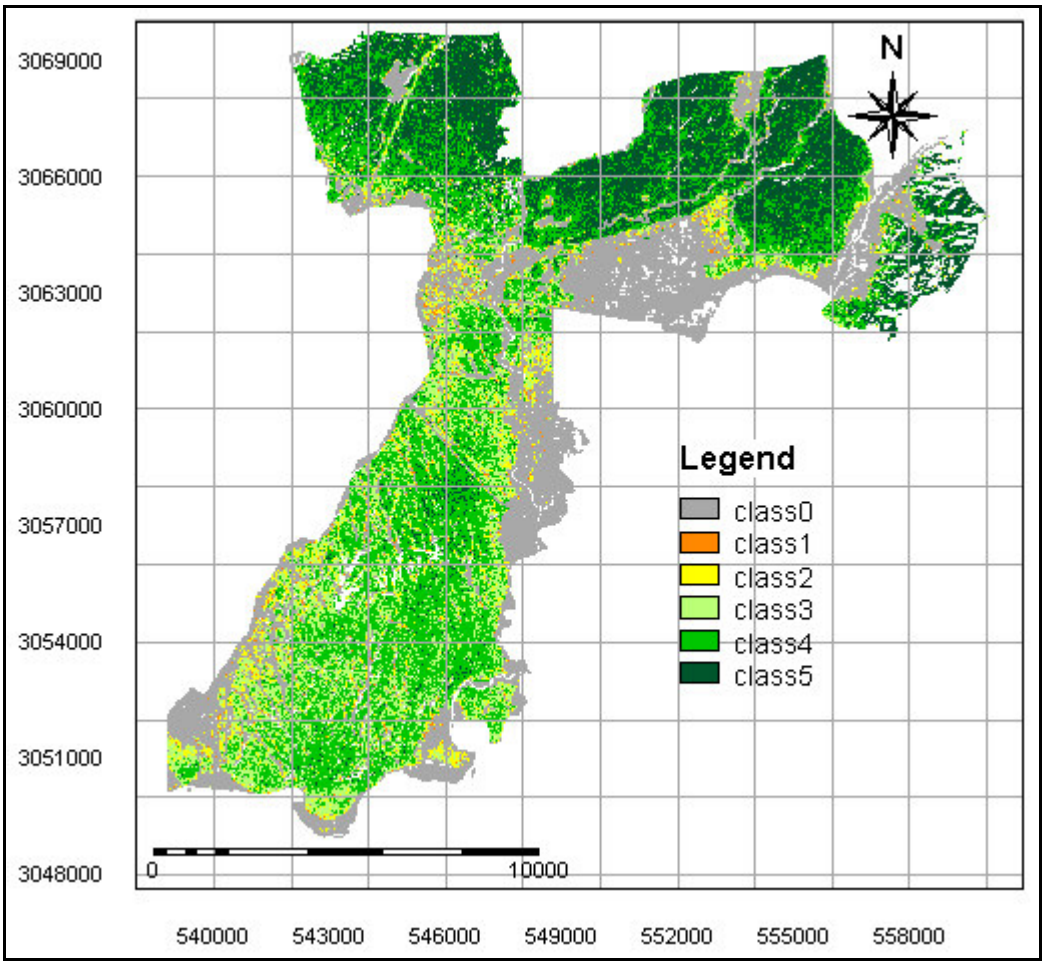


Figure 3-11. Forest Canopy Density Map 2001 using for accuracy assessment with 2001 ground truth.

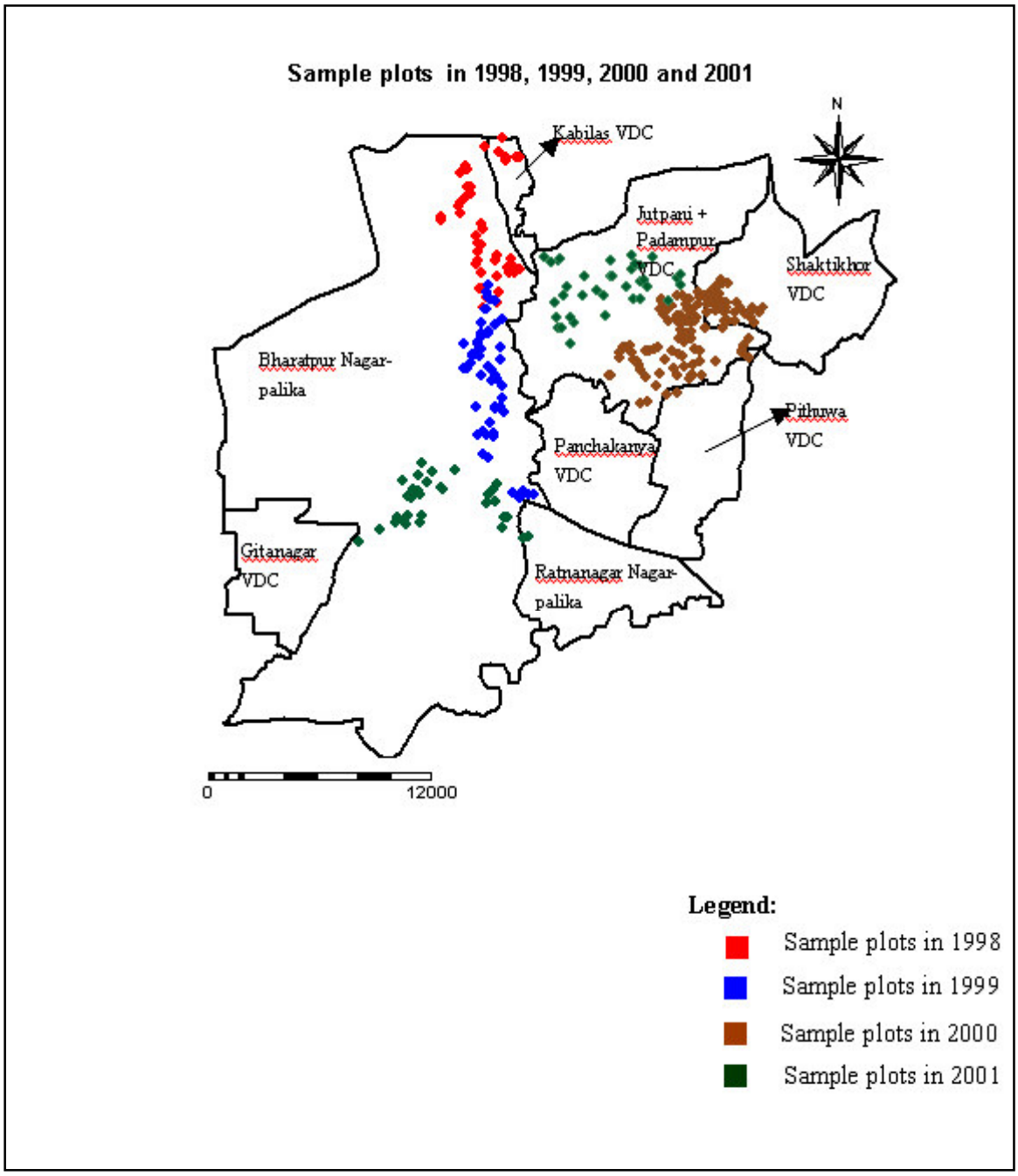


Figure 3-12 VDCs boundary with sample plots. Source data from 1998: A Field Work Report on Forest Inventory in Chitwan District, Nepal, 1999: A Field Exercises Report by FOR 3 and FRD 3 Participation, 2000: Assessment of supply and demand of fuel wood and timber in Chitwan district, Nepal, 2001: A Field Work Report by FSD.3 participation, Forest Science Division ITC, Enschede

3.3 Analysis of factors possibly affecting forest canopy density

The analytical data result showed that the frequency of forest canopy density was significantly correlate to the total number of trees, mean DBH, tree height, distance from road, river and settled area (Descriptive statistics in Appendix A, Table1). Some of the obviously known relationships, like total number of trees with canopy density do not need further discussion (for more detail see Appendix D, graph 1 and 2, figure 1, 2, 3 and 4). The objective here is to give a general overview of the possible influence of distances from road, settled area and river on the canopy density over a period of 13 years. This part describes and discusses the relationship between canopy density and distance parameters that were generated by GIS techniques and some secondary data collected from the Chitwan district

3.3.1 Relationship between forest canopy density and distance from settled area to forest

Figure 3.13 and 3.14 summarize the canopy density change (in terms of pixels) in relation to the distance from the settled area to forest. The correlation shows the relation between canopy density and distance from the settled area (Appendix A, Table 1). Table 1 summarizes the statistically significant result. Close by the settled area (<500 meter), canopy density was much lower than in places further away. Further, Figure 3.13 shows that within each distance class the canopy density occupying pixels changed negatively with in all classes up to 3000m distance. It clearly shows the human influences on forests within 3 km distance. Figure 3.14 also shows the relation between each canopy density class and the distance class: distance from settled area. Although high-density classes have showed some positive change over the period, the lower canopy density classes (1-20% and 21-40%) within 2000m distances from settled area were affected more and converted to other canopy classes (Appendix B, Table 6). It shows the sparse vegetation forest cover area close to the settled area (within 2 km) could be vulnerably encroached by the local people. However, some positive change in high-density class suggests that afforestation and conservation programme seems to be successful within the easily accessible range. Similarly, high canopy density classes (untouched forest) could possibly be difficult to encroach may be due to effective protection, under direct supervision of community members, terrain, slope, unfertile soil or water scarcity in comparison with low canopy density classes.

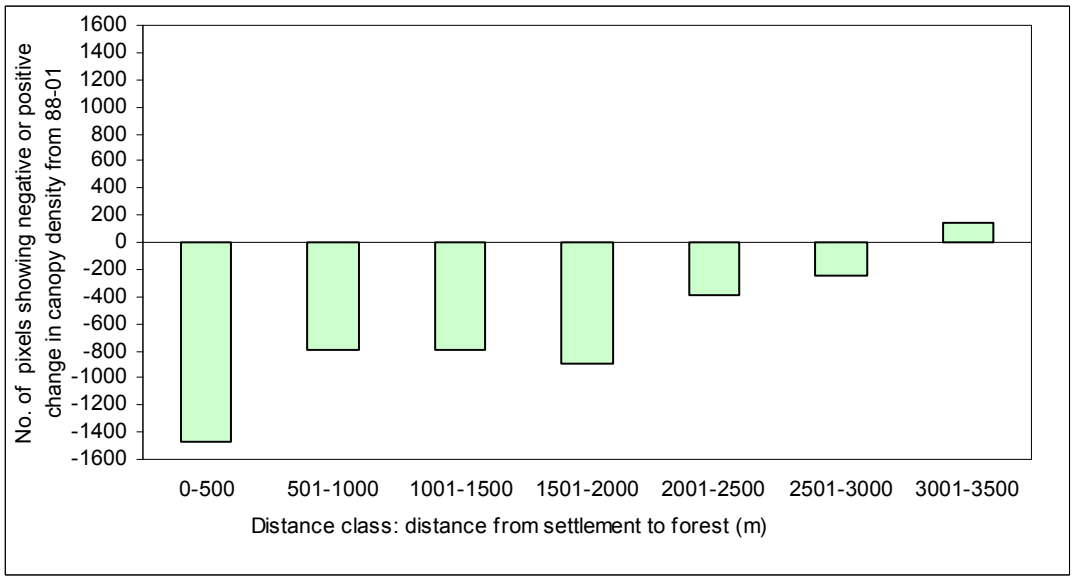


Figure 3-13. Change in Forest Canopy Density with distance from settled area to forest from 1988-2001 (Showing by no. of pixels, showing decrease or increase in canopy density)

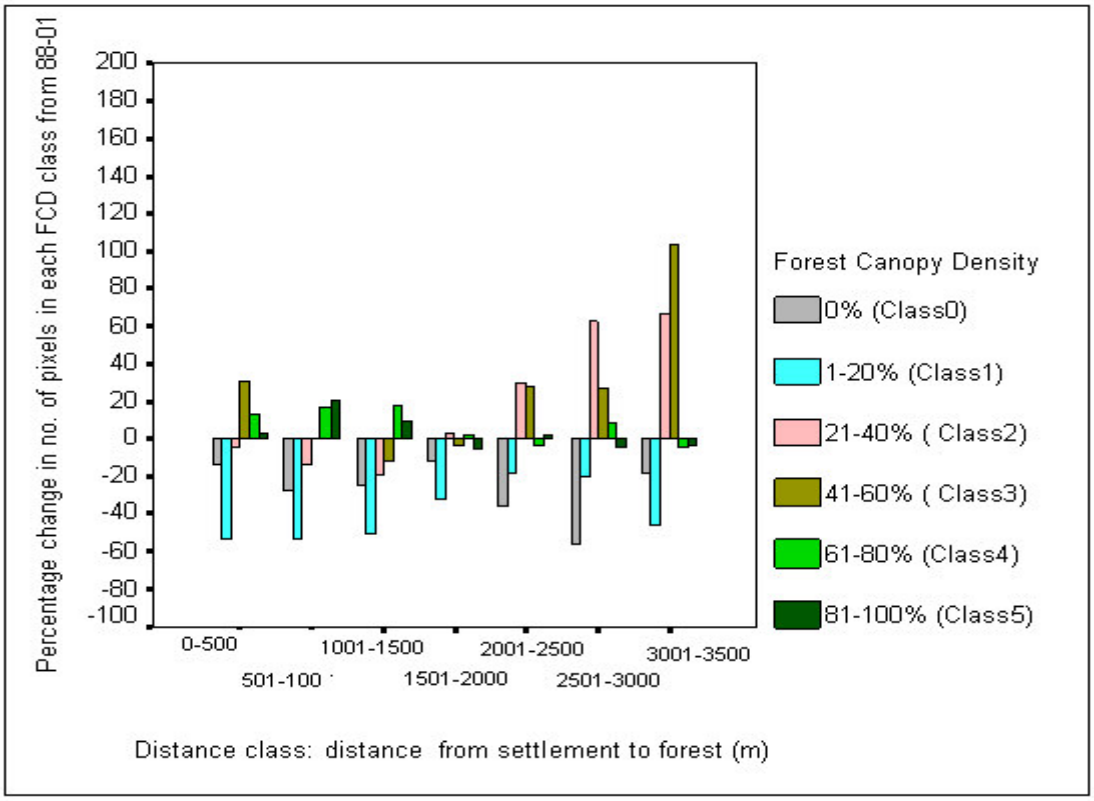


Figure 3-14. Percentage change in number of pixels in each FCD class in relation to distance from settled area to forest from 1988-2001.

3.3.2 Relationship between forest canopy density and distance from road to forest

Figure 3.15 and 3.16 clearly indicate the relationship between canopy density changes with distance from road to forest. Statistically we also could not prove a significant relationship between distance to road and canopy density (Appendix A, Table 1). Further, Figure 3.15. Indicates that close to the road (up to 1000m), canopy density measured by pixels is unexpectedly increase. Interestingly, at distances more than 1500m from road, canopy density in terms of pixels in each distance class was always negatively changed. But, Figure 3.16 shows that in case of percentage change in no. of pixels in each FCD class1 (1-20%) and class2 (21-40%) was remarkably negatively changed by 108% and 165% respectively from 1988 –2001 (Appendix B, Table 9). That also indicate canopy density is heavily degraded in lower density classes within close distance from road to forest. More conservation and rehabilitation strategy has been successfully implemented within close distance with road because of accessibility, which shows forest canopy density (in terms of pixels) is mostly positively changed within close distance from road between the periods 1988-2001 (Appendix B, Table 8). Though percentage change in no. of pixels in some FCD classes shows positive change than far from the road (figure 3.16) , the change in total pixels has been mostly negative (see figure 3.15).

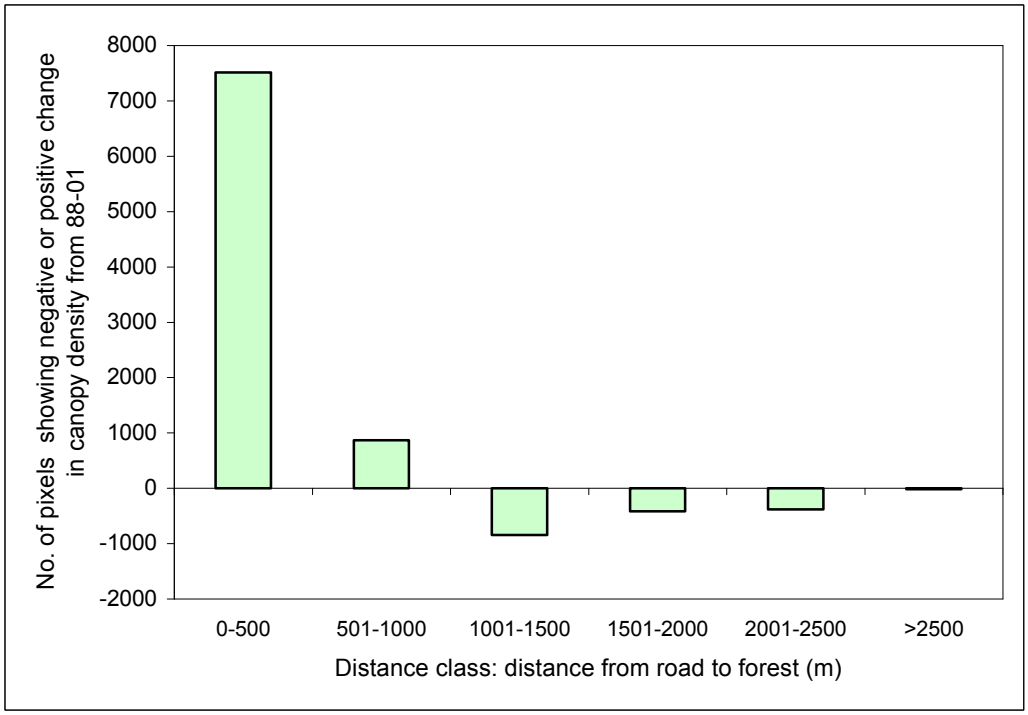


Figure 3-15. Change in Forest Canopy Density with distance from road to forest from 1988-2001 (Showing by no. of pixels, showing decrease or increase in canopy density)

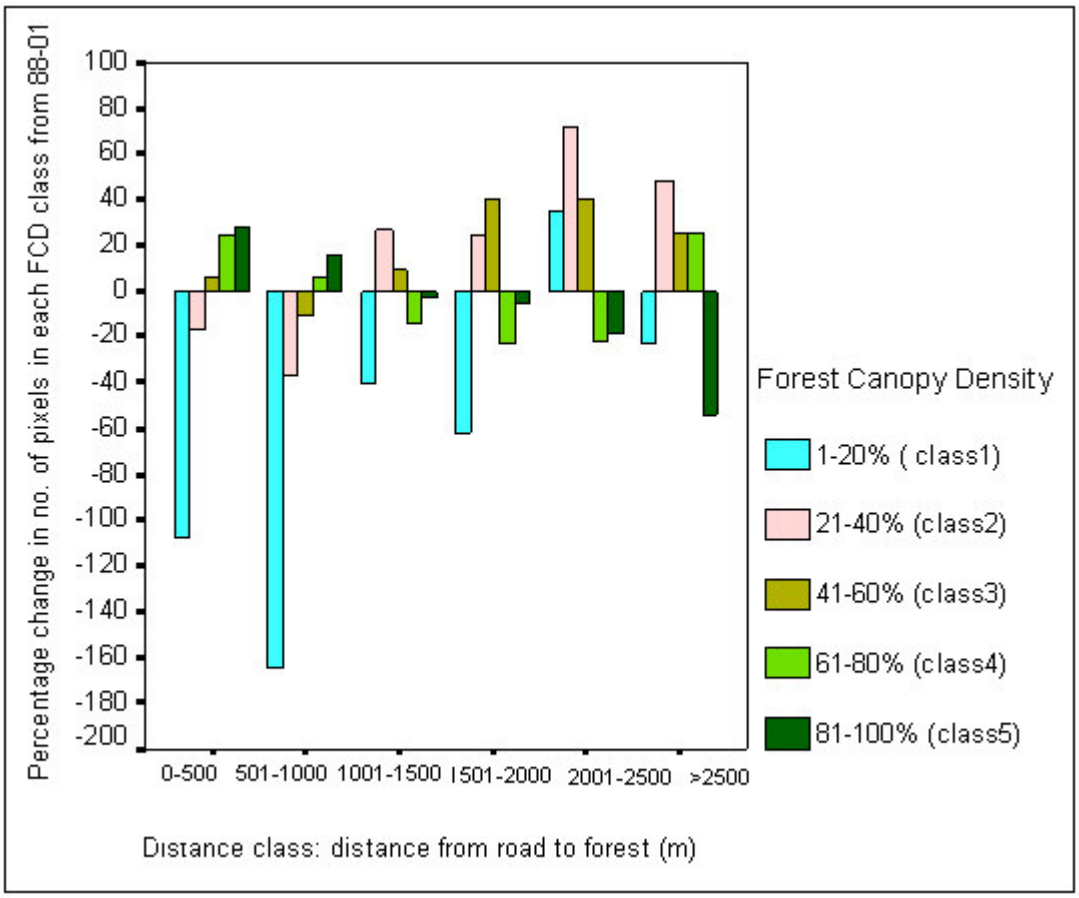


Figure 3-16. Percentage change in number of pixels in each FCD class in relation to distance from road to forest from 1988-2001

3.3.3 Relationship between forest canopy density and distance from river to forest

Figure 3.17 and 3.18 shows forest canopy density related to the distance from the river. It was observed that canopy in lower density classes (class1 and class2) is heavily more reduced within close to river than the farther away. The distance from river and the canopy density had a statistically significant relation observed in this analysis (Appendix A, Table1). Close distance to river clearly shows in figure 3.18 a remarkable effect on canopy degradation, especially in lower classes (class1 and class2). Though in some higher density classes, the canopy density has positive change between the periods within distance of 500m from river, canopy density in class1 (1-20%) is heavily reduced by 54% (Appendix B, Table 12). It is interesting to note that forest canopy density (in terms of pixels) relatively increased within 500m distance from river in 2001 compared with 1988 (Appendix B, Table 11). However, in the lower canopy density classes, canopy class1 (1-20%) and class2 (21-40%) decreased closer distance to river (Appendix B, Table 12).

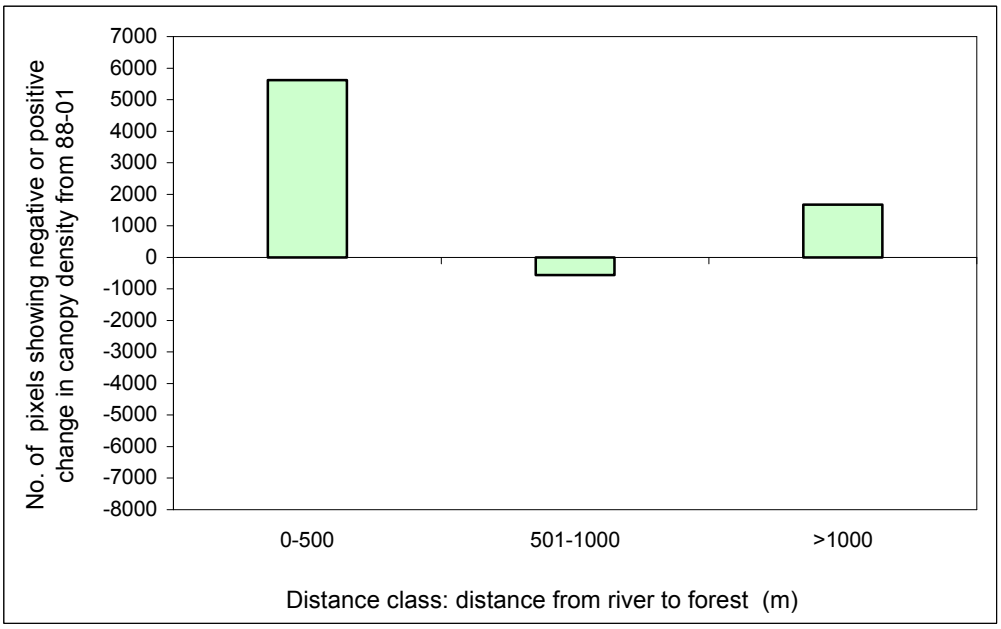


Figure 3-17. Change in Forest Canopy Density with distance from river to forest from 1988-2001 (Showing by no. of pixels, showing decrease or increase in canopy density)

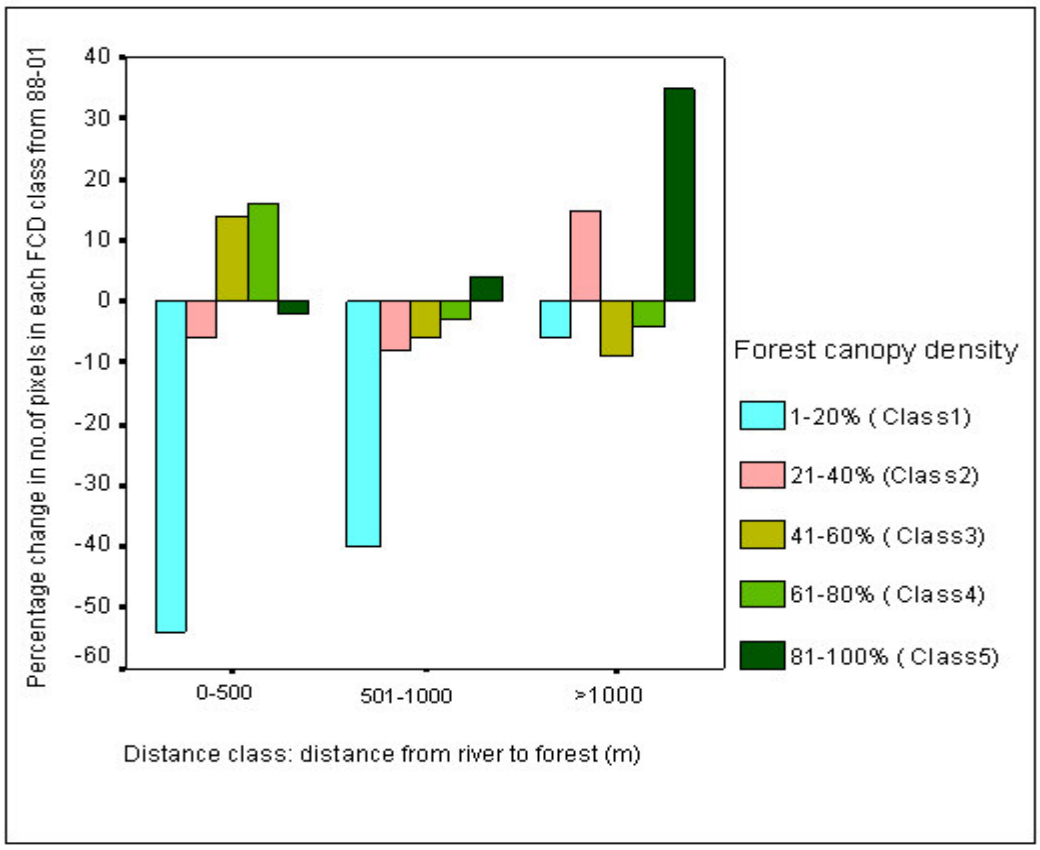


Figure 3-18. Percentage change in number of pixels in each FCD class in relation to distance from river to forest from 1988 to 2001

3.4 Relationship between population change and total forest cover area

The relationship between population and total forest area was analysed within nine VDCs out of 38 including two Municipalities due to data limitation. As shown in Figure 3.19. there is an increasing pattern of population from 1988 to 2001. The population in 1988 was about 135318 whereas in 2001 it has reached up to 175943 (Appendix B, Table 15). If we compare the number of inhabitants and the canopy cover percentage we could not traced any relationship between these parameters. Data set at available generalisation could not establish any relationship between canopy density and number of inhabitants. Further, Figure 3.19. also shows that if we assume in the year 1988 the population, forest and forest ha/person all are equal (100), and then it was observed population has increased steadily up to 2001 whereas forest canopy density occupying area (in ha) became decreased in 1992 but it is again increased in 2001. Forest ha/person on the other hand, has become decreased slowly from 1988 to 2001. Interestingly; it was observed that there was clearly forest area increasing, however forest ha/person still decreasing. So there is no any such kind of relationship observes in this analysis.

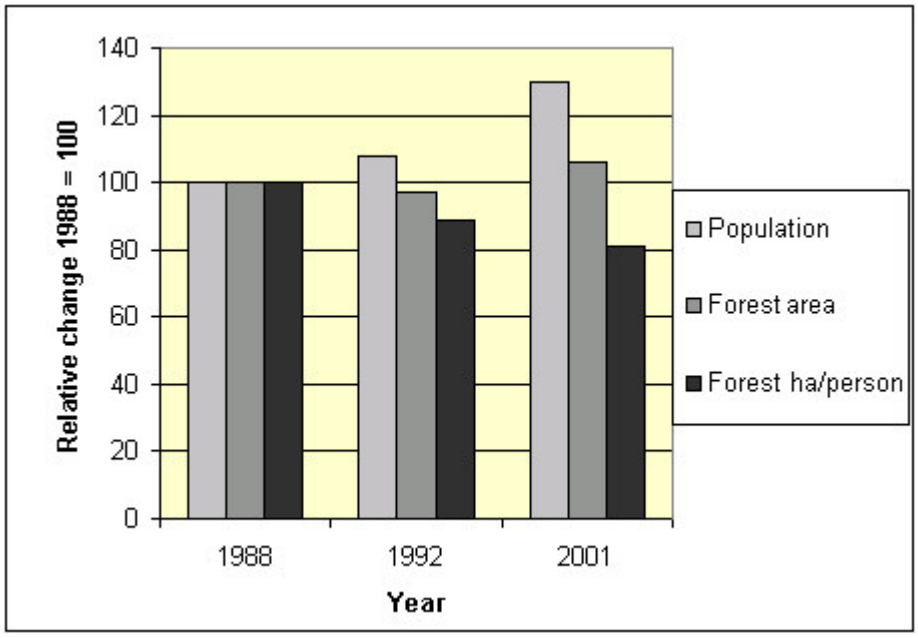


Figure 3-19. Relative change in Population, forest area and forest ha/person in 1988, 1992 and 2001 (1988 data = 100).

3.5 Possible effect of human disturbances on forest canopy density

This section of result describes and discusses the affecting factors of forest canopy density that were recorded in the past. The objective of this analysis is to give a general overview of the effect of anthropogenic factors (human disturbances) on forest canopy density. For this, two data sets collected form two different areas of Chitwan district has been chosen. Forest canopy density and sign of logging, debarking, sign of fire, path, grazing, girdling, coppicing and stumps disturbances were estimated in 69 sample plots.

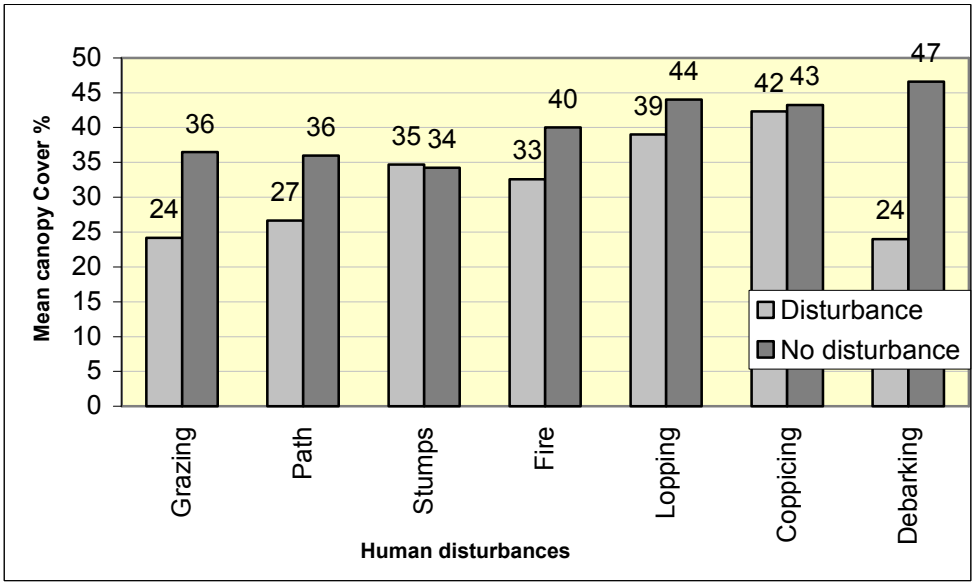


Figure 3-20. Numerical value on the top of graph shows the mean canopy cover % relation with disturbed and undisturbed area (site 1)

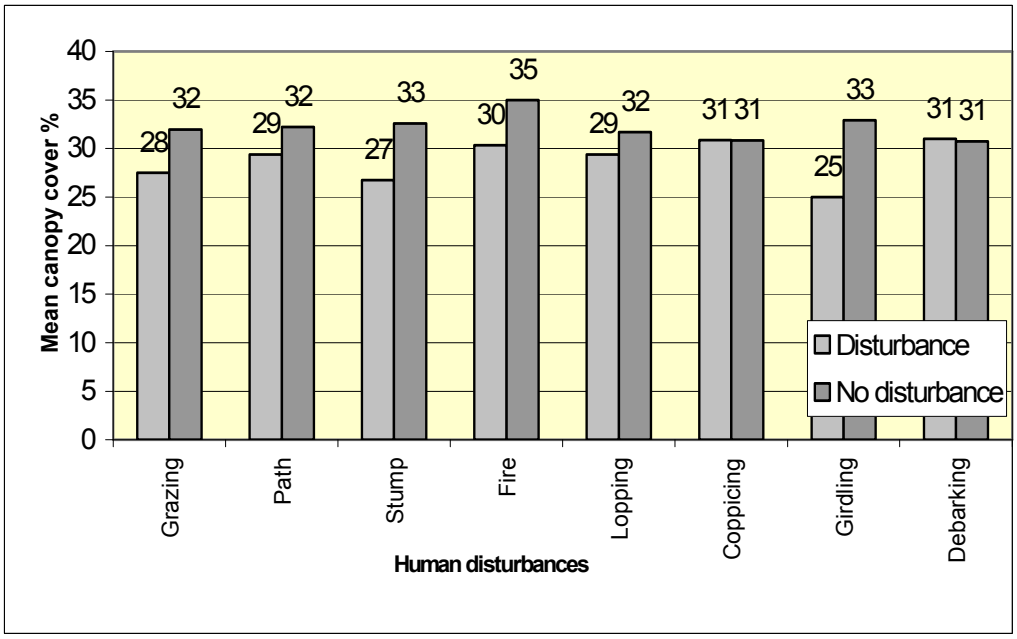


Figure 3-21. Numerical value on the top of graph shows the mean canopy cover % relation with disturbed and undisturbed area (site 2)

The area under high human interference had comparatively low canopy density than low human interference as shown in the graph Figure 3.20. and Figure 3.21. Numerical value on the top of each bar graph shows the clear picture about the canopy cover percentage relation with human disturbances. It also indicates that area having human disturbances relatively low canopy cover % than undisturbed area. The test statistics (nonparametric Kruskal –Wallis Test) of the relationship between canopy density and human disturbances like logging, debarking, sign of fire, path, grazing, girdling, coppicing and stumps within the sample plot was tested at the significant level ($p =< 0.05$). Two variables i.e.

path and sign of fire were statistically significant, but the test failed to detect significant relation for the other factors (Appendix A, Table 4b).

3.6 Relationship between species composition and forest canopy density

Based on canopy dominant species composition, altogether eight forest types were classified. These were the association of *Albizzia–Myrsine*, *Albizzia–Trewia*, *Albizzia odoretissima*, *Dalbergia sissoo*, mixed broad leaved, *Myrsine capitellata, Trewia nudiflora* and *Shorea robusta*. A wide variation in the canopy density of different canopy dominant species (Graph below, Figure 3.22) was found. The canopy density of *Dalbergia sissoo* and *Trewia nudiflora* was found to be highest compared with other dominant species types followed by *Albizzia odoretissima, Albizzia–Myrsine* and Mixed broad-leaved forest. While *Myrsine capitellata* dominated canopy areas have least canopy density. Descriptive statistics (Appendix C, Table 18.) shows that these forest types having corresponding mean canopy cover percentage statistically highly significance (p= < 0.05 level). However, test fail to detect significance difference within each forest type because of some canopy dominant species or forest types belong very few sample plots.

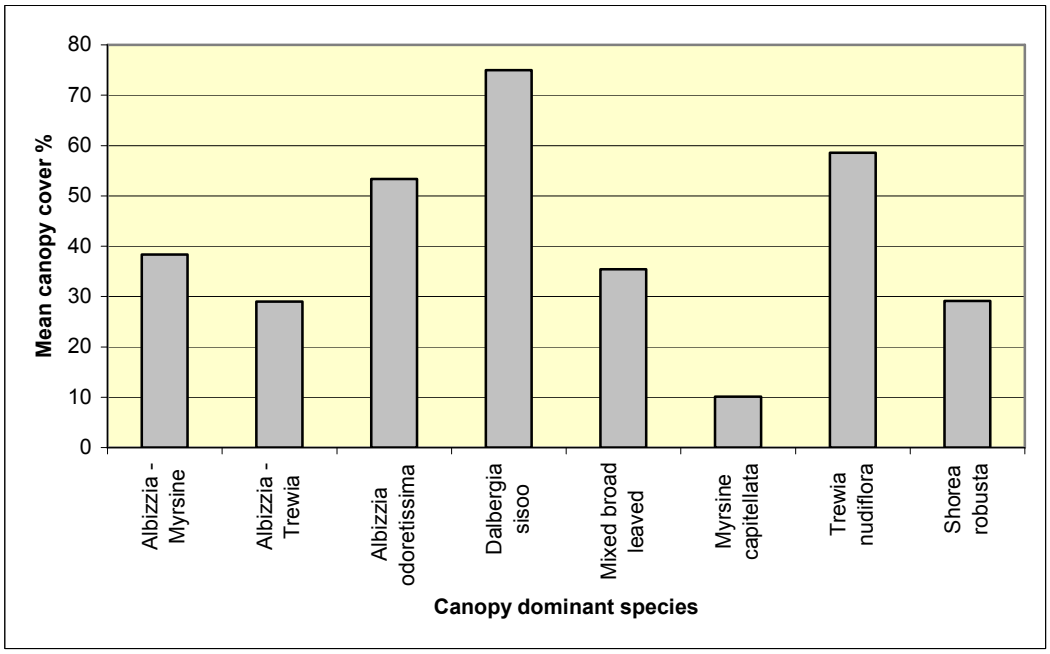


Figure 3-22. Graph shows the relationship between canopy dominant species (forest types) and forest canopy cover.

4 DISCUSSION

Through the integration of Remote Sensing, GIS and ground data, an assessment on the forest canopy density and possible factors affecting canopy density has been executed. "Multispectral remote sensors has capacity to estimate biomass of plant materials by non-destructive way. Landsat TM sensor of bands red and near infrared light reflected from plants is a function of the quantity of photosynthetically active compounds present, which is in turn related to overall plants biomass"(Wilkie, 1996).

4.1 Spatial and temporal change in forest canopy density

The image analysis showed that the forest degradation and deforestation was more prominent than the conservation and rehabilitation between 1988-1992. It shows the forest condition was comparatively of poorer quality in 1992 than the previous and later years. This results may be due to the method used. In particular, seasonality is one of the important factors, which could influence biomass calculation of green vegetation and image interpretation. The image of May 7th 1992 has comparatively less vegetation than that of October of 1988 and 2001, because of the leaf emergence period of Sal tree is just starting in that season and green pigment in the leaves has not fully developed. The result has been also supported from calculated NDVI and SAVI of different years. This can be clearly seen in the vegetation maps of different years (Figure 4.1 and 4.2). (Roy *et al.*, 1996) from Manual of Remote Sensing, Vol. II, American Society of photogrammetry quoted that combination of Landsat TM FCC bands 432 is one of the standard visual techniques to interpret vegetation. So, Landsat TM FCC of band 432 of different years were used to visual image interpretation, and to understand the vegetation status of the study area.

As has mentioned in Chitwan District fieldwork reports, (ITC 1998, 1999, 2000 and 2001) that the democratic movement of 1990 has brought an unstable situation in every sector of Nepal. This was the time where people had free access to illegal felling, logging and encroachment within forest and some unstable political parties created this situation in the study area (Flowchart 4.1 for more detail). On the contrary, between 1992-2001 forest was increased and it seems to be more conservation and rehabilitation programme had been launched.

In Nepal, the Ministry of Forest and Soil Conservation have been done forest management practice through promisingly focused on CF and private forestry program since 1988 (MPFS, 1988). The MPFS has emphasized and focused on people participation in forest management by decentralisation the authority, capacity building of forestry institutions and develop the appropriate legal and policy framework (MPFS, 1988). Further, the Terai forest of Nepal highly prioritised and intended for management through CF, LHF and proper operational forest management plan (HMGN, 1993). Government has launched many other supportive programs under HMG/N the ninth five-year national plan. One of its components is conservation, protection and production increment of forest products in national forest. Further, the concept of Wildlife Reserve and National Park area conservation, management and expansion for conserving and preserving of bio-diversity has been extended under the ninth

five-year national plan (HMGN, 1998). Buffer zones management and promoting IGA, employment generation through active people's participation in forest management has been potentially implemented. Additionally, the government in this period has implemented other training and supportive activities for management of forest to promote the livelihood of rural communities. These programs also supports led to changed forest conditions and quality as well. Apart from this, many NGOs, INGOs and development work organisations such as DADO, VDCs, Women Groups and Human Resource Development organisation are actively contributing to the management of forest in this area (Flowchart 4.2 and Flowchart 4.3). Their technical, financial and moral support improve the livelihood of rural people, which in turn reduces their dependency on national forest. That could be another possible reason, which has supported the forest condition, its coverage and canopy increment between the periods of 1988 to 2001. The results of this analysis are also supported by previous studies. Nepal (1999) found that the forest converted to degraded land was relatively high between 1988 -1992. Similarly, Requene (2000) found some secondary and degraded forest was reduced from 7% to 4%, 18% to 7% respectively in that period. Moreover, Maharjan (2001) observed almost high forest canopy density classes converted to lower and in non-forest canopy class due to deforestation and forest degradation, resulted socio-political situation in this period.

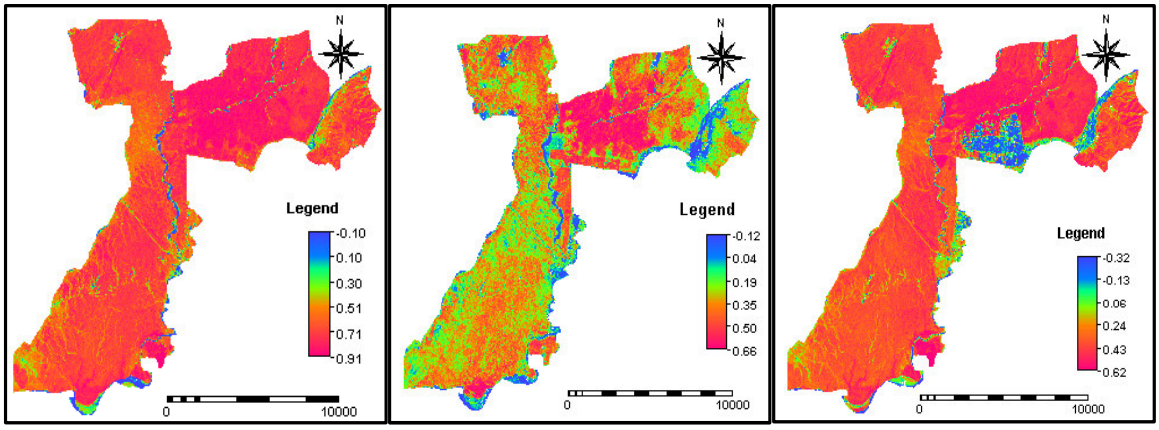


Figure 4-1. SAVI Map of 1988 (left), 1992 (middle) and 2001(right)

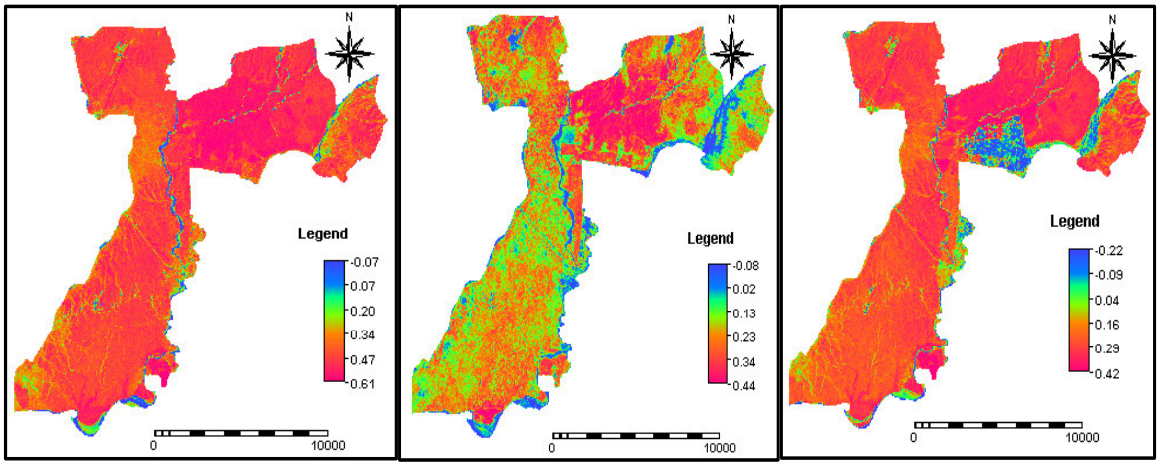
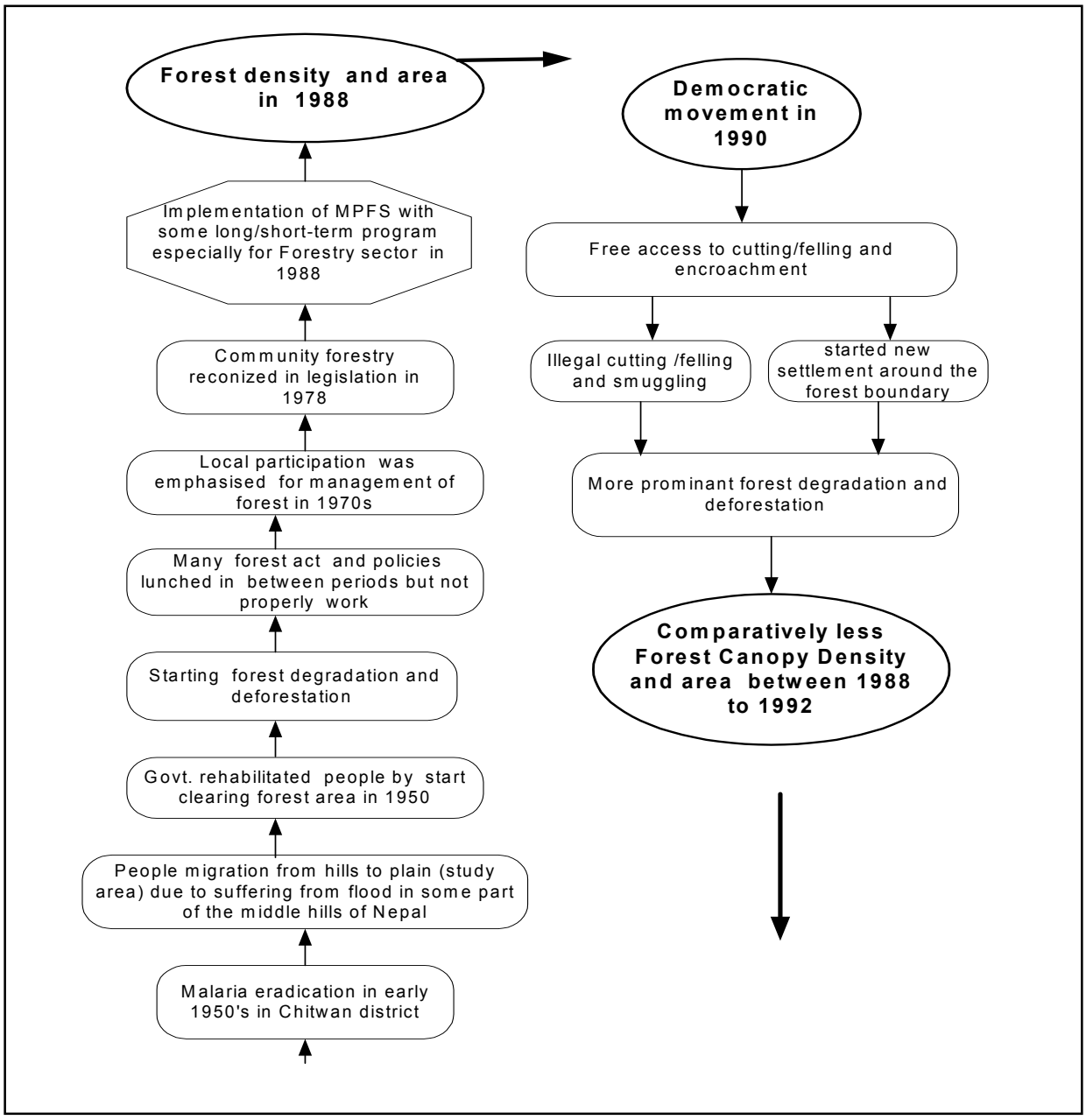
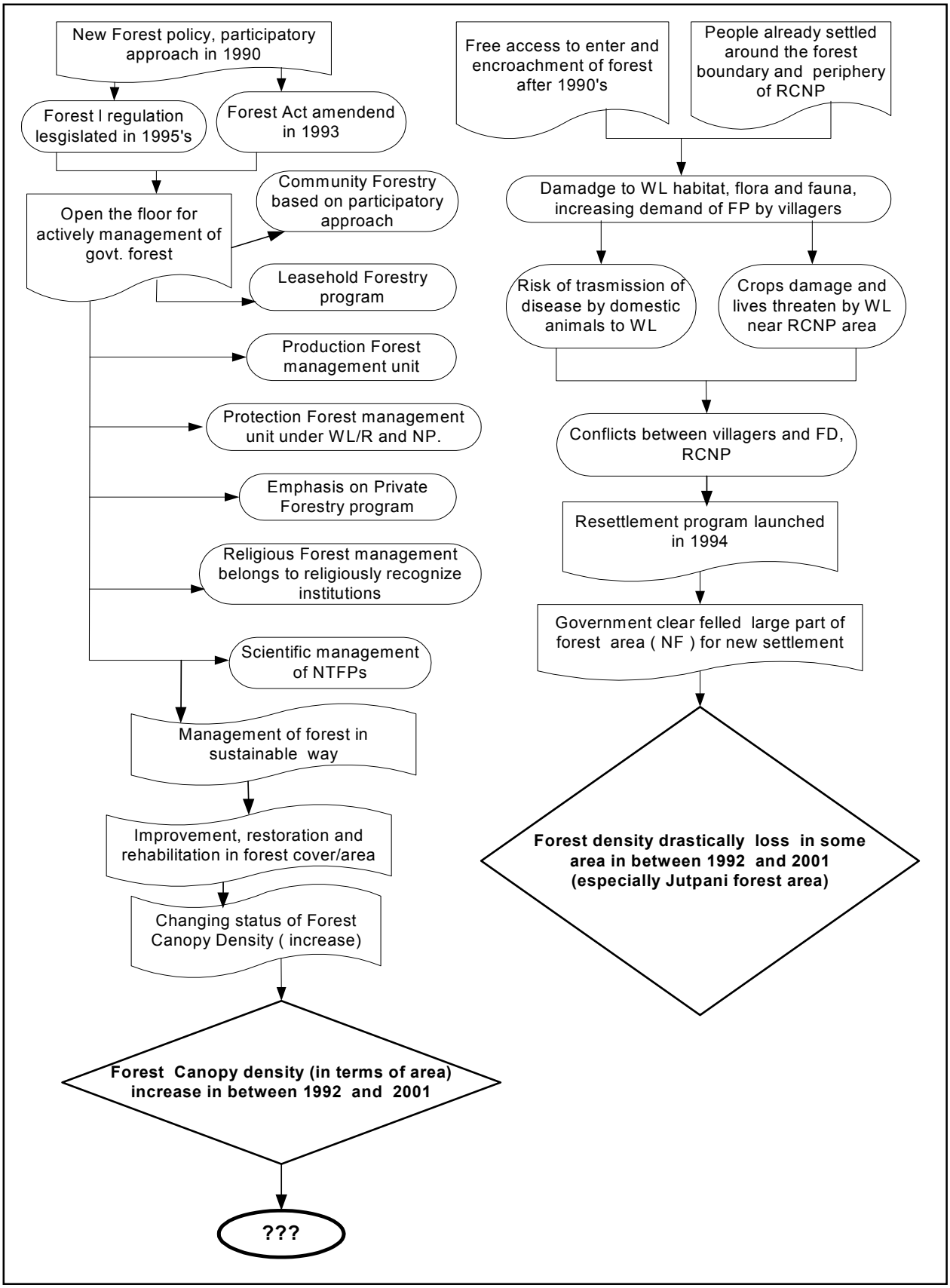


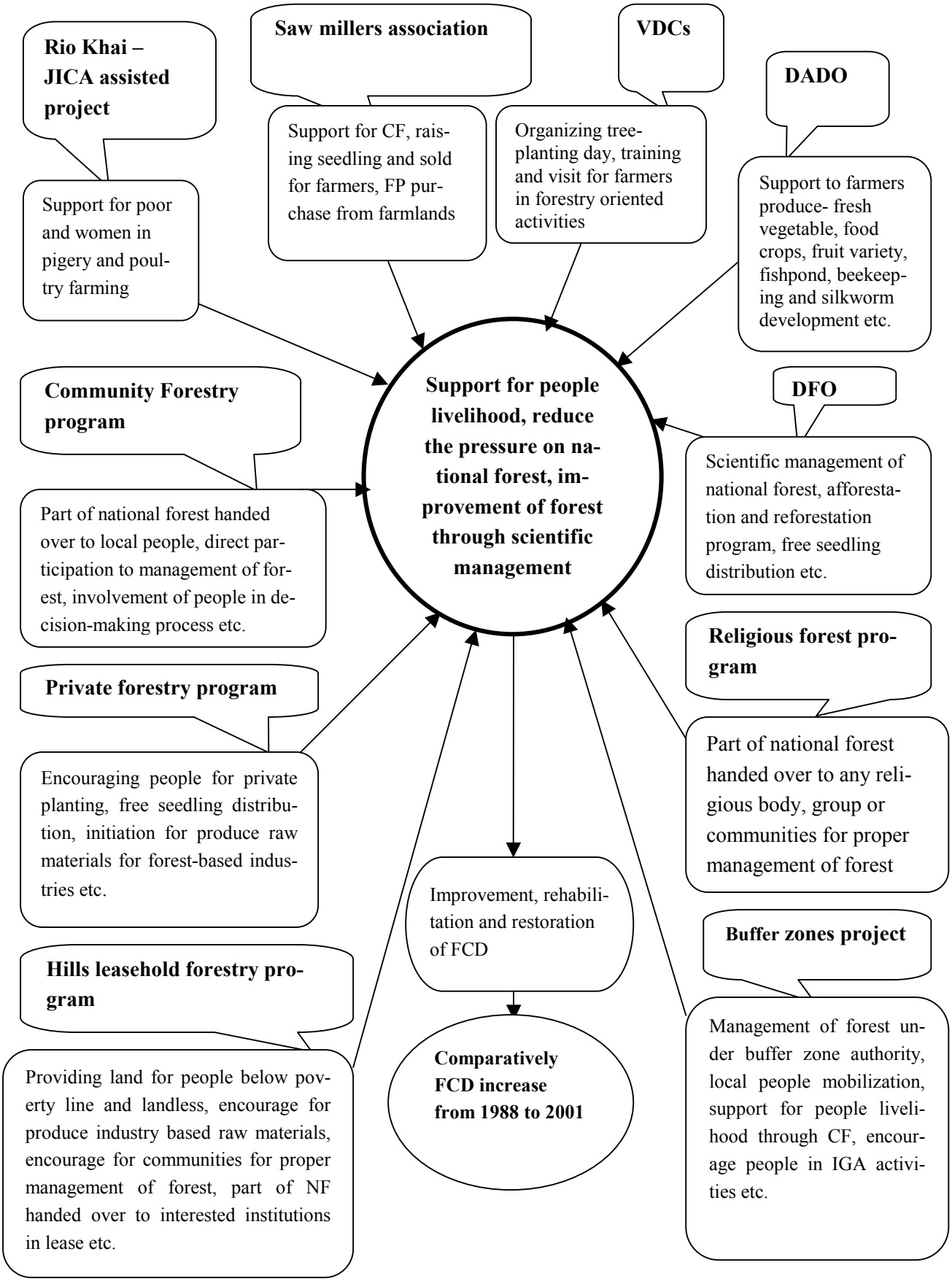
Figure 4-2. NDVI Map of 1988 (left), 1992 (middle) and 2001 (right)



Flow chart 4-1. Logical flow of forest canopy density change between 1988 to 1992



Flow chart 4-2. Logical flow of forest canopy density change from 1992 to 2001.



Flow chart 4-3 Different developmental programs support to increased forest canopy density over the period.

4.2 Forest Canopy Density and biophysical factors

Though statistically did not show very strong relation, reveal from analysis and figures shows that canopy density is clearly affected by the distance from settled area, river and the road. Combination of these three variables can be used for detection Forest Canopy Density. In this study it was observed that the cover of forest canopy clearly relates to the extent of human influence in which distance from settled area is the most important factor.

The forestland closer to the roads and settlements are easily accessible and less work-time consuming for firewood collection, timber transportation, illegal cutting and felling (Shrestha, 1999). Therefore those areas closer to roads and settled area are more vulnerable to the canopy loss. When we compare the changes in canopy density and distance from the settled area, it can be seen that the situation in those areas which are far from the settled area has remained more or less constant during the last 13 years, whereas the forest canopy density near to the settled area has decreased more and hardly increased (Figure 3.13, 3.14 and Appendix B, Table 5 and 6). In this analysis distance from road to forest is not statistically significance factor. However, in some higher canopy density classes have positive changed in 2001 and no. of pixels also increased (Figure 3.15), close distance to road is clearly influenced by vulnerably degradation of canopy in lower density classes (Figure 3.16). It clearly indicates the area under sparse vegetation (lower density class) still away from proper forest management. More communities (people participation) involvement is only concentrate in the densely forest area where people can get quickly benefit. Or close to the road probably have plantation forest due to accessibility. Interestingly, distance more than 1 km canopy density measured in pixels in each distance classes have negative changed. That may indicates due to inaccessibility and lack of proper supervision hence illegal cutting and felling is rather frequent in this area. There are two major roads (one goes to Kathmandu and another east west highway) and forest officers frequently drive their cars on those roads. This checks illegal logging and felling along the roadside. Therefore road does not play a major role in canopy loss within close distance.

Further, in the study area some of the rivers are seasonal and some are perennial. Those areas, which are isolated by a river, are rather far from forest guard's eye and not regularly inspected by them, hence illegal felling is rather frequent in such areas and canopy density is showing affected by close distance from river. Similarly, close to river mostly found Khair - Sisoo (said to be riverine forest) by the nature of the forest type itself. Because of commercially valuable forest species people are more intended to illegal cutting hence canopy could be more affected (Figure 3.18). However, mixed hard wood broad-leaved species e.g *Lagerstroemia parviflora*, *Trewia nudiflora, Aegle marmelos, Schlichera oleosa, Bombax ceiba* etc. which are another type of riverine forest. Some of them forms big canopy structure and this species rather useless. People mostly leave this species hence canopy density within closer to river seems increase in some density classes. Consequently no. of pixels also increased in 2001 (Figure 3.17). On the other hand, plantation forest, which closer to river can supports to increase canopy density.

Shamsulwahab (2001) found that the rate of deforestation is highly influenced by physical factors like distance from roads and rivers. He further concluded that deforestation rate is strongly negatively cor-

related with distance from road and river (R^2 coefficient 0.98 and 0.83, p = <0.001). The reason for getting this result in his case could be the different location of study area. Geographical feature, socio-economic status, livelihood of people, landuse and forest management system, and involvement of developmental organizations is different from that of Chitwan district.

It is interesting to note that, among the factors distance from settled area has remarkably affect on Forest Canopy Density than others two physical factors. People need forest products for their daily life survive and they are mostly depend on closest forest from their houses. Further, the migrating people need constructing materials not only to build their houses but also to fence their farmland as well. The only source to meet these requirement be the near by forest.

Contarary, Nepal (1999) noticed that canopy fluctuating situation within that period was hardly affected by socio- economic condition of rural communities who were settled along the forest boundary. Furthermore, Mujuni (1999) mentioned that distance to forest from the household did not influence the inhabitant's behaviour towards the collection and use of fuel wood from the forest. Degree of influence was determined not by distance, but much influenced by their scarcity of forest products use, socio-economic status and alternative energy sources they had already in their hand. But in this analysis, it was observed that the degradation of canopy density is clearly related with statistically significant relation with physical factors with settled area and river.

However, canopy dynamics differ from place to place and affected by different causal factors. The canopy density inside the Royal Chitwan National Park (Buffer zone area where part of forest is managed by local people under community forest management programme) and some other areas managed by local communities has increased rapidly (Figure 4.3 below.) This is also agreement with Mujuni (1999) who mentioned some areas (part of study area) had increased number of private woodlots (forest patches). Woodlots are highly increased in the study area due to inaccessibility of fuel wood and fodder from buffer zone (RCNP area) and surrounding national forests because of new forest policies. Consequently, it may somehow reduced pressure on national forest and canopy density is increased. Similarly, *Shorea robusta* (Sal) is the main dominant species in the study area and it is prohibited to cutting and felling. So people were started to plant *Dalbergia sissoo* in some part of national forest combine with Sal under communities initiation. These areas have relatively better forest condition than the others. While forest canopy density of government-managed national forests has significantly decreased. It is interesting to note that Kothandapani (2001) mentioned that forest canopy density is depleted even inside the buffer zone area where people have free access to illegal cutting and felling. So, most of the government-managed national forestland near to the settled area was converted to non-forest areas most probably by agricultural activities or completely degraded land (Figure 4.3 below).

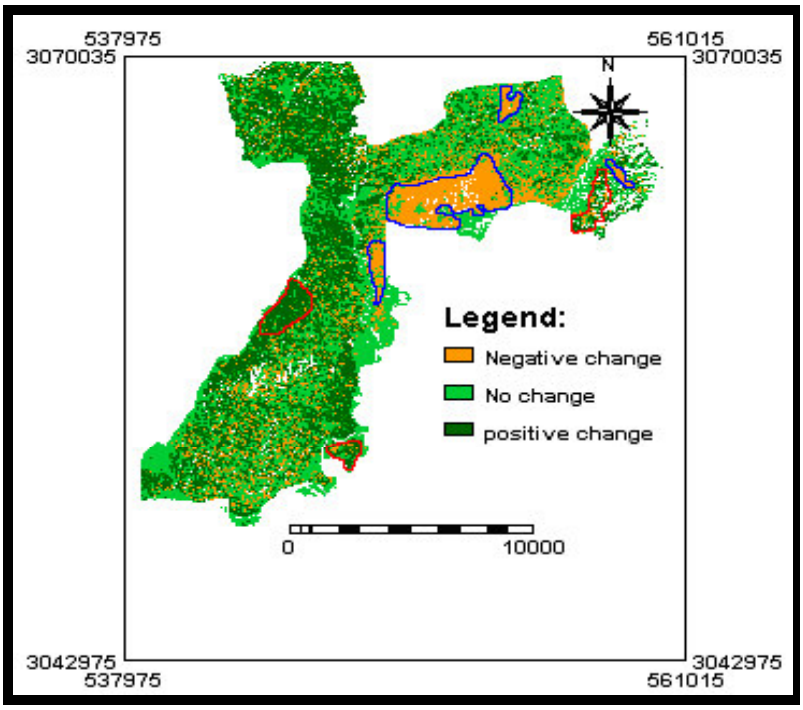


Figure 4-3 Blue line indicate large and small patch of forest land shows, canopies are highly destructed near from settled area and red line indicate patch of CF managed by Communities.

Furthermore, settlers near to the park area increasing damaged on forest products and transmission of diseases by domestic animals to the wild during grazing. On the other hand, people have been suffering from wildlife due to destruction of farmers crop. Those lives have also threatened which results a serious conflict occurred between human- RCNP in the southern part of Chitwan district. Unfortunately, problem has been faced continuously settlers who were near from RCNP and along the forest boundary not only from wildlife also from flood (especially in old Padampur VDCs). HMG/ Nepal decided to relocate the people of Padampur village in the part of Jutpani forests. The government clear felled a large part of the forest area at beginning and the process is still going on. This result in a drastic canopy loss in some areas (Jutpani forest area) mostly right hand side in Figure 4.4 below. Deforestation and forest degradation were more prominent around such new settled areas.

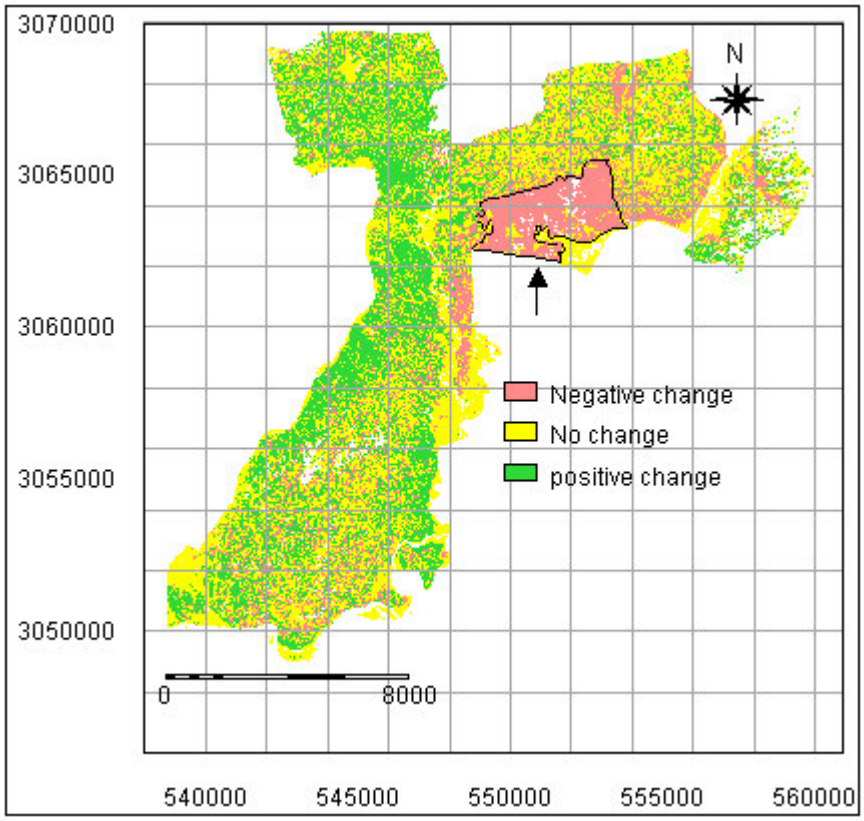


Figure 4-4. Arrow indicates a clear felled Jutpani forest (polygon) by the Government for the new settlers.

Moreover, it is interesting to note that, a highly negative change is observed (right side northern part of the map Jutpani, Shaktikhor forest area) around the settled area (Figure 4.4). In contrast, (left part of the map Bharatpur Nagarpalika forest area) relatively positive change is observed around the settled area. The field report on Chitwan district (2001) reveal that the amount of TROF is about 369.98 ha (volume per hectare of transect line) and proper land use and forest management system (CF) are observed in the left side in figure 4.4. Poor forest management system is noticed (right side of the map Jutpani and Shaktikhor area in figure 4.4) where low amount of TROF is about 291.08 ha observed (volume per hectare of transect line). This result indicates the role of TROF and its consequent in surrounding national forest. Further, it clearly points out that Forest Canopy Density is not affected only by the physical factors but socio-economic factors, forest management and land use system, level of awareness and people perception towards forest management also potentially influence it.

4.3 Forest Canopy Density and anthropogenic factors (human disturbances)

Some of the anthropogenic factors (human interference) for instance grazing, sign of fire, girdling, lopping, coppicing, stumps, debarking and path could spatially and temporally alter the forest canopy cover. Which has been already analysed in that region and concluded that human interference inside the forest like grazing, debarking, firing; stumps, path and illicit felling are the main influencing factors for canopy loss (Joshi, 2001). This study agrees with Kaphley (1999) who mention that the human disturbances are the main causes of forest degradation in Terai region. Figure 3.20. and 3.21.confirms this. Unlikely, the effect of coppicing is considered to be a canopy increasing factor in

this analysis. Because of its specific nature in some species, as might be expected; coppicing has capacity to increases forest canopy coverage. As revealed from the data debarking strongly negatively affects the canopy density. Although debarking kills tree slowly, it significantly affects canopy density. It is interesting to note that the effect of stumps does not appeared as an affecting factor of canopy. Possibly the stumps remains for long period in the ground and at the same time, the area could be covered by surrounding crowns (for more details on canopy dynamics van der Meer, 1995).

4.4 Forest Canopy Density and population factor

Roy et al., (1996) claimed that information obtain about the rate of deforestation is needed analyse of component, the relationship between population density and the percentage of forest cover change of these areas. With this consideration, together with other socio-economic factors are thereby only help in formulating the mitigation plan for decision maker in planning process in natural resource management.

From the literature review, we found three different viewpoints in relation to population and forest degradation. Allen and Barnes (1985); Grainger (1986); Panayotou and Sungsuwan (1989) cited by (Fox, 1993) claimed increasing population density is the major cause of tropical forest destruction and its declination. (Boserup, 1965) quoted by Fox (1993) argued that population growth assist to carry positive change in forest cover with new innovation. Contradictory with these analysis, in a one decade case study from Bhogteni in mid hill of Nepal, Fox (1993) mentioned that major changes in forest resource are the causes of other social, institutional, developmental factors rather than population growth and its density. Similarly, in a study in mid hill's forest of Nepal, (Gilmour & Fisher, 1991) found that although population growth continuously increased, an extensive sustainable forest management system has been established throughout the communities and the forest was comparatively improved than that of previous years.

This analysis did not reveal any remarkable effect of population on forest canopy density change, as Shamsulwahab (2001) concluded. In this case as Fox (1993) reported that an active forest management and land use unit, introduction of new tenure regime for forestland, support from outsiders (NGOs, INGOs and local government) are probably be the main causes of forest resource change. Population growth is less obvious. Boserup (1965) quoted by Fox (1993) state that the population growth leads to internal innovations for managing forestland more efficiently. All the above mentioned components might be present in this area as well. It is important to consider that, city population (Nagarpalika) may not be reliable analyse with village population because most of the city inhabitants use alternative energy sources. In this analysis depletion in forest coverage and density could be caused by other major factors rather than the population phenomenon e.g. (Appendix E, Figure 5 and Figure 6).

4.5 Forest Canopy Density and canopy dominant species composition

Figure 3.22. clearly demonstrates that the canopy dominant species composition and Forest Canopy Density are strongly correlated. Further, the different composition of species leading to formation of different canopy structure and density (Appendix E, Figure 1, 2, 3, and 4). Examining the canopy dominant species association demonstrates the importance of different forest composition in the study area. *Dalbergia sissoo* is canopy dominant species that showed a high canopy density (Figure 3.22).

This highly important commercial tree has been planted since several years in study area (Nepal, 1999). Another canopy dominant species is *Trewia nudiflora.* It is one of the evergreen broad-leaved species, which often forms a dense homogenous forest. This particular species is not an important forest tree and rather useless, hence local people leave this species as such. The leaves are large and broad in size and shape, which remarkably forms a dense canopy. The least canopy density is covered by *Myrsine capitellata*. This is a small leaved shrub and never forms dense thicket. This analysis picked out a good correspondence between canopy dominant species composition and canopy density.

4.6 Secondary data and accuracy issues

With regard to accuracy assessment of canopy density classes from FCD Mapper classifier and canopy cover percentage from field measurement has given result about overall accuracy 71% with Kappa (k) statistic value 0.55.The canopy density map of 2001 was used with ground truth data of 2001. This overall accuracy value depends on several factors such as forest condition and measurement accuracy. The accuracy of analysed result also depends on factors such as the season and/or time, behaviour of the canopy and the satellite data of the different dates, visual observation of canopy based field measurements by the different persons and time period. These are some factors which may increased the sources of error. Similarly, for 1988 and 1992 canopy density maps has unable to carry accuracy assessment because of lack of ground truth data. The uses of 2001 field data for these two maps rather useless due to time interval. However, visual interpretation and compare with previous studies has been done where same year images were used for land cover classification (Appendix F, Figure 6, 7 and 8).

4.7 Strength and applicability of secondary data

Regarding the question, whether the existing secondary data adequate to help answers the related research questions or not? It was observed that the satellite imagery, topographic map, forest inventory data, socio- economic data /population, and anthropogenic factors (human interference) have essentially contribute to answer the research questions in this analysis. Accordingly, the available satellite imagery of different acquisition date, seasonally variation in the imagery considerably gave appropriate results for temporal and spatial change detection of canopy density. Besides these, the calculation of NDVI and SAVI maps of different years also supported the outcome (figure 4-1, 4-2). The NDVI and SAVI map showed high vegetation indices value which correspond high canopy density classes in FCD maps. Although NDVI and SAVI do not calculate the actual canopy density, value showing in the NDVI and SAVI can be compared with FCD maps. Similarly, the distance maps (road, river and settled area) can be easily derived from topographic maps, which notably illustrate the spatial distribution of forest canopy density and its variation due to physical distance. Existing forest inventory data such as canopy cover percentage with dbh, total number of tree, canopy mean height and canopy dominant species statistically correlated with canopy density (Appendix A, Table 1 and Appendix D, graph 1 and 2, Figure 1, 2, 3 and 4). Though only two factors path and sign of fire were statistically significance with respect to their effect on spatial distribution of canopy density in the study area (Appendix A, Table 4b). Most of the anthropogenic factors (human interference) have low canopy density in comparison with undisturbed area (Figure 3.20, Figure 3.21 and Appendix B: Table 13).

In contrast, data on population and some anthropogenic factors (human interference) such as stumps, debarking and coppicing did not show very reliable relation with temporal and spatial distribution of

canopy density. Figure 3.20. and Figure 3.21. clearly illustrate that debarking effect (site 2), stumps effect (site 1) and coppicing effect (in both site) did not show any effect on spatial distribution of canopy density whether its sign of disturbance observed or not. The debarking effect is noticeable observed in site 1 and the same disturbance did not affect in site 2. Therefore, it is difficult to draw concrete conclusion about the actual fact behind this due to data uncertainty. Similarly, population of the area over the periods did not show effect on temporal and spatial distribution of canopy density. Figure 3.19. shows a changing pattern of canopy density and its relation with population dynamic. Interestingly, canopy density has fluctuated within period withought concern the increasing pattern of population. In fact it is difficult to find from this analysis, whether population affects on canopy density or not unless properly consideration of socio-economic factors.

It is important to remember that accuracy is affected by error in the methods used e.g. calculation of forest canopy density by FCD Mapper. Moreover, other biophysical and anthropogenic factors like slope altitude, aspect, soil type and moisture, climatic factors and other institutional intervention could have an effect on the spatial distribution of canopy density. It is better to analyse these factors in a comprehensive way.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The forest canopy density distribution pattern and the factors affecting canopy density in Chitwan district, Nepal has been summarized Three main sets of conclusions have been from this research.

First are those observations that relate to forest canopy density mapping and change detection in mountainous terrain of central Nepal. These are:

- The conversion of high forest canopy density into low canopy density rather than the other way around is one of the dominant phenomenon observed in the study area.
- The forest canopy density has been changing within same forest type and a different landscape. This phenomenon can be detected by using multi temporal remote sensing imagery, GIS and forest canopy density mapping techniques.
- The outcome could be affected by setting threshold value in the process of FCD calculation in FCD Mapper. In case of large area classification, field together with prior knowledge on images interpretation should be consider to overcome these problem.

The second group of conclusions concerns the factors affecting forest canopy density. This assessment illustrates the potential alteration of canopy density into the forest areas that are degraded due to anthropogenic activities.

- It is concluded that some human interference such as fire and path, and environmental factors are closely related with alteration of canopy density.
- The effect of factors leading to forest canopy density change varies from place to place. Distance from the settled area appeared to be the most altering factor of forest canopy density followed by road and river.
- Based this analysis, it can be concluded that population growth only may not explain human dimensions of environmental degradation unless good understanding of other additional social factors is available.
- Seasonality is one of the major factors, which affects the forest canopy density, and which must be considered when interpreting the results.
- Canopy dominant species plays a vital role in determining forest canopy density. This association may be helpful in spatial prediction of distribution of forest types and canopy dominant species in particular. More detailed study in this aspect is needed.

The final group of conclusions relate to the different aspect of secondary data, which has been used in this research.

Advantages:

- Secondary data sharing could be useful and benefited for the organization, institution and offices where investment is repeated for the collection of similar data types.
- Cost effective in the sense of time, money and manpower already saved.
- Secondary data could be highly important for the organizations together with persons where the situation is not favourable for conducting fieldwork because of insecurity and risk (as in many countries at present).
- It could be benefited to obtain further information about the area where some previous data already exists.
- It gives extent and limitation of the study. Then researcher could be able to set their research objective and priority within periphery of the existing data.

Disadvantages:

- Secondary data sources collected for general purposes may not be appropriate for the specific purpose.
- Data collected by different people, different time interval and season reduces the accuracy of the result.
- Such data sets may not be consistent.
- Researcher may not properly argue in some analysis and results, which may need field verification.
- The constraints of secondary data highly affecting to narrow down research objectives.

5.2 Recommendation:

- As a first recommendation, pixel based (30m x 30m) forest canopy mapping with Landsat data is capable of consistently detecting the dynamics of canopy depletion, canopy increment or no change in forest stands.
- Site-specific change information as generated from GIS and remote sensing effectively contribute to the management of valuable tropical forest of Nepal.
- Regarding further analysis of FCD and its influencing factors in future, time series data should be gathered from the same places or establishment of some permanent plots could be affective way.
- The result of spatial dimension of road, river, and effect of total population, and human interference to the forest does not show the sharp distinction. Therefore, detailed study of the other socio-economic, institutional and biophysical factors should be executed.
- Annual increment of forest products should be considered for further analysis.
- Chitwan district is highly supported by numerous innovative organizations. It could be better if Ministry of Forest and Soil Conservation pay an attention for proper co-ordination to formulating the plan and their implementation in a GIS and RS environment for sustainable management of natural resources.
- Based on species canopy density analysis, FCD could be the one of the important tool to analyse forest type and species composition.
- More variables are required to better explain forest canopy density change, such as the availability of total agricultural land, productivity, fuel wood market price, changing the population growth rate, migrating population and their income sources. Growth models that closely represent reality, may also help to provide more reliable results on the state of the forest canopy.
- These conversion factors should be looked at in an integrated and comprehensive way.

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Appendix A.

Table: 1. Pearson correlation test for all variables in relation to forest canopy density

		CC	TT	MDBH	MHT	DIST_ROAD	DIST_RIVER	DIST_SETT
CC	Pearson Correla-tion	1	**.744****	**.561****	**.500****	-0.04	**.429***	**.449****
	Sig. (2-tailed)	.	0	0.001	0.003	0.822	0.011	0.008
	N	34	34	34	34	34	34	34
TT	Pearson Correla-tion	**.744****	1	**.442****	**.462****	0.074	**.344****	0.261
	Sig. (2-tailed)	0	.	0.009	0.006	0.676	0.046	0.136
	N	34	34	34	34	34	34	34
MDBH	Pearson Correla-tion	**.561****	**.442****	1	**.847****	-0.199	-0.032	0.197
	Sig. (2-tailed)	0.001	0.009	.	0	0.259	0.858	0.263
	N	34	34	34	34	34	34	34
MHT	Pearson Correla-tion	**.500****	**.462****	**.847****	1	-0.18	-0.038	0.041
	Sig. (2-tailed)	0.003	0.006	0	.	0.309	0.83	0.82
	N	34	34	34	34	34	34	34
DIST_ROAD	Pearson Correla-tion	-0.04	0.074	-0.199	-0.18	1	0.217	-0.26
	Sig. (2-tailed)	0.0822	0.676	0.259	0.309	.	0.218	0.138
	N	34	34	34	34	34	34	34
DIST_RIVER	Pearson Correla-tion	**.429***	**.344***	-0.032	-0.038	0.217	1	**.390***
	Sig. (2-tailed)	0.011	0.046	0.858	0.83	0.218	.	0.023
	N	34	34	34	34	34	34	34
DIST_SETT	Pearson Correla-tion	**.449****	0.261	0.197	0.041	-0.26	**.390***	1
	Sig. (2-tailed)	0.008	0.136	0.263	0.82	0.138	0.023	.
	N	34	34	34	34	34	34	34

Cont:

* Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

CC = Canopy Cover
TT = Total Trees
MDBH = Mean Diameter Breast Height
MHT = Mean Height of Trees
DIST_SETT = Distance from settlement
DIST_RIVER = Distance from river
DIST_ROAD = Distance from road

Table: 2. Normality test for study area 1 of 2001 field data

One-Sample Kolmogorov-Smirnov Test (Distance parameter in meter (Road, river and settlement)							
		CC%	**TT**	**MHT**	**ROAD**	**RIVER**	**SET-TLE**
N		36	36	36	36	36	36
Normal Parameters	Mean	34.4167	13.1944	8.7222	1375.9166	377.4167	2082.0278
	Std. Deviation	29.2178	9.6860	6.8059	906.3244	233.4159	750.5967
Most Extreme Differences	Absolute	0.187	0.148	0.105	0.161	0.090	0.118
	Positive	0.187	0.148	0.105	0.126	0.090	0.073
	Negative	-0.119	-0.087	-0.100	-0.161	-0.053	-0.118
Kolmogorov-Smirnov Z		1.123	0.890	0.632	0.965	0.542	0.706
Asymp. Sig. (2-tailed)		0.160	0.407	0.819	0.309	0.930	0.701

a Test distribution is Normal.
b Calculated from data.

N = Number of sample plots
CC = Canopy Cover
TT = Total Trees
MHT = Mean Height of Trees

Table: 3. Normality test for study area 2 of 2001 field data

One-Sample Kolmogorov-Smirnov Test (Distance parameter in meter (Road, river and settlement)								
		CC %	**TT**	**MDBH**	**MHT**	**ROAD**	**RIVER**	**SETTLE**
N		34	34	34	34	34	34	34
Normal Parameters	Mean	25.7059	3.4118	45.0882	18.4706	251.4118	325.5882	536.3235
	Std. Deviation	17.2899	2.4633	25.5893	11.7917	241.5227	290.1597	433.1847
Most Extreme Differences	Absolute	0.250	0.130	0.192	0.118	0.198	0.172	0.128
	Positive	0.142	0.130	0.137	0.118	0.198	0.172	0.128
	Negative	-0.250	-0.124	-0.192	-0.102	-0.159	-0.138	-0.121
Kolmogorov-Smirnov Z		1.455	0.760	1.122	0.687	1.156	1.003	0.747
Asymp. Sig. (2-tailed)		0.029	0.610	0.161	0.733	0.138	0.267	0.633

a Test distribution is Normal

b Calculated from data.

N = Number of sample plots

CC = Canopy Cover

TT = Total Trees

MHT = Mean Height of Trees

Table: 4a. Kruskal- Wallis Test statistics for variables in relation to forest canopy density change

Kruskal- Wallis Test:	**Study Area_1**		
Variables	**H**	**DF**	**P value**
Total tree no	31.61	20	**0.048**
Mean height of tree	21.23	20	0.384
Distance to road	33.33	34	0.500
Distance to river	32.88	33	0.473
Distance to settle	35	35	0.468
Grazing	0.82	1	0.366
Path	0.86	1	0.355
Stumps	0.03	1	0.872
Signs of fire	0.36	1	0.547
Lopping	2.5	1	0.114
Coppicing	0.97	1	0.325
Debarking	0.74	1	0.389

Table: 4b. Kruskal- Wallis Test statistics for variables in relation to forest canopy density change

Kruskal- Wallis Test:	**Study Area_2**		
Variables	**H**	**DF**	**P value**
Total tree no	23.21	8	**0.003**
Mean height of tree	26.41	19	0.119
Distance to road	28.86	29	0.472
Distance to river	32.89	31	0.374
Distance to settle	31.64	28	0.289
Grazing	0.95	1	0.329
Path	5.05	1	**0.025**
Stumps	3.21	1	0.073
Signs of fire	12.26	1	**0.000**
Lopping	3.11	1	0.078
Coppicing	0.01	1	0.916
Girdling	1.85	1	0.174
Debarking	2.36	1	0.125

Appendix B.

Table: 5. Forest Canopy Density in terms of pixel change (negative or positive) in relation to distance from settled area to forest from 1988 to 2001

1988	Distance class: distance from the settled area to forest (in metre)						
Forest Canopy Density class	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	>3000
0% (canopy less)	26135	11566	7894	4902	2436	1643	1141
1-20% (class1)	1145	815	555	273	101	70	41
21-40% (class2)	3320	2707	2170	1105	443	219	120
41-60% (class3)	4811	5198	5625	3596	1864	1134	419
61-80% (class4)	8287	9442	10288	9178	7014	4111	1805
81-100% (class5)	4385	7966	7581	6024	3786	2469	1733
Total pixels numbers	48083	37694	34113	25078	15644	9646	5259
2001							
0% (canopy less)	22647	8382	5929	4347	1565	713	932
1-20% (class1)	532	379	272	186	83	56	22
21-40% (class2)	3163	2336	1756	1141	576	356	199
41-60% (class3)	6313	5194	4977	3457	2397	1446	852
61-80% (class4)	9427	11012	12101	9351	6763	4479	1730
81-100% (class5)	4531	9593	8281	5704	3869	2354	1671
Total pixels numbers	46613	36896	33316	24186	15253	9404	5406
Change in pixels from 88-01	-1470	-798	-797	-892	-391	-242	147

Table: 6. Percentage change in number of pixels (negative or positive) in each canopy class in relation to distance from settled area to forest from 1988 to 2001

Forest Canopy Density class	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3001-35000
0% (class0)	-13	-28	-25	-11	-36	-57	-18
1-20% (class1)	-54	-53	-51	-32	-18	-20	-46
21-40% (class2)	-5	-14	-19	3	30	63	66
41-60% (class3)	31	0	-12	-4	29	28	103
61-80% (class4)	14	17	18	2	-4	9	-4
81-100% (class5)	3	20	9	-5	2	-5	-4

Table: 7. Forest Canopy Density (in terms of pixels) in relation to distance from roads to forest in 1988 and 2001

1988	Distance class: distance from roads to forest (in metre)					
Forest Canopy Density class	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500
1-20% (class1)	2035	509	200	146	52	58
21-40% (class2)	6672	1938	665	488	143	178
41-60% (class3)	13037	5106	2259	1417	565	293
61-80% (class4)	19920	12638	8110	5996	2784	677
81-100% (class5)	6181	7592	7785	6870	4095	1421
2001						
1-20% (class1)	979	192	142	90	80	47
21-40% (class2)	5704	1409	914	643	515	342
41-60% (class3)	13805	4622	2487	2386	943	393
61-80% (class4)	26333	13405	7067	4879	2271	908
81-100% (class5)	8537	9022	7568	6506	3447	923

Table: 8. Forest Canopy Density in terms of pixels change (negative or positive) in relation to distance from road to forest from 1988 to 2001

Year	0-500	501-1000	1001-1500	1501-2000	2001-2500	>2500
2001	55358	28650	18178	14504	7256	2613
1988	47845	27783	19019	14917	7639	2627
Change in pixels from 88-01	7513	867	-841	-413	-383	-14

Table: 9. Percentage change in number of pixels (negative or positive) in each FCD class in relation to distance from road to forest from 1988 to 2001

Distance class: distance from the road to forest (in meter)						
Forest Canopy Density class	0-500	501- 1000	1001-1500	1501-2000	2001-2500	>2500
1-20% (class1)	-108	-165	-41	-62	35	-23
21-40% (class2)	-17	-38	27	24	72	48
41-60% (class3)	6	-10	9	41	40	25
61-80% (class4)	24	6	-15	-23	-23	25
81-100% (class5)	28	16	-3	-6	-19	-54

Table: 10. Forest Canopy Density (in terms of pixels) in 1988 and 2001 in relation to distance from rivers to forest

1988	Distance class: distance from river to forest (in meter)		
Forest Canopy Density class	0-500	501-1000	>1000
1-20 % (class1)	2311	548	141
21-40 % (class2)	7527	2034	523
41-60 % (class3)	17133	4258	1286
61-80 % (class4)	33084	11858	5183
81-100 % (class5)	16302	12158	5484
Total pixels numbers	76357	30856	12617

2001	Distance class: distance from river to forest (in meter)		
Forest Canopy Density class	0-500	501-1000	>1000
1-20 % (class1)	1066	331	133
21-40 % (class2)	7056	1871	600
41-60 % (class3)	19474	3986	1176
61-80 % (class4)	38432	11467	4964
81-100 % (class5)	15951	12640	7412
Total pixels numbers	81979	30295	14285

Table: 11 Forest Canopy Density in terms of pixels change (negative or positive) in relation to distance from river to forest from 1988 to 2001

Distance class: distance from river to forest (in meter)			
	0-500	501-1000	>1000
1988	76357	30856	12617
2001	81979	30295	14285
Change in pixels from 88-01	5622	-561	1668

Table: 12. Percentage change in number of pixels (negative or positive) in each FCD class in relation to distance from river to forest from 1988 to 2001

Distance class: distance from river to forest (in meter)			
Forest Canopy Density class	0-500	501-1000	>1000
1-20% (class1)	-54	-40	-6
21-40% (class2)	-6	-8	15
41-60% (class3)	14	-6	-9
61-80% (class4)	16	-3	-4
81-100% (class5)	-2	4	35

Table: 13. Numerical value showing mean canopy cover percentage with corresponding disturbances

Canopy cover in % relation with human disturbances							
	Grazing	Path	Stumps	Fire	Lopping	Coppicing	Debarking
Disturbances	24	27	35	33	39	42	24
No disturbances	36	36	34	40	44	43	47

Canopy cover in % relation with human disturbances								
	Grazing	Path	Stump	Fire	Lopping	Coppicing	Girdling	Debarking
Disturbances	28	29	27	30	29	31	25	31
No disturbances	32	32	33	35	32	31	33	31

Table: 14. Population distribution in per VDCs in year 1988, 1992 and 2001

S.N.	Name of VDCs	Male	Female	Total in 1988	Total in 1992	Total in 2001
1	Baratpur Nagarpalika	40679	38539	60927	66053	79218
2	Ratnanagar "	16474	16561	25407	27545	33035
3	Jutpani VDC	5327	5667	8456	9167	10994
4	Padampur "	4747	4874	7400	8022	9621
5	Pithuwa "	4329	4912	7107	7704	9240
6	Gitanagar "	5124	5495	8166	8853	10618
7	Saktikhor "	3114	3122	4796	5200	6236
8	Kabilas	2342	2364	3619	3924	4706
9	Pancha kanya	5802	5751	9440	10235	12275
	Total	87938	87285	135318	146702	175943

Table: 15. Comparative analysis between total FCD (in terms of area in ha) and population (inhabitants) of 1988, 1992 and 2001

Descriptions	1988	1992	2001
Total FCD (in terms of area in ha)	10782	10431	11380
Population (inhabitants) numbers	135318	146702	175943

Yeaear	Population	Base value (100)	Forest (ha)	Base value (100)	Forest ha/person	Base value (100)
1988	135318	100	10782	100	0.08	100
1992	146702	108	10431	97	0.07	89
2001	175943	130	11380	106	0.06	81

Appendix C.

Table: 16. Forest Canopy Density Statistics for 1988, 1992 and 2001

Range (%)	FCD Class	Area(ha) 1988	Area(ha) 1992	Area(ha) 2001
0-0%	class0	4982	5666	3983
1-20%	class1	268	362	138
21-40%	class2	905	1485	853
41-60%	class3	2040	2961	2208
61-80%	class4	4513	3328	4939
81-100%	class5	3056	2295	3242

Table: 17. Comparative analysis of FCD classes between 1988, 1992 and 2001

Range (%)	FCD Class	Area_88(ha)	Area_92(ha)	Area_01(ha)
0-0 %	Class0	4982	5666	3983
1-20 %	Class1	268	362	138
21-40 %	Class2	905	1485	853
41-60 %	Class3	2040	2961	2208
61-80 %	Class4	4513	3328	4939
81-100 %	Class5	3056	2295	3242

Table: 18. Descriptive Statistics for different forest type (species composition)

Forest Type		N	Mean	Std. Deviation
1- Mixed broad- leaved	%cc	10	35.4	8.909
	Valid N (listwise)	10		
2 – Albizzia- Myrsine	%cc	3	38.33	16.073
	Valid N (listwise)	3		
3 – Trewia nudiflora	%cc	7	58.57	34.365
	Valid N (listwise)	7		
4 – Albizzia- Trewia	%cc	5	29	28.81
	Valid N (listwise)	5		
5 – Albizzia odoretissima	%cc	3	53.33	23.094
	Valid N (listwise)	3		
6 – Dalbergia sisoo	%cc	2	75	21.213
	Valid N (listwise)	2		
7 – Myrsine Capitellata	%cc	1	10	.
	Valid N (listwise)	1		
8 – Shorea robusta	%cc	21	29.1	14.973
	Valid N (listwise)	21		

ANOVA					
%cc					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9319.262	7	1331.323	3.321	0.006
Within Groups	17637.257	44	400.847		
Total	26956.519	51			

Table: 19. Map Accuracy

Confusion matrix table for accuracy assessment

	Non forest	Open forest	Closed forest	Total	Error of Commission (%)	User Accuracy (%)
Non forest	6	9	1	16	64	36
Open forest	2	23	1	26	36	64
Closed forest	3	4	20	27	26	74
Total	11	36	22	69		
Error of Omission (%)	45	36	9			
Producer Accuracy (%)	55	64	91			71
The overall accuracy is **71%**						

Kappa statistics

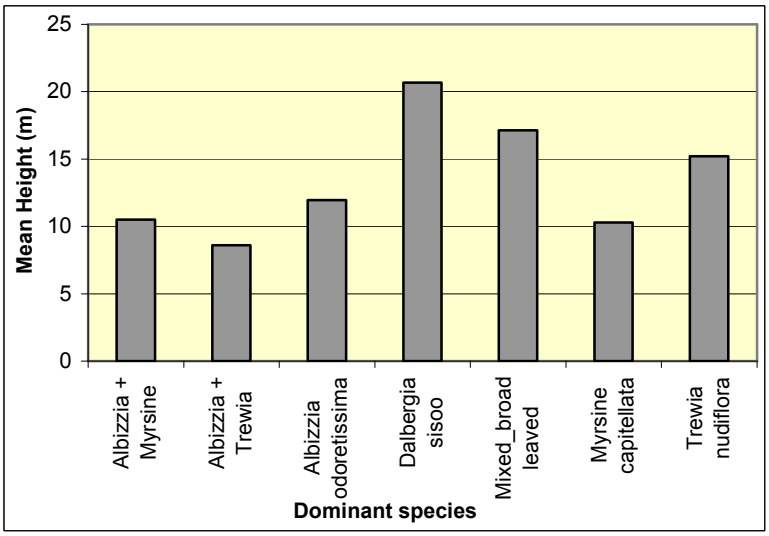
$$\hat{\kappa} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})} \qquad \hat{\kappa} = 0.55$$

Where,

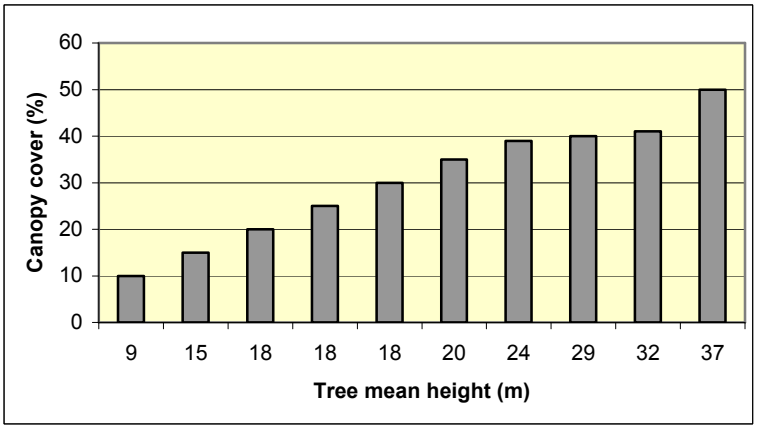
x_{ii} : Diagonal entries of the error matrix. x_{i+} : Sum of row i.

x_{+i} : Sum of column i. N: Total number of observations.

Appendix D.



Graph.1 Relationship between canopy dominant species and mean canopy height in site 1



Graph.2 Effect of tree mean height on canopy cover percentage in site 2

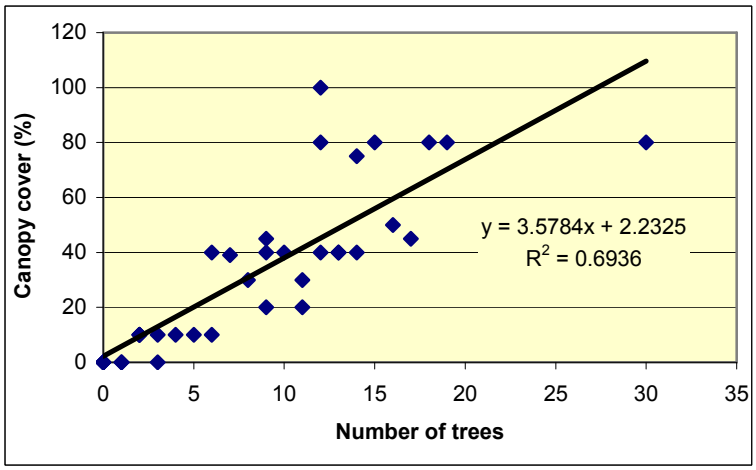


Fig.1 Relationship between canopy cover percentage and number of trees in site 1

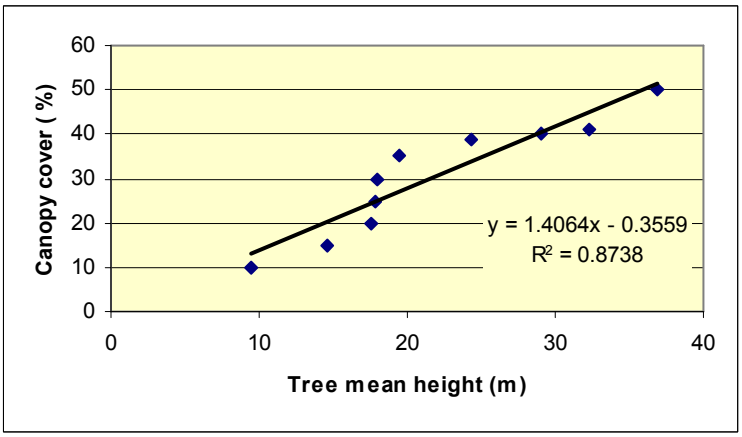


Fig.2 Relationship between canopy cover percentage and tree mean height in site 2

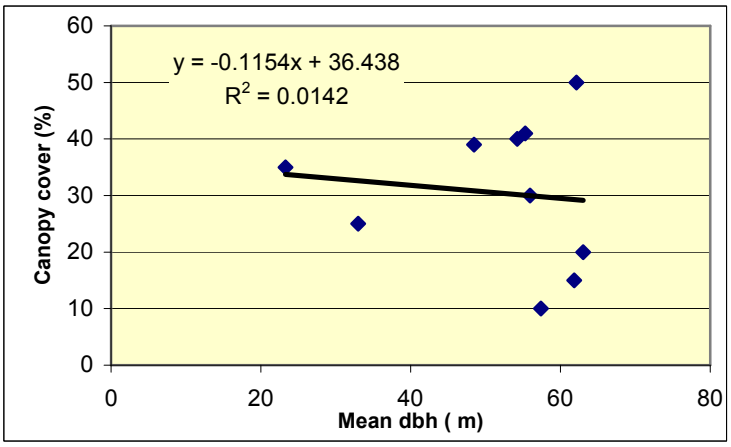


Fig.3 Relationship between canopy cover percentage and mean dbh in site 2

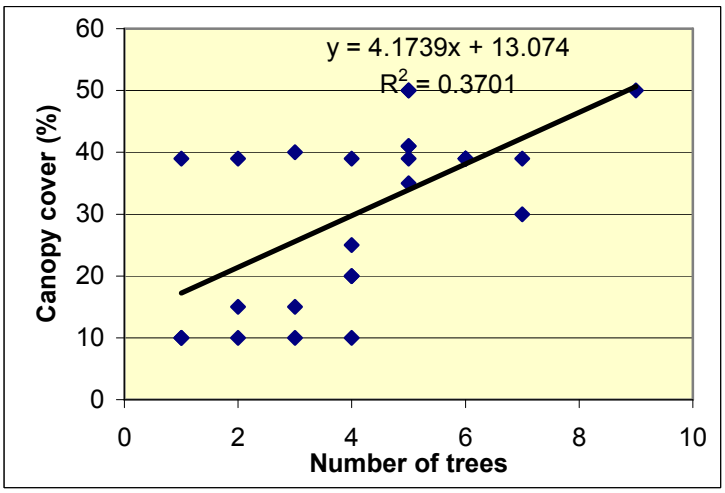


Fig.4 Relationship between canopy cover % and total tree number in site 2

Appendix E.

Fig. 1 Dense Sal forest in the study area (source data from M Sc. Thesis Nepal (1999)

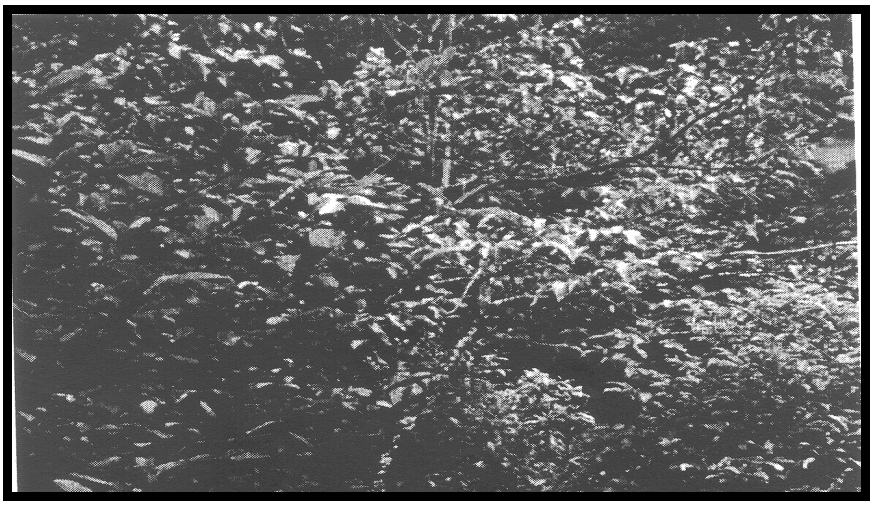


Fig. 2 Dense broad- leaved forest in the study area (source data from Thesis Nepal, 1999)

Fig. 3 *Dalbergia sissoo* plantation forest in the study area (source data from MSc. Thesis Nepal, 1999)

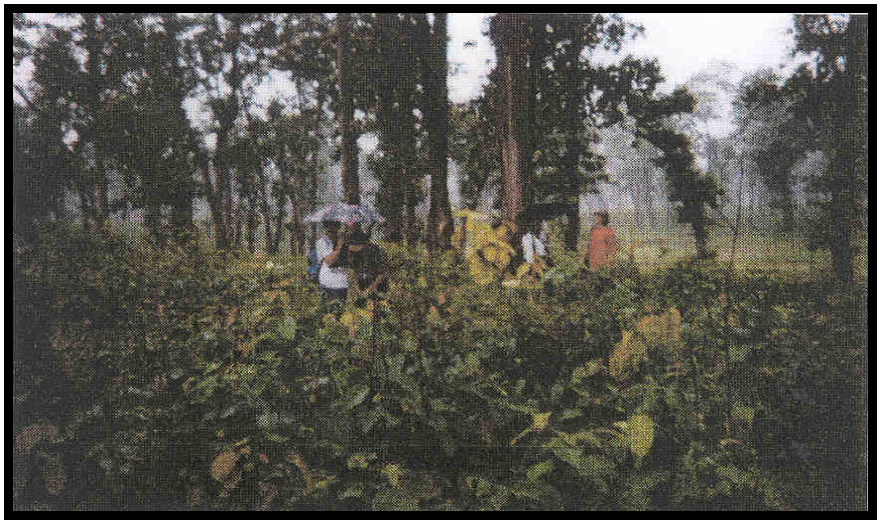


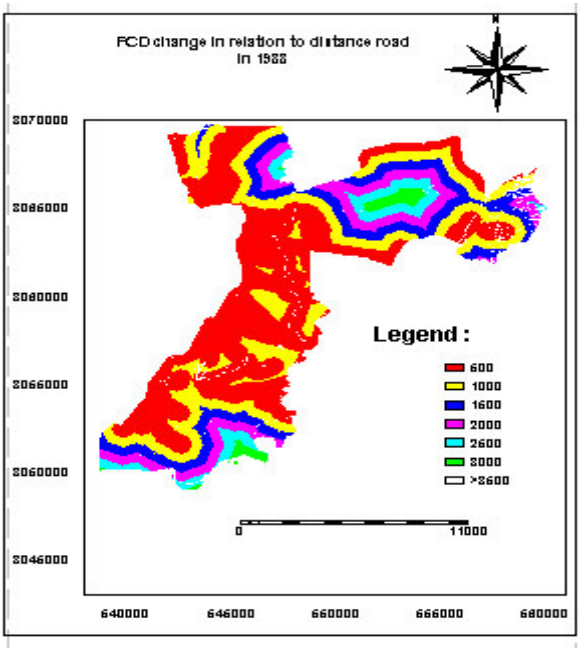
Fig. 4. Sal forest and its regeneration condition in the study area (source data from field report)

Fig. 5. Showing pile of wood stocking in brick factory (source data from 2001 field report)

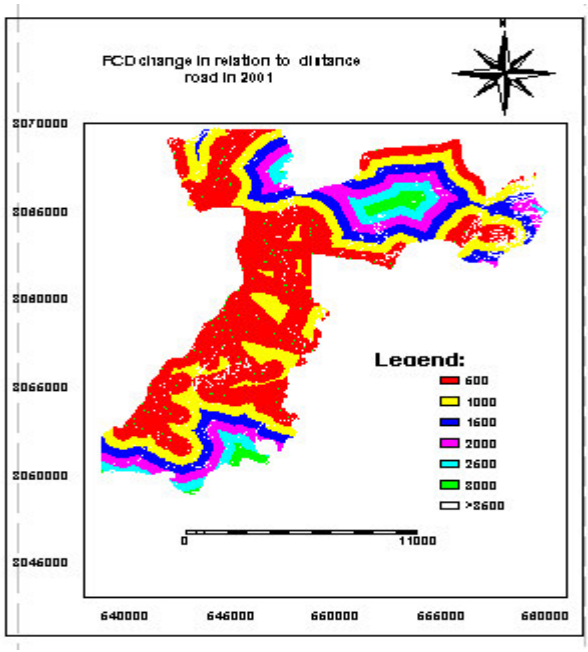
Fig. 6. Beekeeping boxes after conversion of forest in maize field (source data from 2001 field report)

Appendix F.

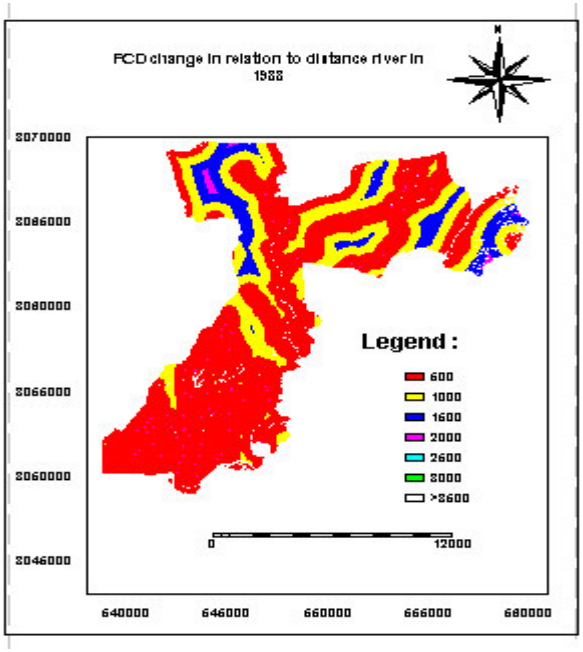
Map 1. FCD change in relation to distance road in 1988



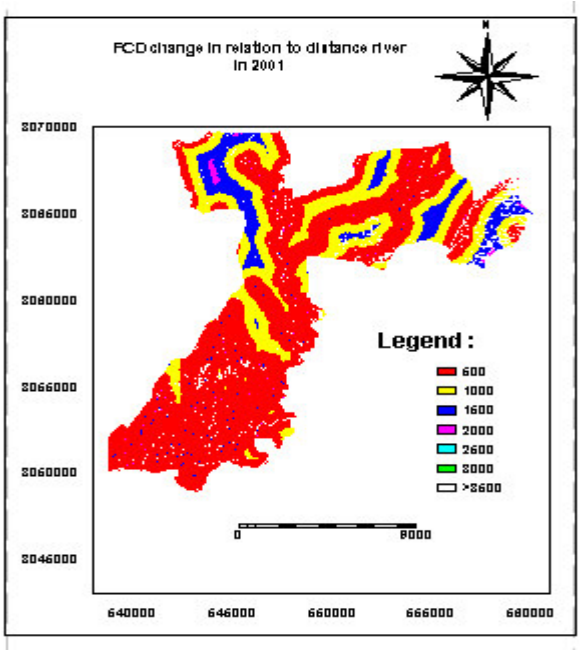
Map 2. FCD change in relation to distance road in 2001



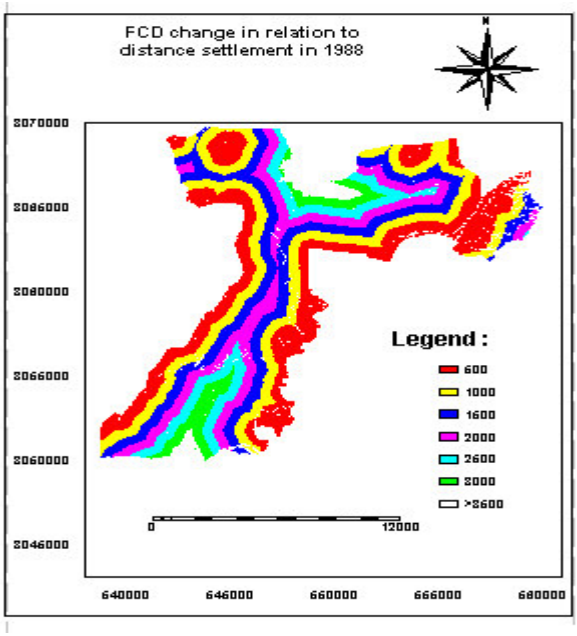
Map 3. FCD change in relation to distance river in 1988



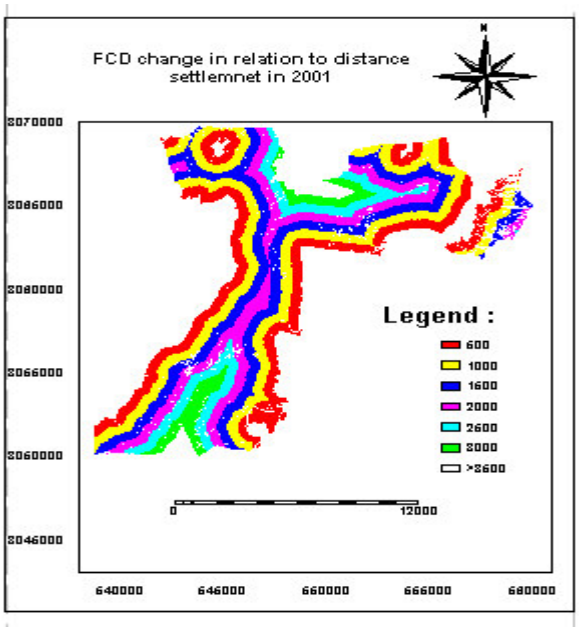
Map 4. FCD change in relation to distance river in 2001



Map 5. FCD change in relation to distance settled area in 1988



Map 6. FCD change in relation to distance settled area in 2001



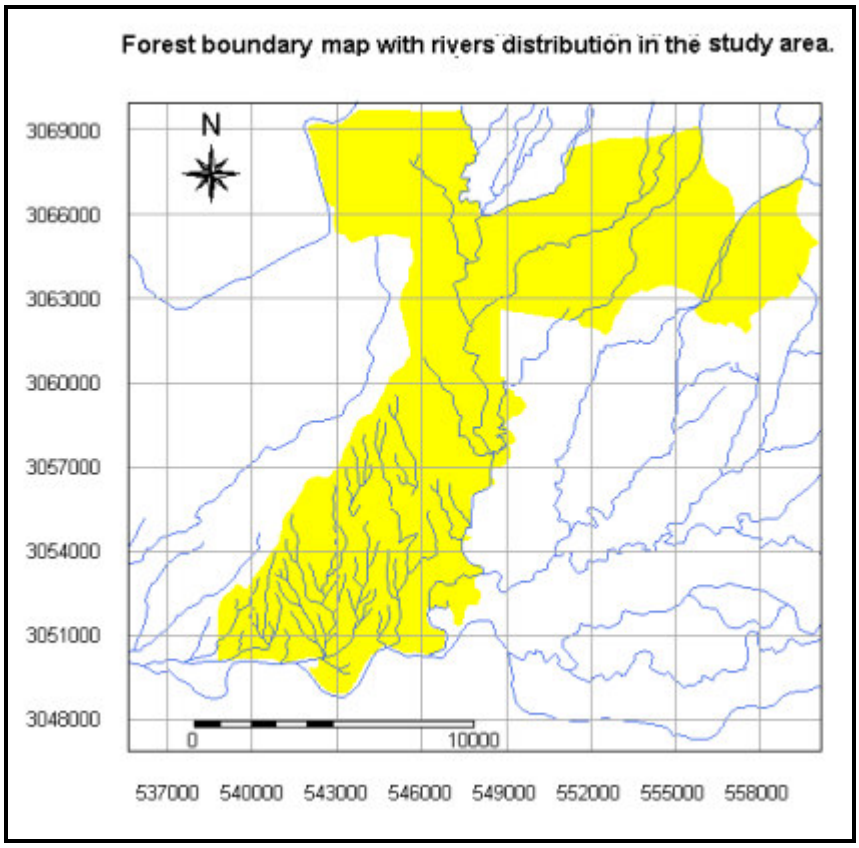


Figure 1. Yellow color shows the area covered by natural forest (based on data from 1994 topographic map) and blue rivers distribution.

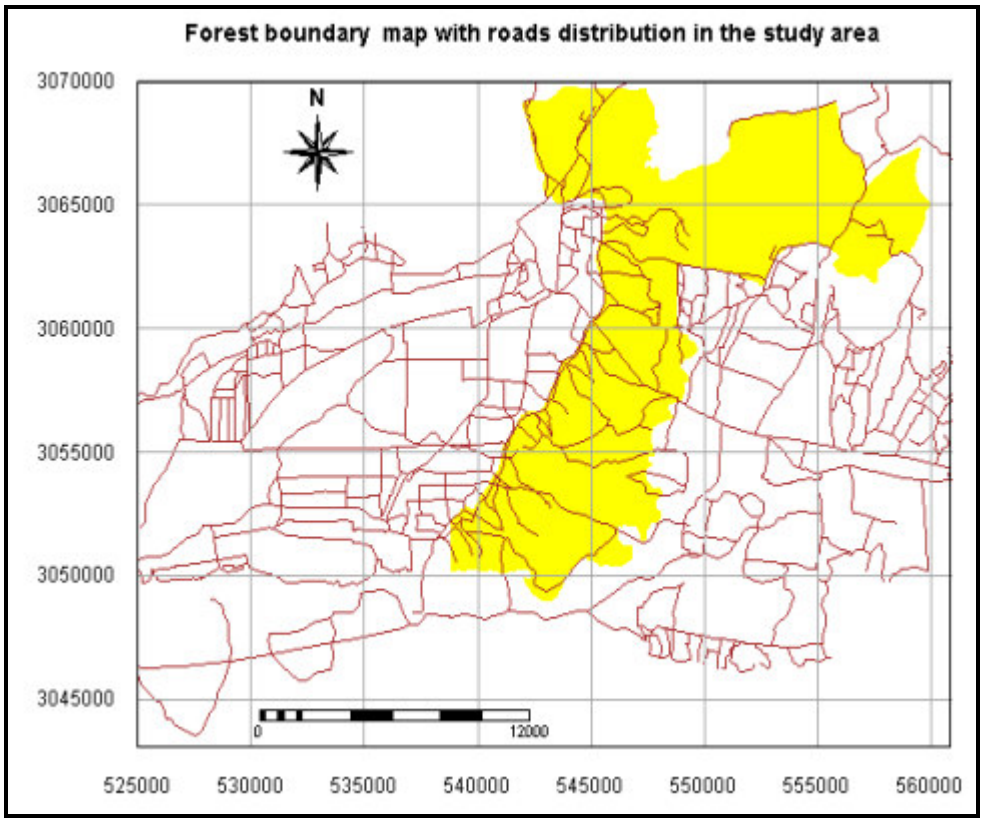


Figure 2. Yellow color shows the area covered by natural forest (based on data from 1994 topographic map) and brown roads distribution

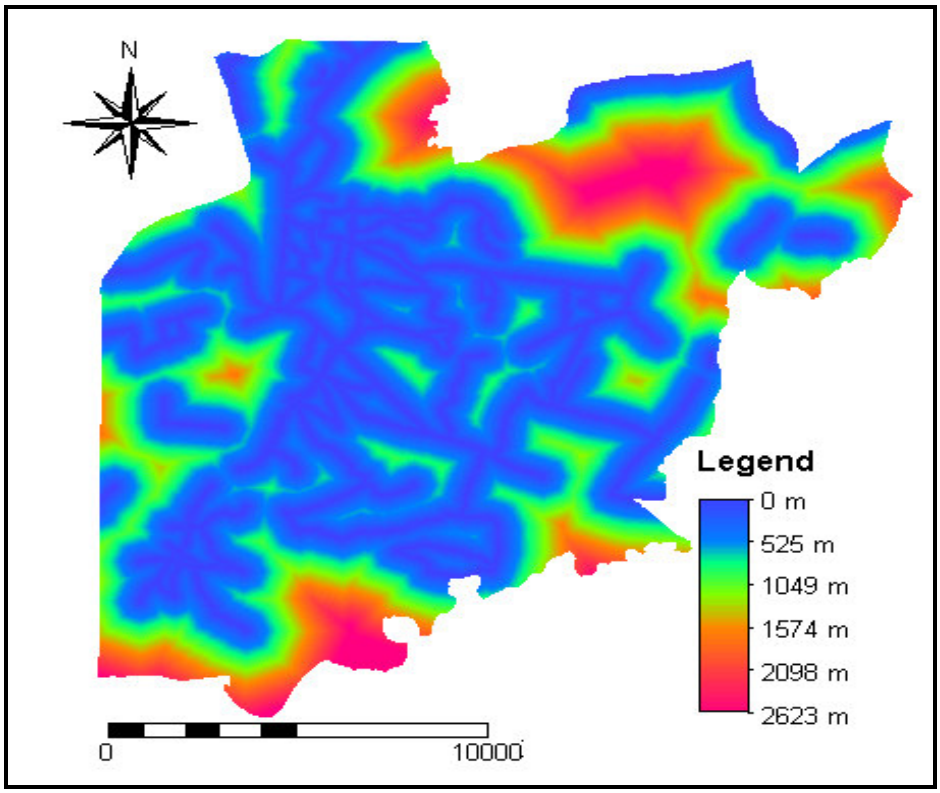


Figure 3. Distance calculation map of road in the study area.

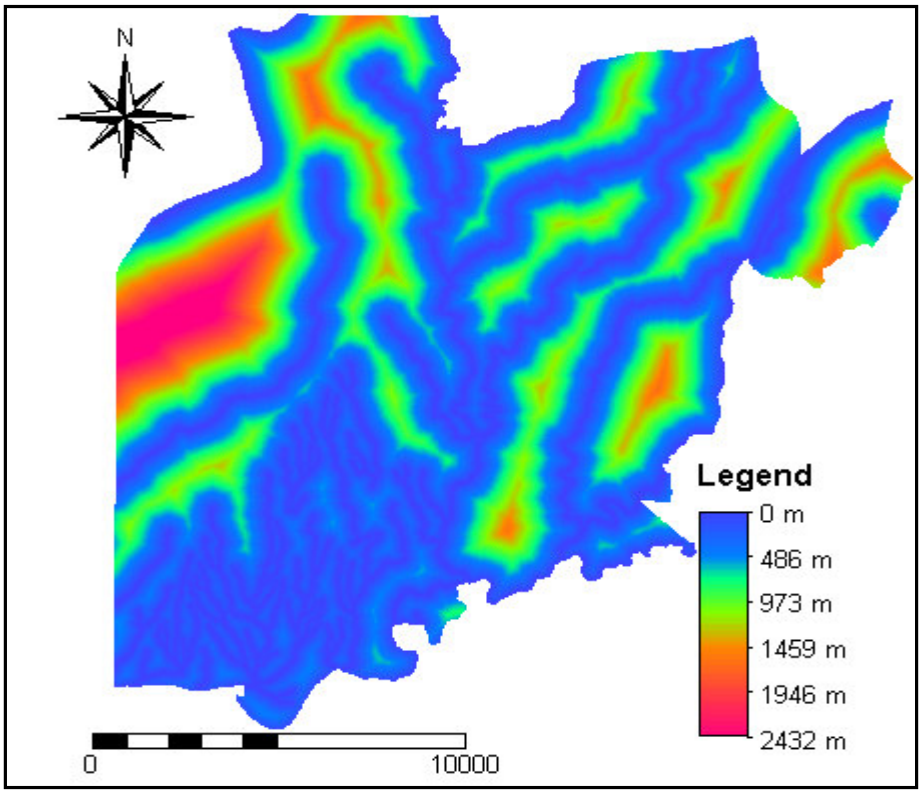


Figure 4. Distance calculation map of river in the study area.

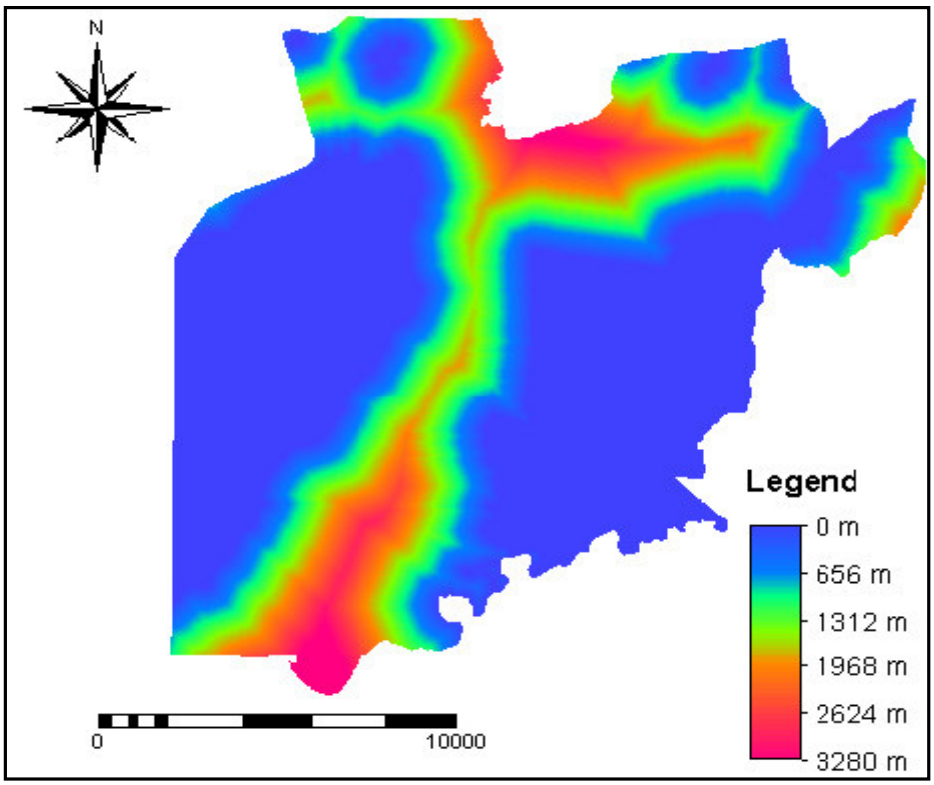


Figure 5. Distance calculation map of settled area in the study area.

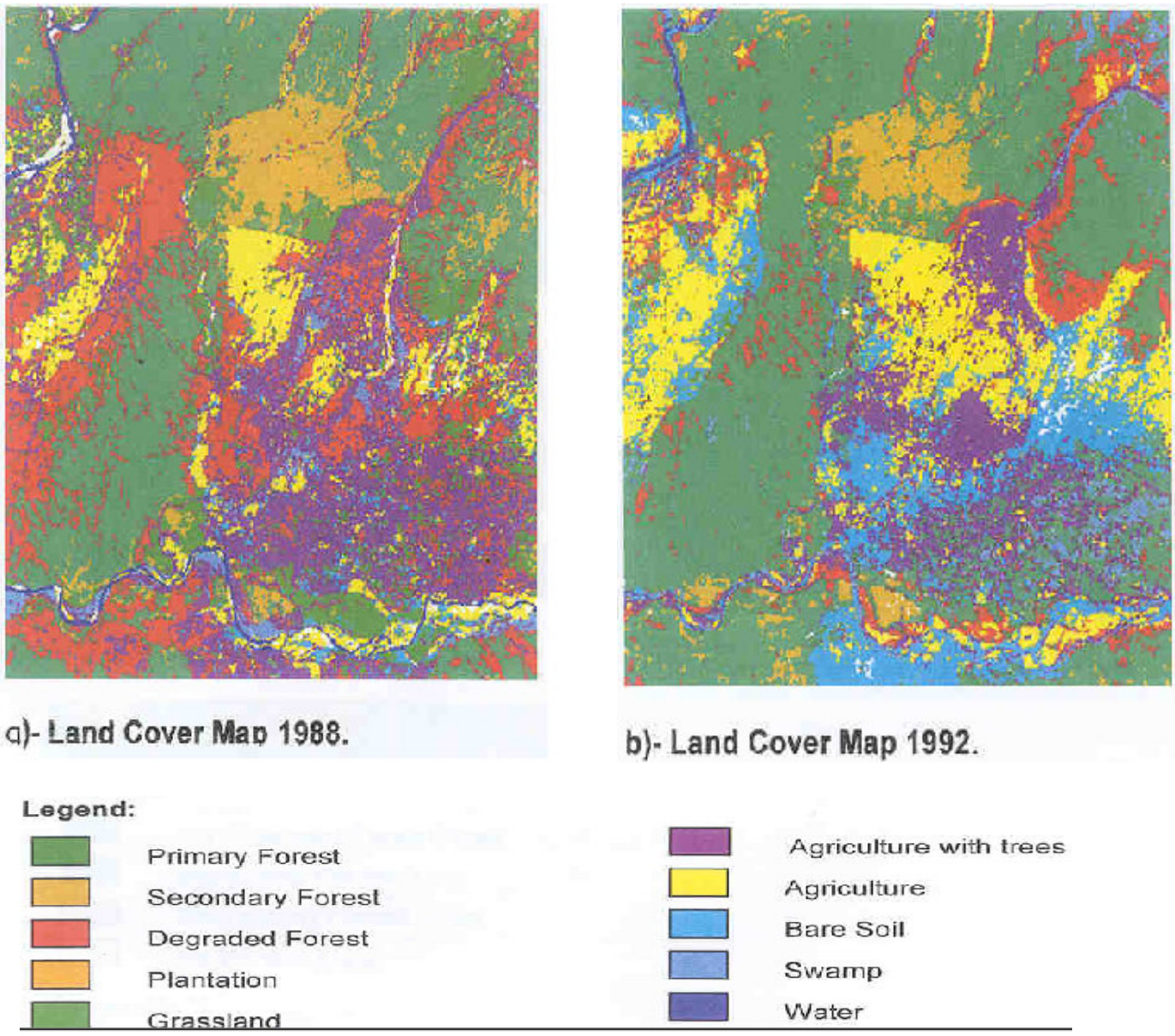
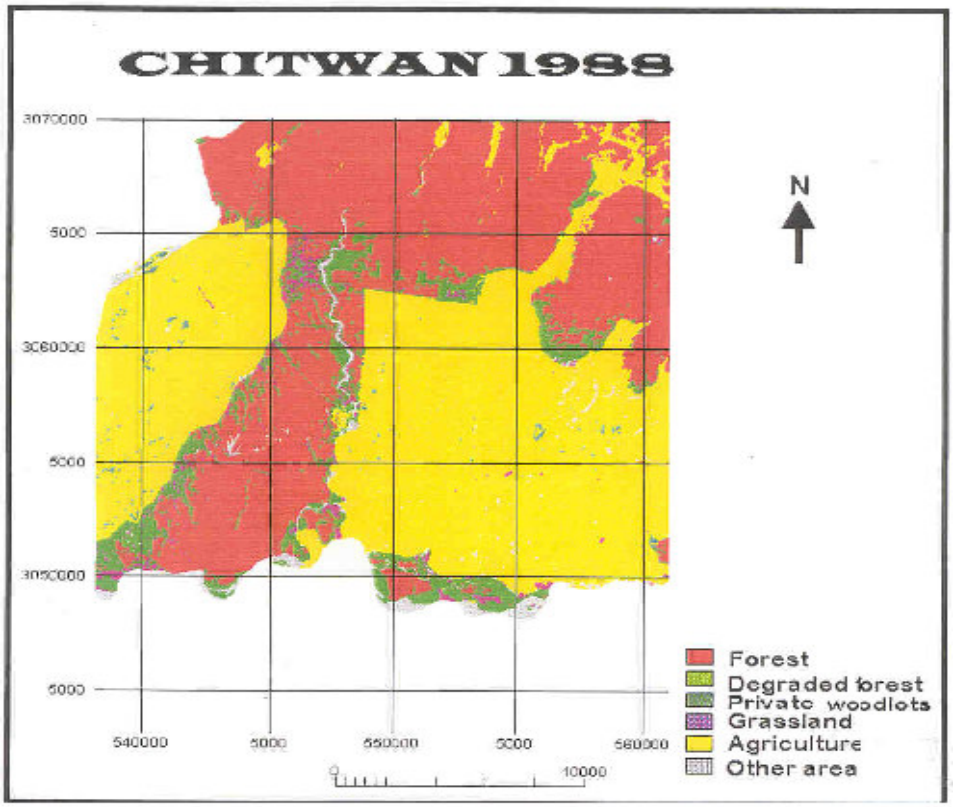


Figure 6. Land cover maps of 1988 and 1992 of the study area. Source data from Requene IFA (2000), ITC, Enschede.



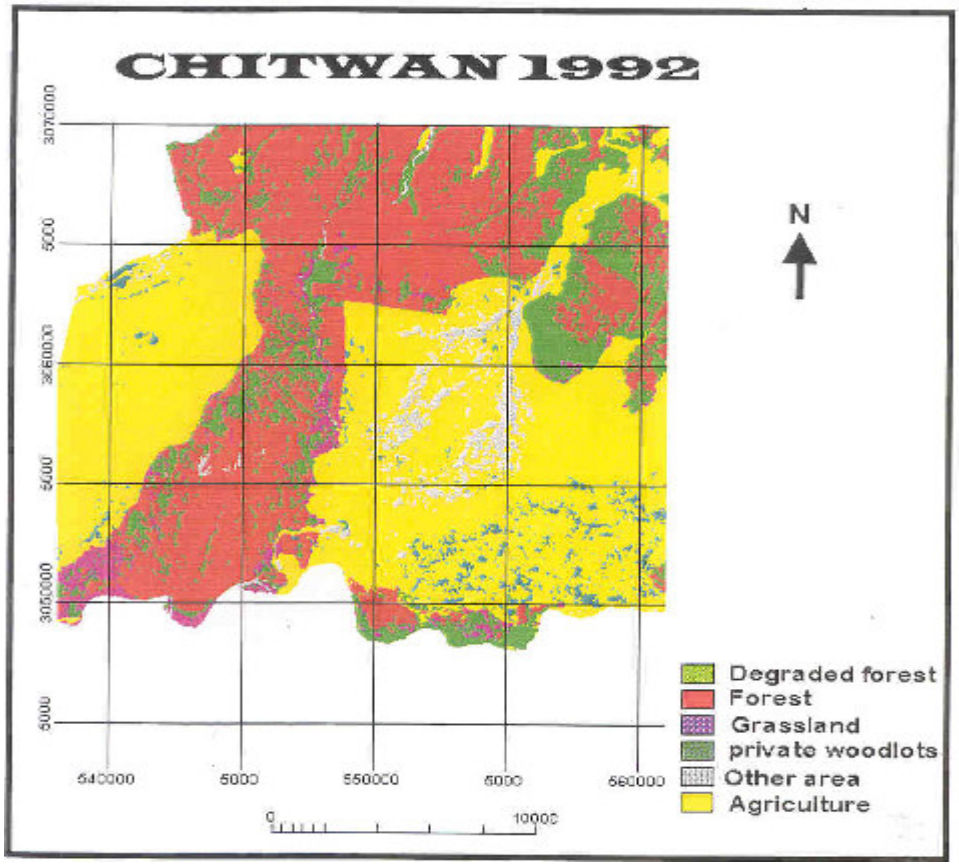


Figure 7. Map 1988 and 1992 showing land cover types in the study area. Source data from M.sc. thesis of S. M. Nepal (1999), ITC, Enschede.

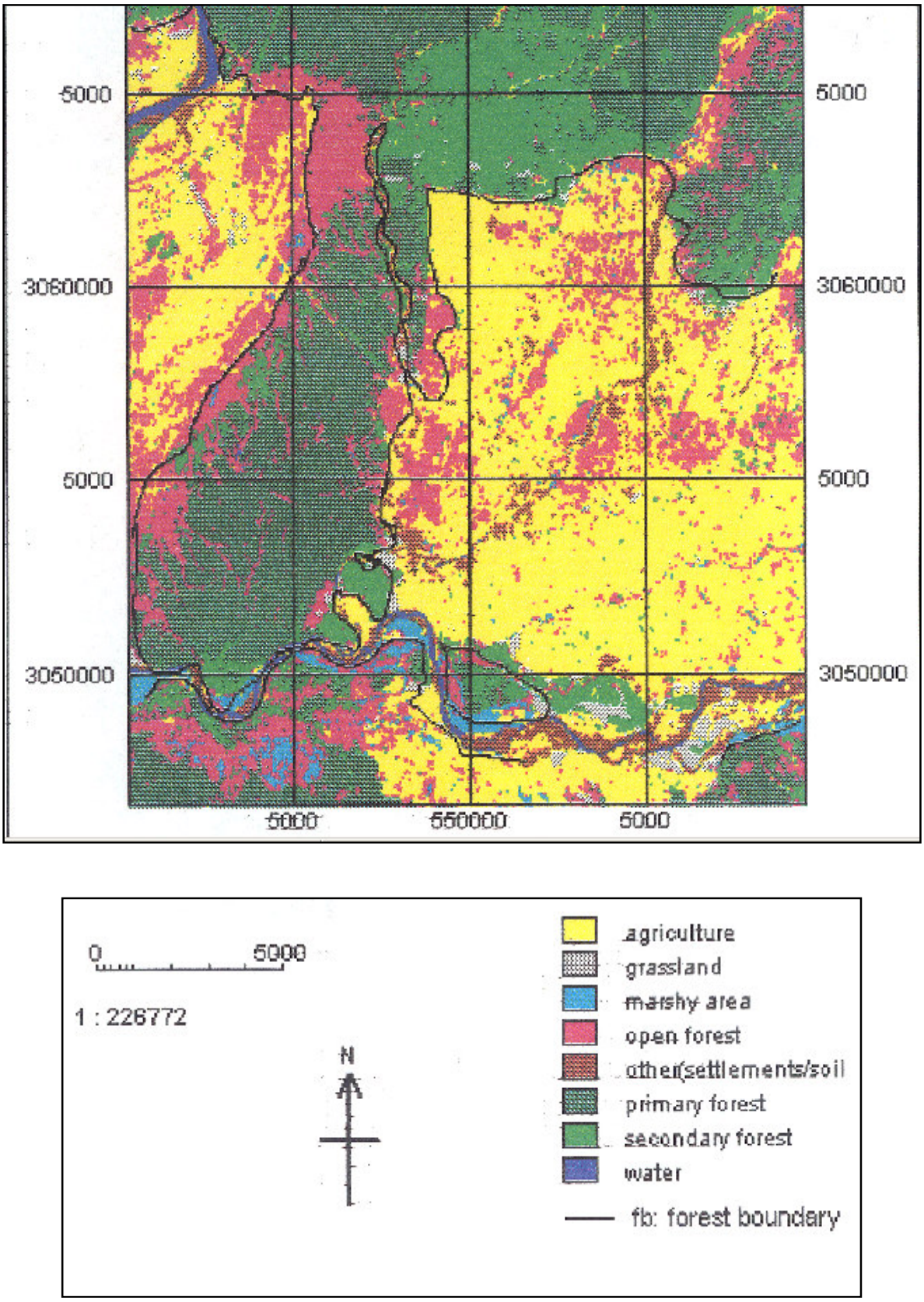


Figure 8. Classified Land sat TM image 1988 showing major land cover types in the study area. Source data from Mujuni IFA, (1999) ITC, Enschede.