Impact of Coal Mining on Vegetation: A Case Study in Jaintia Hills District of Meghalaya, India

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February, 2005

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by

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Thesis submitted to the International Institute for Geo-information Science and Earth Observation (ITC) in partial fulfilment of the requirements for the degree of Master of Science in Geoinformation Science and Earth Observation with specialisation in Natural Hazards Studies

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

Signed …………………….

Disclaimer

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

Acknowledgements

I express my profound indebtedness to my revered teachers Dr. S.P.S. Kushwaha, Head, Forestry and Ecology Division, Indian Institute of Remote Sensing, Dehradun and Dr. Y.A. Hussin, ITC, The Netherlands for their erudite guidance, analytical prowess and much needed critical comments during the thesis writing period.

I must record my gratefulness to Dr. V.K. Dadhwal, Dean, Indian Institute of Remote Sensing for providing me with necessary facilities during the project work.

I shall be grossly failing in my duties if I do not record my gratefulness to Er. V. Hari Prasad, Programme Coordinator, M.Sc. Geoinformation Science and Earth Observation with specialisation in Natural Hazard Studies, who unflinchingly rendered all possible help during the entire study period.

I am grateful to Dr. P.S. Roy, Deputy Director (RS & GIS Application Area), NRSA, Hyderabad and former Dean, IIRS for accepting my candidature for pursuing the course.

I must convey my thankfulness to Dr. C.J. van Westen, Programme Coordinator, the ITC counterpart for his constant help during my stay at ITC, the Netherlands.

I am very much thankful to Prof. R. S. Tripathi, former Coordinator, Regional Centre, NAEB, Shillong for his kind permission and officially sponsoring me to undertake the course.

I sincerely remain obliged to Dr. M.C. Porwal, Dr. S. Singh, Dr. I. J. Singh, Dr. D.N. Pant, Mr. K.K. Das and Dr. P.K. Joshi of Forestry and Ecology Division, IIRS, for their valuable suggestions and encouragement during the entire study period.

I owe my sincere gratitude and appreciation to my friends, Dr. O.P. Tripathi and Dr. K. Upadhayay of Department of Botany, North-Eastern Hill University, Shillong and Shri N. Odyao, Scientist, Botanical Survey of India, North-Eastern Circle, Shillong for their help in carrying out the field work and identifying the plant species.

My sincere appreciation goes to Shri M. Somorjit Singh and Miss Kuntala Bhusan, Scientists, NE-SAC, Shillong for their helping hand during the study.

Grateful thanks are also due to all my friends, Pete, Yogesh, Mohor, Nikhil, Subrata Nandy, Subroto Paul, Navin, Rajiv, Shailesh, Anusuya, Virender, Sudhira, Bikash, Hiten, Mukesh, Upakar for their compassion and forbearance at various phases of the study.

Last but not least, I remain ever grateful to all my family members for their perseverance, unstinted support and benevolence throughout the study period.

Dehradun (Kiranmay Sarma)
3rd Feb. 2005

Abstract

Mining causes massive damage to landscape and biological communities. Plant communities get disturbed due to mining activities and following the mining, the habitats become impoverished presenting a very rigorous condition for its growth. Nutrient deficient sandy spoils that results from the mining are hostile for it and the revegetation and reclamation strategies other than natural colonization are very tardy processes. The coal has been heavily extracted since ages in Jaintia Hills district of Meghalaya. The forests are the greatest victims of these activities, which can be gauged from the depletion of the forests in all the mine belts. As a result, many parts of the district have been converted from the original lush green landscape to mine spoils.

The main aim of this study are (i) to identify, map and determine the extent of vegetation cover and its condition in the coal mined and unmined areas (ii) to find relationship between spatial distribution of vegetation including its condition and mining and (iii) to assess the impact of coal mining on vegetation and to provide evidence for the hypothesis that mining influences the spatial distribution, composition and condition of vegetation. Multi-date remote sensing data were analysed for this purpose and plant community characteristics of the area and the impact of coal mining on them was assessed by comparing certain community attributes of the mined areas with that of the adjacent unmined area.

Due to extensive coal mining, large areas of the district has been turned into degraded land, creating unfavourable habitat condition for plant growth. The number of tree and shrub species got reduced due to mining activity. The number of herbaceous species colonizing the mined areas was found to be much higher than in unmined areas. The high importance value of *Pinus kesiya* in mining areas suggests its ability to grow in the disturbed environments. Higher importance value of *Schima wallichii* indicates the degraded environment of the area. Due to the dominance of one or two tree species Shannon-Weaver diversity index was much lower in the mined areas than the unmined areas. The broken-stick series model of dominance-diversity curves for the mined areas indicated lesser number of species occurring in these areas. There was stable tree population structure in unmined areas; density of young and middle-sized trees was higher than the older trees. However, in the mined areas, the tree density in all the girth classes was extremely low and did not follow any standard density diameter population curve. The contagious distribution pattern of species, prevailing in entire mining area, suggests the increase in fragmentation of the natural vegetation due to mining.

About 6 km^2 of the study area were changed from dense forest to open forest during 1975 and 1987. During 1987 and 1999 about 4 km^2 area of dense forest converted into open forest. The trend of change of open forest area to non-forest increased in passage of time. During the initial stage, the mining was carried out mostly in the dense forest. These forest areas got fragmented and existed as the open forest. There has been considerable impact on the open forest areas in recent years. The area under low fragmentation decreased significantly as the time passed. The high fragmentation areas, which were the areas at risk, increased in area that were previously under low fragmentation. The areas under high fragmentation are located close to mines. The non-forest area also increased with the passage of time.

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1. Introduction

1.1. Introduction

Mining tends to make a notable impact on the environment, the impacts varying in severity depending on whether the mine is working or abandoned, the mining methods used, and the geological conditions (Bell *et al.,* 2001). It causes massive damage to landscapes and biological communities of the earth (Down and Stock, 1977). Natural plant communities get disturbed and the habitats become impoverished due to mining, presenting a very rigorous condition for plant growth. The unscientific mining of minerals poses a serious threat to the environment, resulting in the reduction of forest cover, erosion of soil in a greater scale, pollution of air, water and land and reduction in biodiversity (UNESCO, 1985). The problems of waste rock damps become devastating to the landscape around mining areas (Goretti, 1998).

Mining operations, which involve extraction of minerals from the earth's crust is second only to agriculture as the world's oldest and important activity. In a sense, the history of mining is the history of civilization (Khoshoo, 1984). From the pre-historic days man has been interested about earth's mineral wealth. The crude stone implements of the early Paleolithic period, post-Neolithic pottery, the Egyptian pyramids, iron and copper smelting in various civilizations, and the modern steel-age are all testimony of mining activities of man (Sarma, 2002). Natural resources have been over-exploited for almost two centuries, without any concern for the environment.

Coal was known as burning rock and believed to possess supernatural power (Sharan *et al.,* 1994). It was known to the Chinese before Christian era and the Greeks knew about the use of coal in the 4^{th} century A.D. It was used as a domestic fuel in England in the 9^{th} century. The invention of the steam engine in England and the consequent industrial revolution in the 18^{th} century provided great impetus to coal mining. The demand for coal got further increased when coke made from bituminous coal began replacing charcoal in the iron ore smelting industries (Brown *et al.,* 1975). Today coal is used primarily for producing electricity and, to a lesser extent, by heavy industries such as iron and steel industries (Raven *et al.,* 1993). Coal contains a significant amount of ferrous sulphate in the form of pyrites. The exposure of pyrite to atmospheric oxygen through the mining operation, brings about an oxidation process in which pyrite is converted into ferrous sulphate and sulphuric acid in the presence of bacteria. The sulphuric acid thus formed, lowers the pH of the soil and water in the terrestrial and aquatic environments, respectively, which affects the population and activity of organisms inhabiting those environments. Chemicals released from the coal mines, overburden and tailings also contain high concentration of metals such as Cu, Cd, Fe, Hg and Zn, which also affect the organisms adversely.

The Indian sub-continent is replete with minerals and many states have rich coal resources. Soon after independence, India witnessed a spurt in the growth of heavy industries that needed a large amount of mining of coal and metals. Thus the mining operations in India began on a large scale in 1950s. Presently, in India, more than 80,000 ha of land are under various types of mining (Valdiya, 1988). Coal is the most abundantly available fossil fuel in India and provides a substantial part of energy needs. It is used for power generation, supply of energies to industry as well as for domestic needs.

India is highly dependent on coal for meeting its commercial energy requirements. India ranks the third largest coal producer of the world next only to China and USA. Coal mining in India was started in the year 1774 in the state of West Bengal. At the beginning of 20th century, the total production of coal was just about 6 million tonnes per year. The production was 154.30 million tones in 1985-86 and it reached 298 million tonnes in the year 1997-98. The expectation to reach the production of coal by 2000 A.D. was 417 million tonnes (Coal India, 1997).

In north-east India, coal mining was initiated by Medlicott in 1869 and 1874. Some coal occurrences in Jaintia Hills were examined by shallow drilling by Dias in 1962-63 and Goswami and Dhara in 1963-64 (Bulletin of Geological Survey of India, 1969). Commercial exploitation of coal in Meghalaya started in the Khasi Hills during the 19th century. Since most of the coal deposits were small and isolated and it was not amenable for scientific mining to be conducted in the organized sector and mining operations were left to the local miners to take up coal mining as a cottage industry. In due course of time, the tribal miners accepted coal mining as one of their customary rights. From Khasi Hills these activities proliferated to other parts of the state, viz., Jaintia Hills and Garo Hills in the beginning of the 1970s (Directorate of Mineral Resource, 1992).

Meghalaya, one of the seven states of north-east India, is bestowed with rich natural vegetation as well as large reserve of mineral resources. During the last few decades, there have been phenomenal increase in mining of coal, limestone, sillimanite and clay causing large-scale destruction and deterioration to the environment of the state. The forests and the mining are intimately linked. The forests are the greatest victims of the mining activities, which can be gauged from the denudation of the forest cover in all the mine belts. Because of the complex landholding systems, and exclusive rights of land owners on land resources as guaranteed under 6th Schedule of Indian constitution, very little governmental control can be exercised on the lands in Meghalaya. Mining is done under customary rights and are not covered by any mining acts, rules or any other legislations. No environmental acts and rules can be enforced in these areas. As a result, in most parts of the state coal is being indiscriminately mined in most unscientific manners, causing large-scale damage to the natural ecosystems (Tiwari, 1996).

Coal deposits of the state occur as thin seams, which range in thickness from 30 cm to 1.5 m in sedimentary rock, sandstone and shale of the Eocene age (Guha Roy, 1991). The coal deposits are found along the southern fringe of the Shillong plateau extending over a length of 400 km. In the hills of Meghalaya, the coal bearing sedimentary formations are sub-horizontal to gently dipping in nature. It is estimated that there is 562.8 million tonnes of coal reserve in 20 major or minor deposits distributed throughout the state. Some of the areas where extensive coal mining is going on within the state are: Laitryngew, Cherrapunjee, Laitduh, Mawbehlarkar, Mawsynram, Lumdidon, Langrin, Pynursla, Lyngkyrdem, Mawlong-Shella-Ishamati in Khasi Hills, Bapung, Lakadong, Sutnga, Jarain, Musiang-Lamare and Ioksi in Jaintia Hills and West Darrangiri, Siju, Pyndengru-Balphakram, Selsela Block in Garo Hills.

The total deposit of coal in Jaintia Hills district of the state is approximately 40 million tonnes spreading over patches of different sizes. The areas where coal mining is prominent are Bapung, Lakadong, Jarain-Shkentalang, Lumshnong, Malwar-Musiang-Lamare, Sutnga, Ioksi, Chyrmang and Mutang. Bapung has the largest deposit of 34 million tonnes covering an area of 12 km^2. The main characteristics of the coal found in Jaintia Hills are its low ash content, high volatile matter, high calorific value and comparatively high sulphur content. The coal is mostly sub-bituminous in character. The physical characteristics of the coal of Jaintia Hills district are that it is hard, lumpy, bright and jointed. Composition of the coal revealed by chemical analysis indicates moisture content between 0.4 to 9.2 percent, ash content between 1.3 to 24.7 percent, and sulphur content between 2.7 to 5.0 percent. The calorific value ranges from 5,694 to 8230 kilo calories/kilogram (Directorate of Mineral Resources, 1985).

The mining activities in Jaintia Hills district are small scale ventures controlled by individual owners of the land. Coal extraction is done by primitive sub-surface mining method commonly known as 'rat-hole' mining. In this method, the land is first cleared by cutting and removing the ground vegetation and then pits ranging from 5 to 100 m^2 are dug into the ground to reach the coal seam. Thereafter, tunnels are made into the seam sideways to extract coal which is first brought into the pit by using a conical basket or a wheel barrow and then taken out and dumped on nearby unmined area. Finally, the coal is carried by trucks to the larger dumping places near highways for its trade and transportation. Entire road sides in and around mining areas are used for piling of coal which is a major source of air, water and soil pollution. Off road movement of trucks and other vehicles in the area causes further damage to the ecology of the area. Hence, a large extent of the land is spoiled and denuded of vegetal cover not only by mining but also by dumping and storage of coal and associated vehicular movement (Figure 1.1). Mining operation, undoubtedly has brought wealth and employment opportunity in the area, but simultaneously has lead to extensive environmental degradation and erosion of traditional values in the society. Environmental problems associated with mining have been felt severely because of the region's fragile ecosystems and richness of biological and cultural diversity. The indiscriminate and unscientific mining, absence of post mining treatment and management of mined areas are making the fragile ecosystems more vulnerable to environmental degradation and leading to large scale land cover/ land use changes. The current modus operandi of sub-surface mining in the area generates huge quantity of mine spoil or overburden (consolidated and unconsolidated materials overlying the coal seam) in the form of gravels, rocks, sand, soil, etc., which are dumped over a large area adjacent to the mine pits (Figure 1.2). The dumping of overburden and coal destroys the surrounding vegetation and leads to severe soil and water pollution. Large-scale denudation of forest cover, scarcity of water, pollution of air, water and soil, and degradation of agricultural lands are some of the conspicuous environmental implications of coal mining in Jaintia Hills. The district of Jaintia Hills has been most extensively extracted in terms of coal, among all the districts of the state (Das Gupta, 1999). As a result of this, in many parts of the district there has been conversion of the original lush green landscape into mine spoils. The crude and unscientific 'rat-hole' method of mining adopted by the primitive operators lead to the degradation of the landscape (Sarma, 2002).

The studies related to the floristic composition of the mining areas have been conducted by several workers in different parts of the world (Cornwell, 1971; Fyles *et al.,* 1985; Game *et al.,* 1982; Singh and Jha, 1987; Prasad and Pandey, 1985). An understanding of the impact of mining on the environment particularly on vegetation characteristics is a prerequisite. However, only a few studies (Lyngdoh *et al.,* 1992; Lyngdoh, 1995; Pandey *et al.,* 1993; Das Gupta, 1999; Das Gupta *et al.,* 2002; Dkhar, 2002; Rai, 2002; Swer and Singh, 2004) have been conducted in this field of research in the coal mine affected areas in Jaintia Hills district of Meghalaya. Here an attempt has been made to find out the impact of coal mining on the vegetation by using remote sensing and geographic information system (GIS) techniques in Jaintia Hills district of Meghalaya.

(a) (b)

Figure 1.1: Rat-hole mining method - a crude mining technique is the sole method of coal extraction in the district (a). Damage to natural vegetation due to piling of coal (b).

(a) (b)

Figure 1.2: Landscape degradation (a) and damage to soil system (b) of the district due to coal mining.

1.2. Research Objectives

- To identify, map and determine the extent of vegetation and its condition in the coal mined and unmined areas by using temporal remote sensing data.
- To find relationship between spatial distribution of vegetation including its condition and mining.
- To assess the impact of coal mining on vegetation.

1.3. Research Questions

- What is the impact of coal mining on vegetation?
- What are the variations in condition and the spatial distribution of vegetation in mined and unmined areas?
- What might be the areas at risk for vegetation degradation?

1.4. Research Hypothesis

Mining influences the spatial distribution, composition and condition of vegetation.

1.5. Organisation of the Study

The present thesis on "Impact of coal mining on vegetation: a case study in Jaintia Hills district of Meghalaya, India" has been divided into five chapters.

1. Introduction
2. Study Area
3. Materials and Methods
4. Results and Discussion
5. General Discussion and Conclusions

1.6. Literature Review

Ecosystem disturbance may be defined as an event or series of events that alters the relationship of organisms and their habitat in time and space. Ecosystem disturbance by mining is an evitable fall out of industrialization and modern civilization. With accelerating demand for fuel energy the world over, coal is certainly going to retain its place of primacy well in to the future. Mining of coal causes enormous damage to the flora, fauna, hydrological relations and soil biological systems. Destruction of the vegetal cover during the mining activity is invariably accompanied by an extensive damage and loss of the system. The disturbed and haphazardly mixed infertile, consolidated and unconsolidated materials overlying a coal seam are known as overburdens. These overburdens when dumped in unmined areas in the vicinity of the coal mines create mine spoils. Nutrient deficient sandy spoils are generally hostile to plant growth and the regevetation and reclamation strategies other than natural colonization of mine spoils are very tardy process. Some important researches on the study of the impact of mining on the vegetation that relevant to the present study are being reviewed here.

Coal mine spoils when freshly tipped has a great range of particle size ranging from large pieces of shale to silt and clay (Molyneux, 1963). These mine spoils represent extremely rigid substrata for plant growth and development. Colonization, establishment and maintenance of vegetation on these spoils are enormously difficult. Among the factors which hinder the growth of plant species on these spoils, acidity merits special attention. Extreme acidity is caused due to the oxidation of iron pyrites (Chadwick, 1973). Continued acidification for many years may lead to die back of well established vegetation (Costigan *et al.,* 1981). Besides acids, coal mine spoils contain toxic levels of soluble elements such as Fe, Al, Mn and Cu. The physical factors which limit plant establishment and survival include high temperature, moisture stress (Richardson, 1975), soil particle size (Down, 1974) and compaction (Hall, 1957, Richardson, 1975). Soil fertility is also a major factor regulating plant growth. The two limiting nutrient on coal mine spoils are nitrogen and phosphorus (William, 1975). The shortage of organic matter is attributed to the absence of litter (Schafer *et al.,* 1980). Power (1978) considers soil physico-chemical characteristics like texture, pH, electrical conductivity, soluble Ca, Mg, Na, B, cation exchange capacity, exchangeable cations, gypsum and calcium carbonate equivalents as being crucial to the prediction of plant growth potential of mine overburdens with water holding capacity and infiltration rates as the other important variables. Bradshaw *et al.* (1975) and Bell and Ungar (1981) found high temperature and low moisture of surface coal mine spoils to be important factors limiting plant growth.

The colonization of plant species on coal mine spoils is influenced by the particle size of the soil derived from the overburden and coal mine wastes. This was conclusively proved by Richardson *et al.* (1971). They reported that with high clay content, the soils become water logged, whereas with high silt content, the soils become compact forming crust which often restrict seedling growth and entry of water and air into the soil system. pH is a major determinant in controlling plant growth on impoverished lands such as mine spoils. The average value of pH is 3.5, which indicates the acute acidity of the soil (Johnson and Bradshaw, 1977).

Intensive studies on the vegetation characteristics of the mined areas have been undertaken in different parts of the globe. The development of an ecosystem on china-clay wastes was studied by Dancer *et al.* (1977). The vegetation establishment on asbestos waste was studied by Moore and Zimmermann (1977). Saxena (1979) has provided a list of plant species for revegetation of gypsum, bentomite and fuller's earth mined areas in Rajasthan. Revegetation of iron-ore mine areas of Madhya Pradesh was studied by Prasad in 1989 who observed better growth performance of *Dalbergia sisso, Albizzia procera, Pongamia pinnata* etc. in the manured pits.

The factors contributing to the early colonization of mine dumps have given considerable attention by various workers. Bradshaw (1983), Chadwick (1973), Byrnes *et al.* (1973) found natural succession on coal mine spoils a slow process due to surface mining altering physico-chemical properties. These spoils present a special habitat where conditions are extremely unfavourable for plant growth and establishment. Marrs and Bradshaw (1980) and Marrs *et al.* (1980 and 1981) studied the development of ecosystem of China clay waste. Iron mine tailings were studied by Leisman (1957) and Shetron and Duffek (1970). Floristic diversity of lead mining wastes was studied by Clarke and Clarke (1981), lead and zinc by Kimmerer (1984) and copper mining wastes by Goodman and Gemmel (1978) and Veeranjaneyulu and Dhanaraju (1990).

Doerr and Guernsey (1956) dealt with the environmental effects of strip mining and underground mining, which create conspicuous landscape features and associated phenomena. Mukherjee (1987 and 1988) described about the land degradation associated with surface and sub-surface mining. Chadwick *et al.* (1987) outlined the environmental implications of increased coal production and utilization. Chaudhury (1992) dealt with the impact on mining activities on environment and also the management and protection of the mined areas.

The ecology of the mined lands has been the subject of extensive study the world over (Bradshaw *et al.,* 1986, Brenner *et al.,* 1994, Rodrigues *et al.,* 2004, Fretas *et al.,* 2004, Wiegleb *et al.,* 2001, Grant 2003, Bell *et al.,* 2001, Goretti 1998, Game *et al.,* 1982). In India, Banerjee (1981), Singh and Jha (1987), Valdiya (1988), Saxena (1979), Mann and Chatterjee (1979), Prakash (1998), Soni *et al.* (1989) have made pioneering contributions to the ecology of Indian mines. In the context of Meghalaya, studies have been done by Lyngdoh *et al.* (1992), Uma Shankar *et al.* (1993), Lyngdoh (1995), Tiwari (1996), Rai (1996), Das Gupta (1999), Das Gupta *et al.* (*2002*), Sarma (2002), Rai (2002), Dkhar (2002) and Swer and Singh (2004).

The state of Meghalaya is rich in mineral resources. The coal deposits occur as thin seams, which range in thickness from 30 cm to 1.5 m in sedimentary rocks, sandstone and shale of the Eocene age. The deposits of coal in the state are Cretaceous origin (Guha Roy, 1991). The unscientific mining of coal poses a serious threat to the environment (Dadhwal, 1999). Mining of coal causes massive damage to landscape and biological communities. The natural plant communities are disturbed by mining activity because the mining environment alters the climatic and edaphic complexes of the plant communities leading to a drastic reduction in the plant growth (Down and Stock, 1977). Acute scarcity of potable and irrigated water, pollution of air, water and soil, soil erosion, reduced soil fertility and loss of biodiversity are some of the manifestations of coal mining (Das Gupta *et al.,* 2002).

Rai (1996) involved in study of coal mining and environmental degradation with special reference to soil, water and air pollution of Meghalaya. Sarma (2002) has studied the impact of coal mining on the environment of Nokrek biosphere reserve, Meghalaya. He analysed different phyto-sociological characteristics of the mined and unmined areas of the biosphere reserve. The impact of coal mining on ecosystem health in Jaintia Hills district of Meghalaya was studied by Tiwari (1996) and Das Gupta *et al.* (2002) put efforts to give an ecological perspective of the district due to the impact of coal mining. Rai (2002) also alalysed the implication of coal mining on environment in the district. Dkhar (2002) studied the micro-landforms of the district, which were affected due to the sub-surface coal mining. Swer and Singh (2004) analysed the water quality and its availability in the coal mining areas of the district. They also studied the impact of mining on the aquatic fauna and flora of the region. Das Gupta (1999) analysed the vegetal and microbiological processes in coal mining affected areas. In his study vegetation changes on coal mine spoils in different years was carried out. Pandey *et al.* (1993) studied vegetation and soil of the coal mining areas of the district. Physico-chemical properties in the aquatic system in the mining affected areas was analysed by Sharma and Das (1993). The study related to the microbiology of soil and water bodies was carried out by Tiwari and Das Gupta (1993). Socio-economic, anthropological and epidemiological impact of mining was studied by Mishra and Lyngdoh (1993) and Pathak and Dkhar (1993).

There have been several major developments in the assessment of forest condition by visual methods over the past decades. Remote sensing and GIS techniques are useful to identify the areas of degradation due to mining activity. These are important tools for studying the pattern of vegetation dynamics. The changes of land cover are invariably associated with mining of natural resources. Remote sensing provides multi-spectral and multi-temporal synoptic coverages for any area of interest. The satellite data provides a permanent and authentic record of the land-use patterns of a particular area at any given time, which can be re-used for verification and re-assessment. Kushwaha (1990) explained the use of multi-time data in detecting changes in the forest cover. GIS provides the facility to integrate multi-disciplinary data for dedicated interpretations in an easy and logical way. This integrated approach proves to be time saving and cost-effective (Prakash and Gupta, 1998). Satellite data has provided an important basis for vegetation mapping, monitoring and understanding ecosystem functions, primarily through the relationships between reflectance and vegetation structure and composition (Joshi *et al.,* 2003). Kushwaha *et al.* (2000) studied the land area change and habitat suitability analysis in the national park. Kushwaha and Kuntz (1993) analysed the changes in the environment in the tropical forests of north-east India by using multi-time remote sensing data. Airborne multi-spectral techniques are the most effective way to detect and monitor vegetation damage at mine sites and have been used successfully by Singh Roy and Kruse (1991), King (1993) and Singh Roy (1995). Multi-spectral remote sensing technique can detect the vegetation damage caused by the acid drainage from mine and mill tailings and waste rock and can monitor regeneration success at sites undergoing restoration. Graham *et al.* (1994) used Principal Component Analysis technique on Landsat Thematic Mapper images to monitor vegetation change in large areas affected by iron ore mining operation at Noranda, Quebec. The normalized difference vegetation index (NDVI) is an index that provides a standard method of comparing vegetation greenness between satellite imageries. This can be used as an indicator of relative biomass and greenness (Boone *et al.,* 2000, Chen, 1998). This is used to calculate primary production, dominant species, and anthropogenic impact, and stocking rates with the help of field study (Ricotta *et al.,* 1999; Paruelo *et al.*, 1997).

Prakash and Gupta (1998) studied the impact of coal mining on the land use changes by using temporal remote sensing data. Change detection analysis method was conducted in their study. Koster and Slob (1994), Scheijbal (1995), Ghosh (1998), Rathore and Wright (1993) studied the changes and impact on the land use/ land cover due to the mining activities. Goretti (1998) concluded the result that the vegetal cover got lost due to the spread out of waste materials haphazardly, which were coming out from the mines, in and around the coal mining.

2. Study Area

2.1. Study Area

Jaintia Hills district is located in the eastern most part of Meghalaya. It lies between 91°58'E to 92°50'E longitudes and 25°02'N to 25°45'N latitudes. The district is bounded in the north and east by the state of Assam; west by East Khasi Hills district of the state and south by Bangladesh (Figure 2.1). The total area of the district is 3819 km^2, which is about 17 percent of the total area of the state.

2.2. Geology

Jaintia Hills district of Meghalaya form a continuous part of the Meghalaya Plateau that represents a remnant of the ancient plateau of Pre-Cambrian Indian peninsular shield. The district is composed of a variety of rock formations ranging from Pre-Cambrian to Recent. The Pre-Cambrian formation is traversed by swarms of dykes and sills of both acidic and basic nature. The major part of the district is covered by the rocks of Jaintia series of Eocene period and Barail and Simsang formation of Oligocene periods. A considerable portion is covered by the Gneissic Complex of Pre-Cambrian. Tertiary Formation of Shangpung and Laskein are encountered with the host of Quartzites and Gneissic rocks (Figure 2.2). The general stratigraphic sequence of the formation in Jaintia Hills is given Table 2.1. The consolidated hard crystalline rocks of granite gneiss, amphibolite, poroxenite, carbonatites along with quartzites of Pre-Cambrian period occur in the northern part occupying an area of about 1300 km^2 mainly in the Thadlaskein and Laskein C.D. Blocks. The rocks are highly fractured and jointed and were subjected to intense weathering. The Shillong group of rocks including granite, schist, conglomerate etc., overlies the gneissic complex and are marked by the presence of sills and dykes. The Tertiary group of rocks is represented by the Shella formation comprising alterations of sandstone and limestone and cover extensive areas of Amlarem and Khliehriat C.D. Blocks of the district. These also include formation of Kopili, Borail, Surma and Dupitala. The Quaternary deposits (older alluvium) overlie the Tertiary rocks. They occur in separate patches along the southern border of the district. These deposits include assorted pebbles with coarse and brown coloured clay. Recent alluvium is found in the river valleys and consists of fine silt and light to dark grey clay with pockets and layers of coarse sand and shingles. From the structural point of view the Gneissic group of rocks show evidence of basement deformation through intricate folding and faulting, having a general trend of NE-SW. The Shillong group of rocks usually shows broad open folds with a steep dipping zone, apparently due to faulting.

In the southern part, the predominant structural feature is the Dawki fault that runs in E-W direction and continues towards east in the North Cachar Hills district of Assam. At the closure of the Jurassic period, faulting made the southern block to subside and the area the northern block upheaved. The rate of subsidence gradually slowed down towards Paleocene-Eocene times during which the area attained a stable shelf condition and the calcareous formation of the Jaintia group were deposited (Anon, 1964).

The district of Jaintia Hills reveals that most of the lineaments have NE-SW trend but a few have NNE, SSW and ENE-WSW. Concentration of lineaments in the western part shows that this part had more tectonic activities than the other parts.

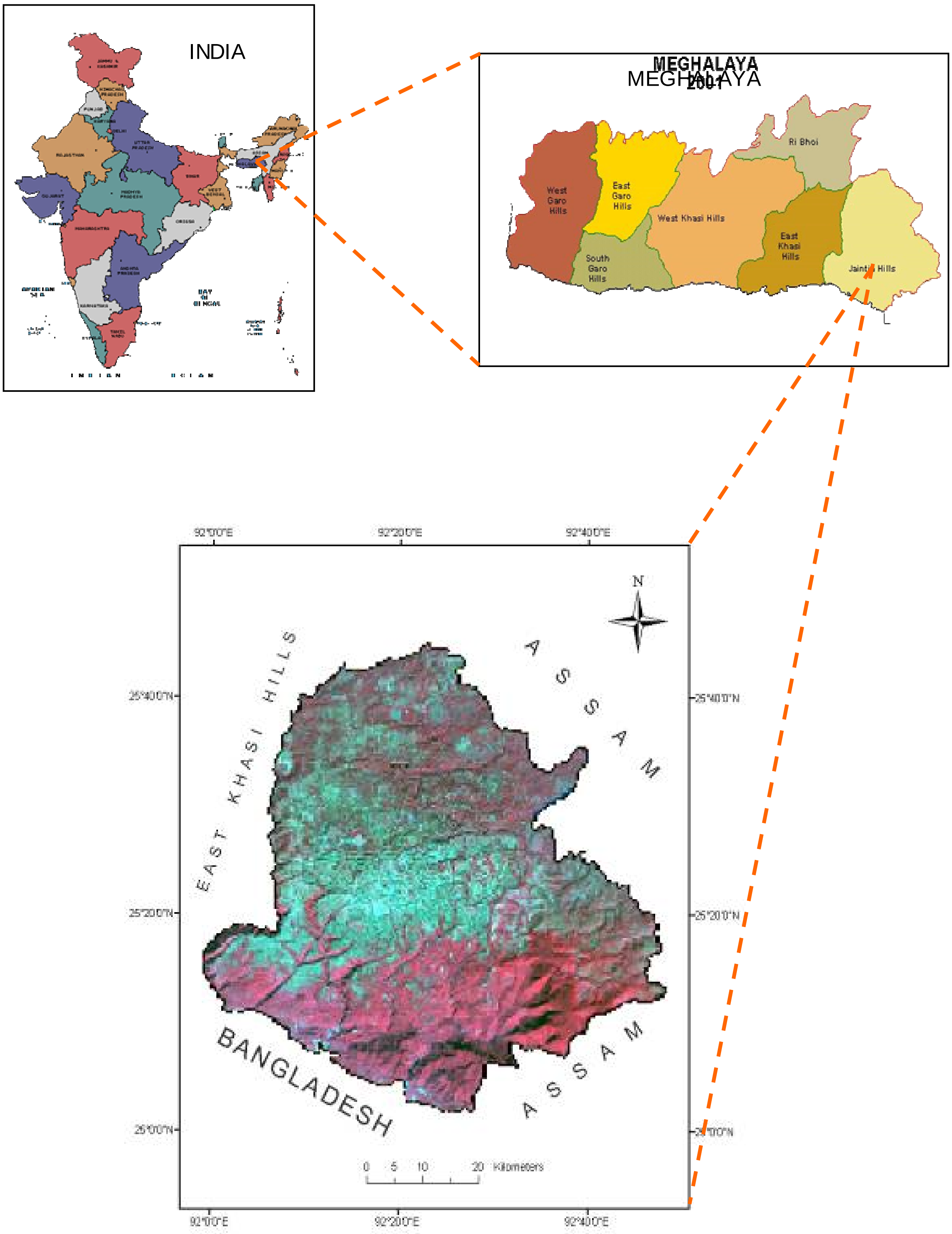

Figure 2.1: Location of Jaintia Hills district in Meghalaya, India.

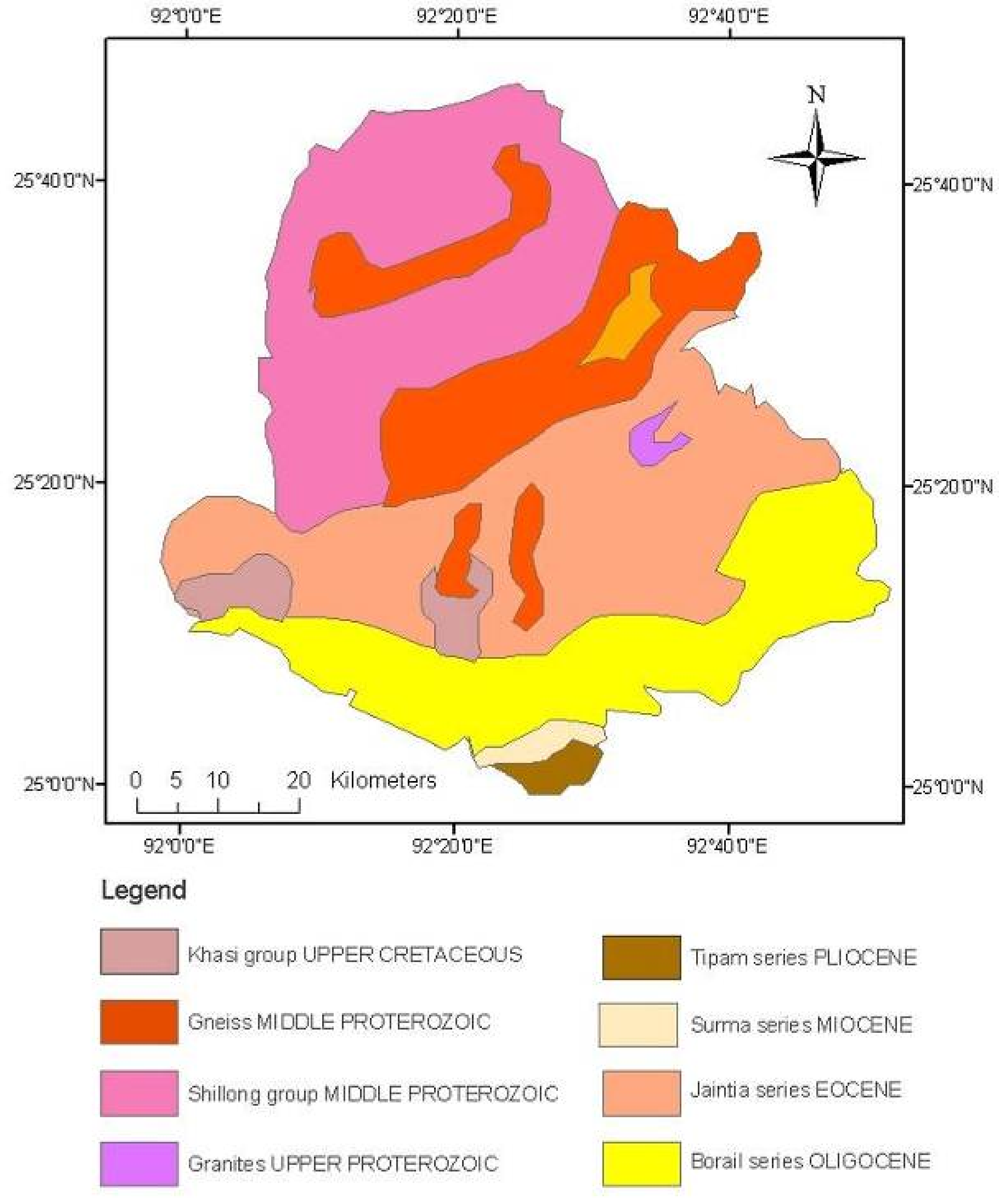

Figure 2.2: Geology of Jaintia Hills district (Geological Survey of India, 1974).

Table 2.1: Lithostratigraphic Succession of Jaintia Hills district

Age	Group	Formation	Rock type
Recent	Newer alluvium (Thickness not known)	Unclassified	Sand, silt and clay
Pleistocene	Older alluvium (Thickness not known)	Unclassified	Sand, clay, pebble, gravel and boulder deposits
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Mio-Pliocene	Dupitila		Mottled clays, felsphathic sandstone and conglomerate
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Oligo-Miocene	Surma		Sandstone, shale, siltstone, mudstone
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Oligocene	Barail		Hard, compact, fine grained grey-sandstone, shale, siltstone
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Eocene	Jaintia	Kopili	Shale, sandstone, marl
		Shella	Alteration of sndstone-limestone
		Langpar	Calcareous shale, sandstone, limestone
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Proterozoic	Intrusives		Porphyrytic and coarse granite, dolerites
	Shillong		Quartzites, phyllites, conglomerates
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Precambrian	Gneissic Complex		Biotite gneiss, granitic gneiss, migmatite, mica, schist, amphibolite

Source: Anon, 1974

2.3. Physiography and Drainage

The relative relief of the district is 1200 m. The elevation ranges from 76m (at Dawki) and 1627m (at Maryngksih). Physiographically the district is divided into three broad divisions. They are (i) the northern hills, (ii) the central plateau or the central Jowai upland and (iii) the southern escarpment. The northern hills exhibit undulating topography. Denudational hills and less dissected topography covers the northern part of the district. The area is less dissected showing youthful topography with denudational hills trending N-S, E-W, NE-SW. The central plateau is characterized by rolling mounds and hummocks of gentle height and shows flat topography. The southern escarpment exhibits denudo structural hills, highly dissected undulating topography with sharp crested hills, deep gorges and waterfalls. The region is at higher elevation than the northern hills. The district is drained in the north by the Umkhen river, in the northeast by Kopili river and its main tributaries like Kharkor, Saipung, Umluren, Myntang, Mynriang and Litang. In the southern part, the district is drained by Myntdu river and its tributaries. The main tributaries are Umlatang, Lynriang, Lubha, Umlunar and Lukha. In the west Umngot river separating the East Khasi Hills district with the Jaintia Hills.

2.4. Climate

The district experiences a tropical monsoon climate. From the prevailing weather conditions the rainy season occurs during mid May to September. October and November is the transition period between rainy and winter seasons and it represents the autumn. The period between December and February is characterized by cold and dry weather conditions. The period between March to mid-May is warmer. The annual rainfall from 1991 to 2001 of the district varies from 3797 mm and 7912 mm. December is the driest month as it contributes average rainfall of 18.8 mm and June is the wettest month with average rainfall of 1326.2 mm. It is observed that summer months (May to September) only contribute more than 70 percent of the total rainfall. August is the hottest month of the district with average minimum and maximum temperatures of 18.4°C and 24.5°C, respectively. The coldest month is January where the average minimum and maximum temperatures are 7.8°C and 15.6°C (Figure 2.3). The average relative humidity is highest in the month of July (85.2 percent) while December records the lowest relative humidity of 61.2 percent.

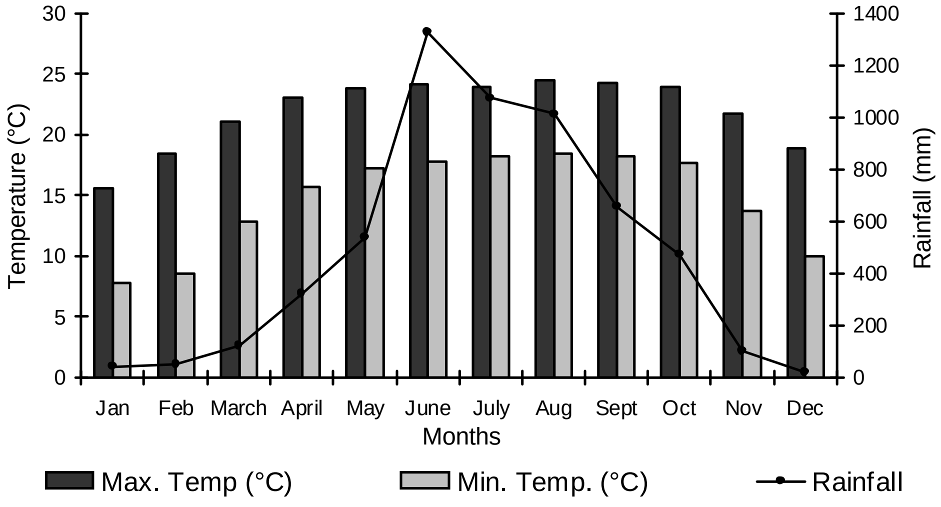

Figure 2.3: Monthly average maximum and minimum temperature and rainfall in Jowai, the district headquarters of Jaintia Hills (Mean of 1991 to 2001).

2.5. Soil

The soil is mostly sandy, reddish brown to yellow brown in colour, acidic in reaction with low water holding capacity and has poor contents of organic matter and nutrients. The pH value ranges between 4.1 to 5.6. The concentration of organic carbon content varies from 0.28 to 3.1 percent. Low phosphorus content is the characteristics of the soil of the district, varying between 1.8 and 4.5 kg/ha. The potassium content ranges between 28.0 and 112.0 kg/ha, which is quite lower than normal soil (Dkhar 2002).

2.6. Natural Vegetation

The district of Jaintia Hills claims to have the biggest forest reserve in the state of Meghalaya. According to the 1991 Census, the total area under forest in the district is 1436.1 km^2, which is 37.6% of the total area of the district. The natural vegetation of the district is subtropical (Chouhan and Singh, 1992). The large scale unscientific land use practices have resulted in the depletion of primary forest and colonization of the degraded sites by *Pinus kesiya,* which grows well to develop into secondary forests. Besides, the forest floor is covered with the species like *Eupatorium adenophorum, Lantana camara, Rubus* sp. *Paspalum orbiculare, Isachne himalaica, Globba clarkii* etc. The presence of isolated patches of degraded forests amidst the grassland imparts a savanna like appearance to the landscape of the region. The acidic and highly impoverished shallow soil layer is neither conductive for regeneration through seeds nor for healthy plant growth.

2.7. Population

According to the Census of India, 2001, the total population of the district is 295692. The literacy rate is 52.8 percent. The settlement pattern in the district is mainly compact or nucleated.

2.8. Coal Deposits and Coal Fields

In Meghalaya, coal occurrence is confined to the Tertiary sediments. The coal is deposited over a platform (Shillong plateau) under stable shelf conditions. The coal occurrences are developed more or less along the southern fringe of the state. The coalfields of the Jaintia Hills are small and spread out in different patches. Coal occurs in nine important deposits of the district. They are Bapung, Lakadong, Jarain-Shkentalang, Lumshnong, Malwar-Musiang-Lamare, Sutnga, Ioksi, Chyrmang and Mutang. Jaintia Hills district has a total coal deposit of about 40 million tonnes, which is only 7 percent of the total coal deposits of the state (Table 2.2). The district has been most extensively exploited in terms of coal, though it has the lowest deposits among all the districts. The district contributes more than 74 percent of the total coal production of the state (Table 2.3).

Table 2.2: Coal deposits (million tonnes) in different districts of Meghalaya

District	**Deposit**	**% of deposit**
Khasi Hills	164.57	29.2
Garo Hills	359	63.8
Jaintia Hills	39.25	7.0
State	**562.82**	**100**

Source: Directorate of Mineral Resources, Government of Meghalaya, 2003

Table 2.3: Coal production ('000 tonnes) and percentage in Jaintia Hills district of Meghalaya

Year	Meghalaya	Jaintia Hills	% of the district
1992-1993	3487.7	3040.80	87.18
1993-1994	2583.5	2062.20	79.82
1994-1995	3266.2	2389.70	73.16
1995-1996	3247.5	2159.50	66.49
1996-1997	3240.9	2273.60	70.15
1997-1998	3233.5	2414.60	74.67
1998-1999	4237.8	3246.10	76.59
1999-2000	4057.0	2935.00	72.34
2000-2001	4160.8	2839.80	68.25
2001-2002	5149.32	3869.32	75.14
Total	**36664.22**	**27230.62**	**74.27**

Source: Directorate of Mineral Resources, Government of Meghalaya, 2003

2.8.1. Bapung Area

Bapung coalfield has the largest deposit of coal (34 million tonnes) covering an area of 12 km^2. Two coal seams producing good quality coal occur within the undifferentiated Sylhet sandstone in and around Bapung (25°25' N and 91°49'E). The lower seam varies from 0.3 to 1.2m in thickness. The upper seam is thin, and the thickness is 0.3m. The NH-44 passes through the heart of the coalfield connecting Shillong and Silchar. The area represents a vast undulating surface with gentle slopes towards south. The general elevation varies from 1073m to 1370m above mean sea level (Rai, 2002). The coal seams around Bapung are hard, lumpy, bright and sub-bituminous type. The coal shows the moisture content from 2.2 to 9.2 percent, ash from 2.6 to 7.8 percent, volatile matter from 38.3 to 44.3 percent, fixed carbon from 46.2 to 52.3 percent, sulphur from 3.2 to 7.1 percent and calorific value from 6080 to 7494 k. cal/kg (DMR, 1985).

2.8.2. Lakadong Area

The Lakadong coal field covering the Umlatdoh (25°12'N and 92°17'E) plateau between the Myntdu and Prang rivers in the southern part of the district. Coal occurrence is found around Umlatdoh and Pamsaru area. The reserve of coal has been estimated to be 1.5 million tonnes and exposes a very irregular and inconsistent coal seam varying from 0.3 to 3.0m in thickness. This spreads over an area of 3 km^2. The coal shows the moisture content from 0.4 to 0.8 percent, ash from 2.3 to 24.7 percent, volatile matter from 29.7 to 33.5 percent, fixed carbon from 44.7 to 59.8 percent, sulphur from 3.4 to 4.9 percent and calorific value from 5694 to 7500 k. cal/kg (DMR, 1985).

2.8.3. Jarain-Shkentalang

The Jarain-Shkentalang area is located in the western part of the district. The total inferred reserve of coal is 1.1 million tonnes covering an area of 2.8 km^2. In Jarain there is only one coal seam with a thickness of 0.3 to 1.1m, whereas there are two coal seams in the Shkentalang coalfield that ranges from 0.1 to 1.0m. The coal found in the Shkentalang is bright and hard but in Jarain area coal is soft and friable (GSI, 1974). The coal shows the moisture content from 1.2 to 1.6 percent, ash from 4.4 to 6.7 percent, volatile matter from 41.6 to 48.1 percent, fixed carbon from 45.9 to 50.5 percent, sulphur is 2.7 percent and calorific value is 6944 k. cal/kg (DMR, 1985).

2.8.4. Lumshnong

Several isolated exposures of coal have been recorded to the west and southwest of Lumshnong (25°10'N and 92°23'E) over an area of 0.6 km^2. The estimated reserve of coal in this field is 0.2 million tonnes. The seam thickness varies from 0.3 to 0.6m (GSI, 1974). The coal seams in this area are hard and lumpy and strongly coking. The coal shows the moisture content from 1.6 to 1.8 percent, ash from 3.2 to 3.8 percent, volatile matter from 30.8 to 45.5 percent, fixed carbon from 42.1 to 64.6 percent and calorific value from 7250 to 8230 k. cal/kg (DMR, 1985).

2.8.5. Malwar-Musiang-Lamare

Exposure of coal have been recorded around Malwar (25°12'30"N and 92°24'00"E) and Musiang-Lamare (25°13'N and 92°21'E) villages over an area of 2.3 km^2. The total reserve of coal is estimated to be 1.1 million tonnes. The coal field includes a thin, inconsistent coal seam, extremely variable in thickness ranging from 0.3 to 1.6m (GSI, 1974). The coal shows the moisture content from 0.6 to 3.6 percent, ash from 1.3 to 21.2 percent, volatile matter from 32.6 to 40.0 percent and fixed carbon from 42.1 to 60.4 percent (DMR, 1985). The coal seams in this area are hard and lumpy.

2.8.6. Sutnga

Sutnga coalfield is the eastern extension of Bapung coalfield. The coal seams occur in the Shella formation of the Paleocene age. The coal seams are interbedded with shales and sandstone. Coal is found in two seams, the top one being only 0.1 to 0.2m and the bottom seam varies in thickness from 0.3 to 0.6m and the vertical interval between the two seams is 3 to 5m. The total reserve of coal is 0.65 million tonnes over an area of 0.16 km^2. The physical characteristics of coal of this area is hard, lumpy and bright (GSI, 1974). The coal of Sutnga coalfield shows the moisture content from 1.3 to 7.0 percent, ash from 2.2 to 9.7 percent, volatile matter from 32.9 to 42.8 percent and fixed carbon from 49.9 to 53.2 percent (DMR, 1985).

2.8.7. Ioksi

Ioksi is located in the eastern part of the district. The estimated reserve of coal in this area is 1.3 million tones covering an area of 3.6 km^2. The thickness of seams varies from 0.5 to 0.9m. The coal in Ioksi area occurs in the Lower Sylhet sandstone of Eocene age. The nature of coal deposits is bedded type. The physical characteristics of coal in this area is hard, bright and jointed (GSI, 1974). The coal of Ioksi coalfield shows the moisture content from 4.2 to 7.5 percent, ash from 6.0 to 18.1 percent, volatile matter from 33.0 to 43.4 percent and fixed carbon from 41.3 to 46.4 percent (DMR, 1985).

2.8.8. Chyrmang

An outlier of the undifferentiated Sylhet sandstone covering the Chyrmang (25°26'N and 92°25'E) area in the Jaintai Hills exposes two thin seams of coal. The average thickness of the seam is 0.6m. The characteristic of the coal is similar to that of the Bapung coal field. The reserve of coal is not fully assessed (GSI, 1974).

2.8.9. Mutang

Mutang coal field is located in the southwest extension of the Malwar. The thickness of the coal seam varies from 0.25 to 1.08m. The seam shows conspicuous pinching and swelling.

2.9. Present Study Area

An area of about 420 km^2 in the core of the coal mining areas of the district is selected for the present study. The area is extended from 92°13'52"E and 92°25'16"E longitudes to 25°16'7"N and 25°27'28"N latitudes (Figure 2.4). The topography of the area is undulating and elevation ranges from 700m to 1400m (Figure 2.5). The area is drained by Laphirawi river and its tributaries (Figure 2.6). The total number of settlement of different sizes covered under the study area was 45. The length total road network was 520 km (Figure 2.7).

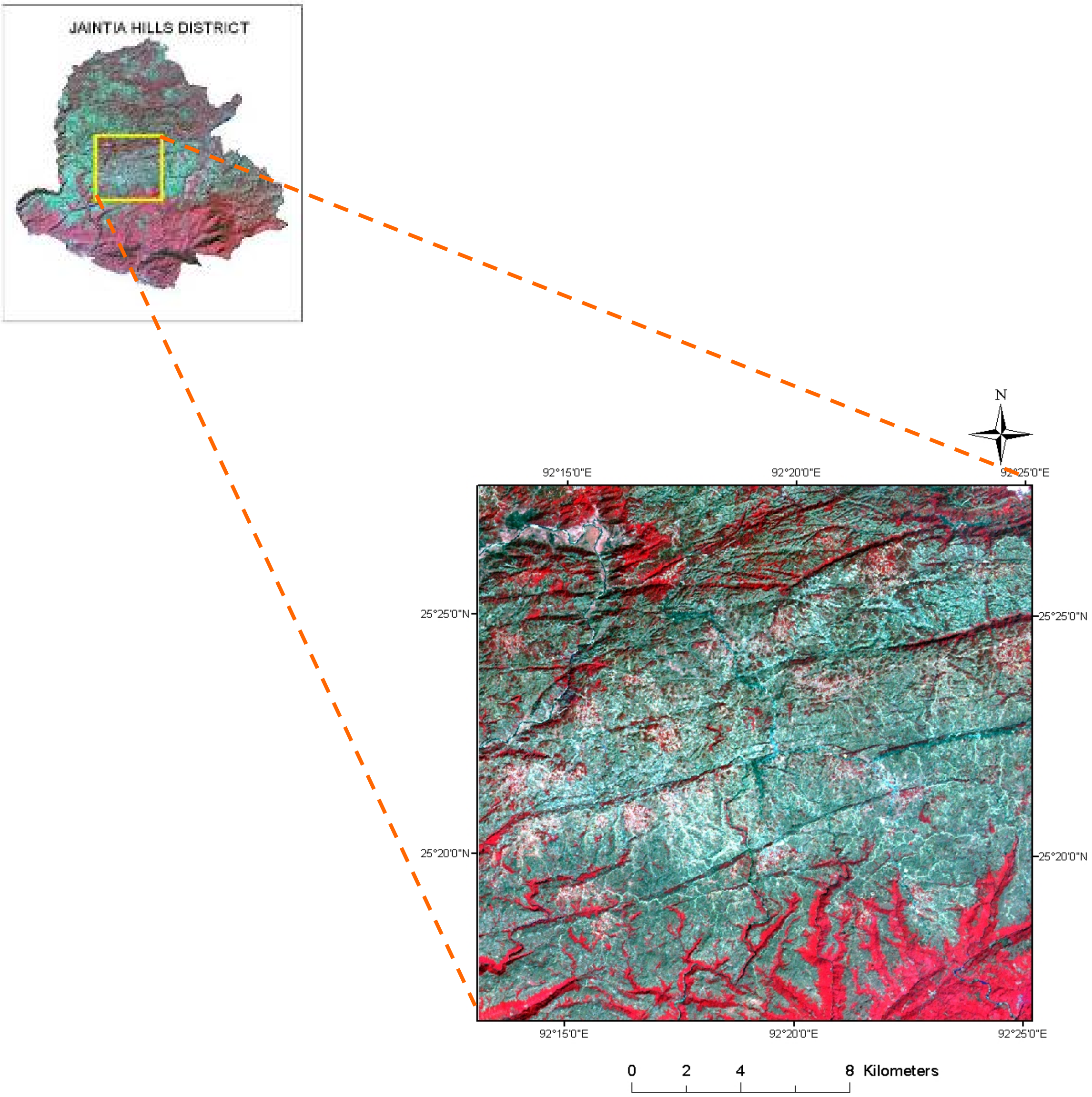

Figure 2.4: Location of the study area in Jaintia Hills district.

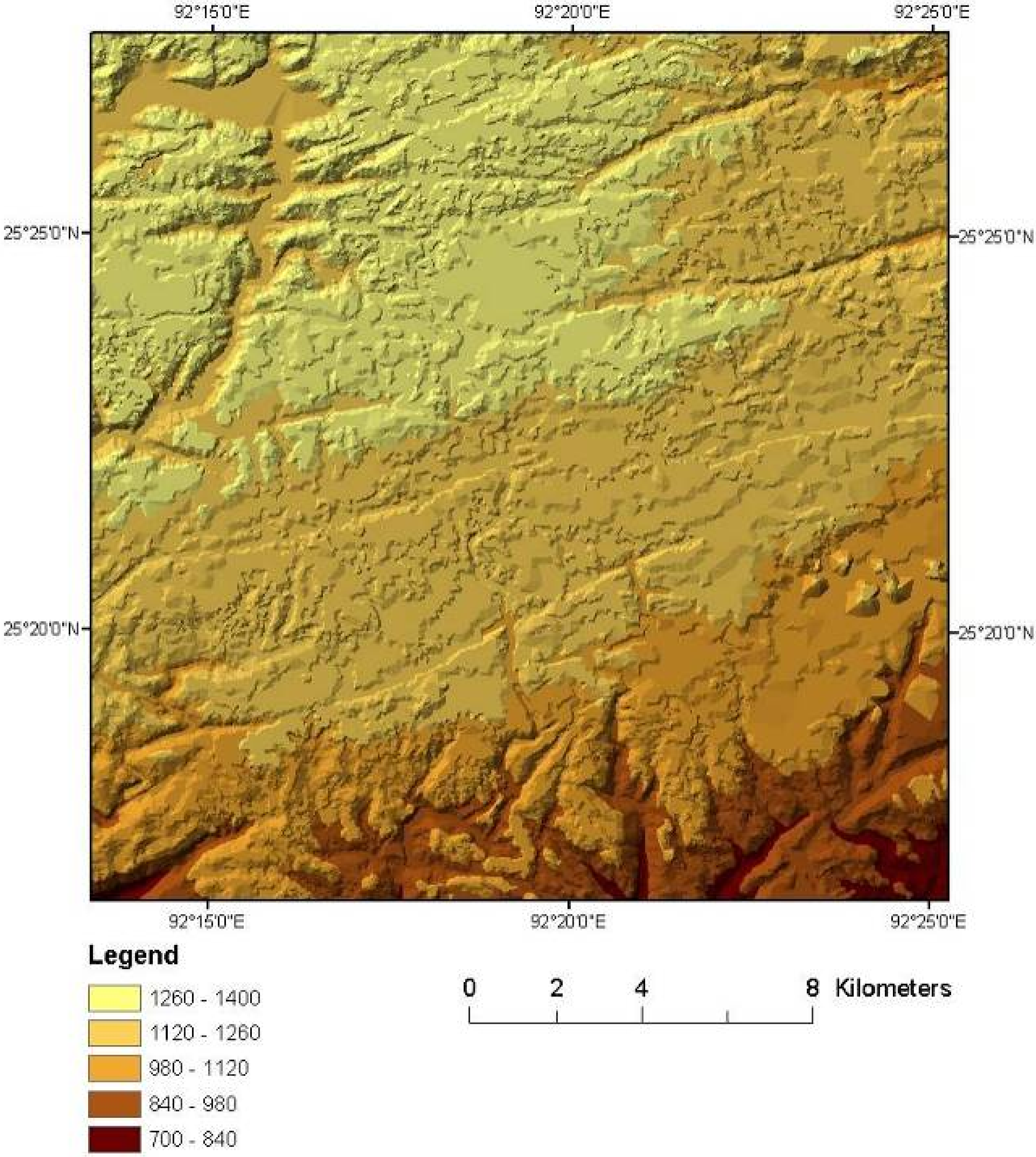

Figure 2.5: Digital elevation model (m).

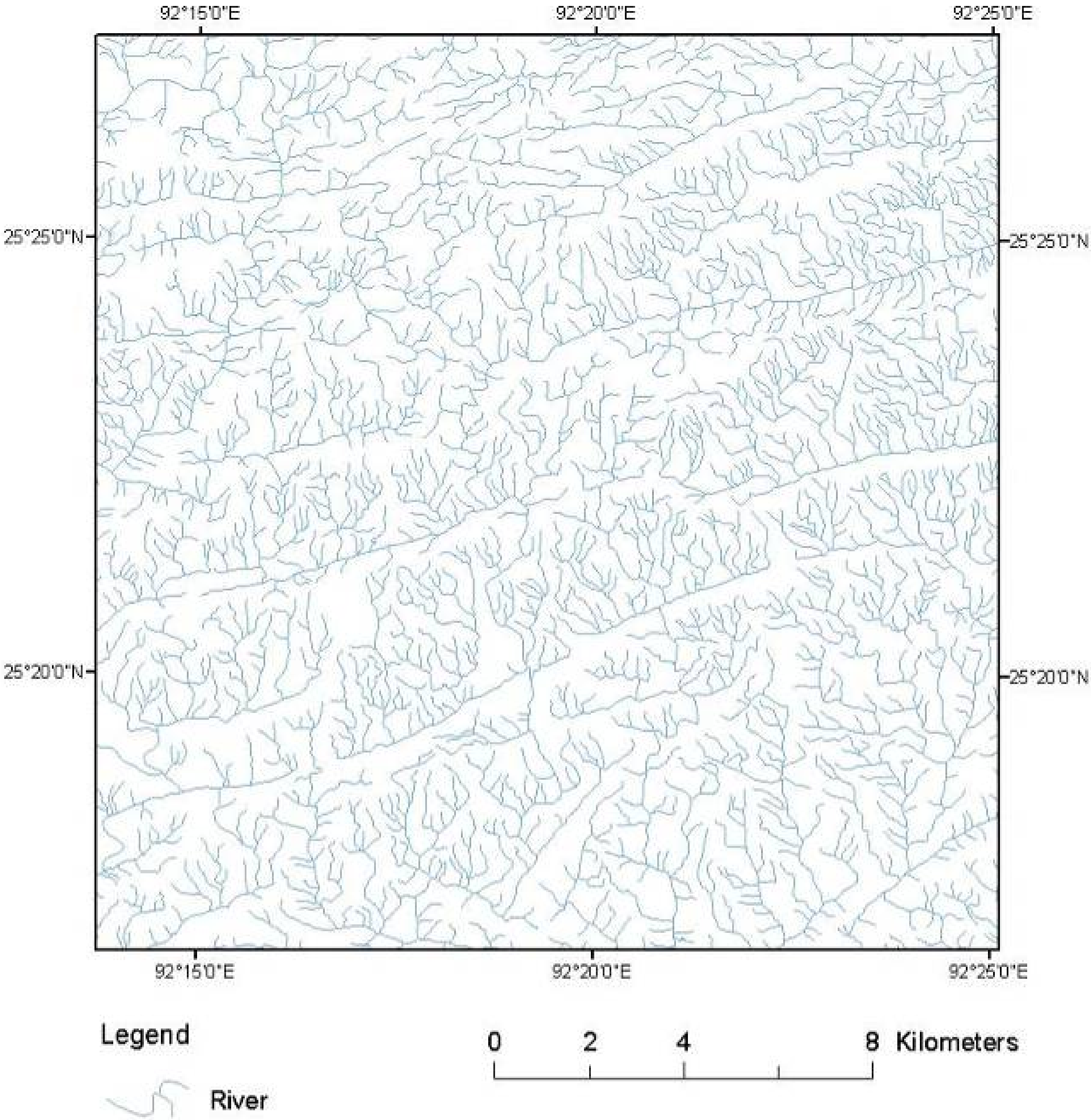

Figure 2.6: Drainage in the study area.

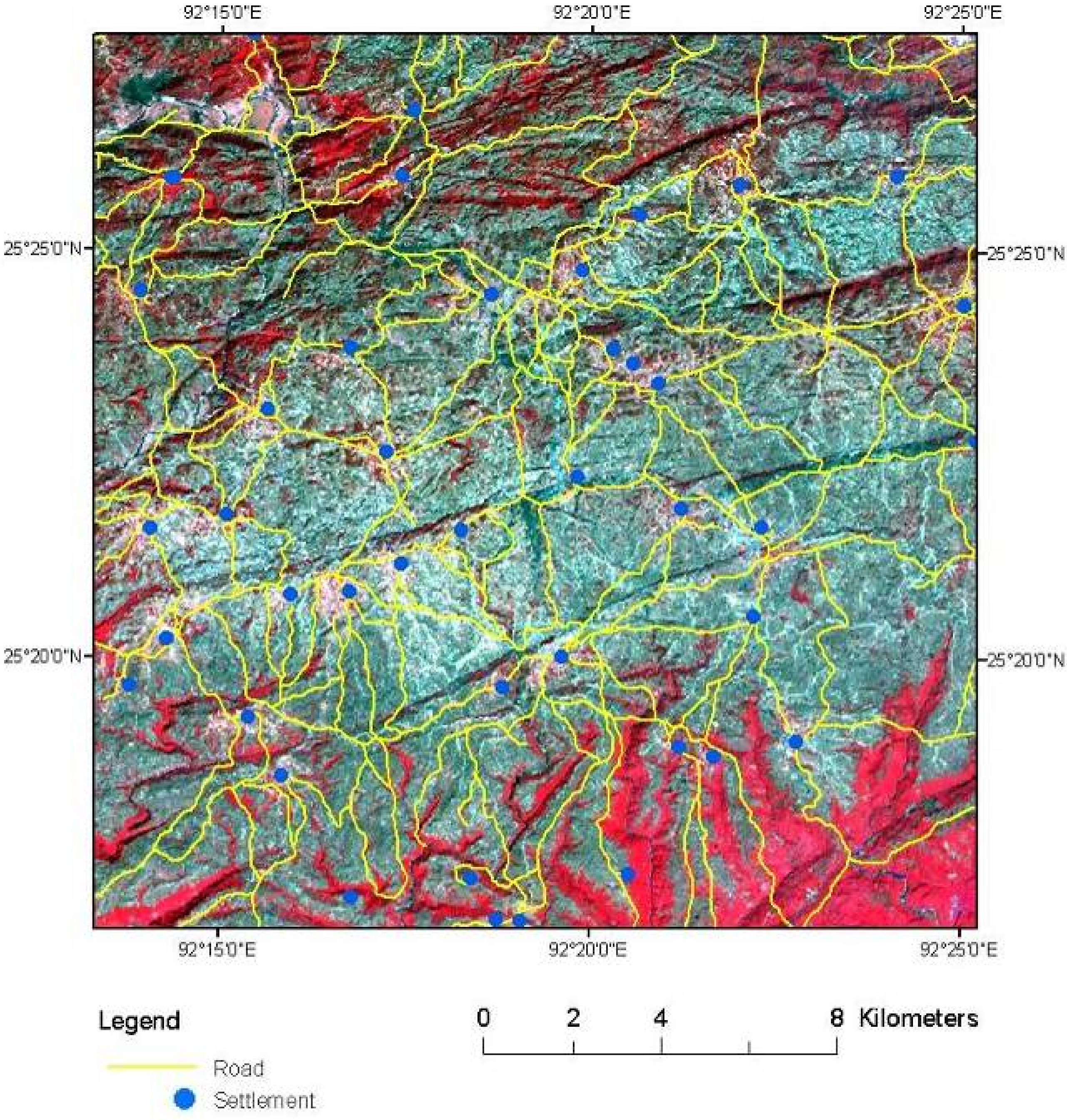

Figure 2.7: Settlement and road network.

3. Materials and Methods

3.1. Study Area

The Jaintia Hills district of Meghalaya is bestowed with rich natural vegetation as well as large reserve of mineral resources. During the last few decades, there have been phenomenal increases in mining of coal, limestone, sillimanite and clay causing large-scale destructions and deterioration of the natural vegetation. The district has been most extensively extracted in terms of coal, among all districts of the state. Excessive mining operation of coal in many parts of the district has been responsible for the conversion of original lush green landscape of the area into mine spoils. The crude and unscientific method of mining adopted by the primitive operators in several parts of the district has caused severe ecosystem destruction. Uncontrolled and unscientific mining operation within the district has been detrimental to the fragile ecosystem. It is of urgent need to understand the impact of mining on the vegetation characteristics of the district for further management plan.

For the present study an area of approximately 420 km^2 was delineated in the core of the coal mining areas of the district (92°13'52"E to 92°25'16"E longitudes and 25°16'7"N and 25°27'28"N latitudes). Lad Rymbai (25°21'53.2"N and 92°19'15.8"E), the major centre for coal mining was taken as the centre of the study area.

3.2. Materials

IRS Satellite data for four different years period of 1975, 1987, 1999 and 2001 were used for temporal analysis. The data used are Landsat MSS for 1975, Landsat TM for 1987, Landsat ETM^+ for 1999 and IRS-1D-LISS III data for 2001 (Figure 3.1, Figure 3.2, Figure 3.3, Figure 3.4).

The ancillary data used for the study are topographic maps of the study area, GSI map, GPS and Compass.

The software used are *ERDAS IMAGINE 8.7, ArcGIS, ILWIS 3.2* and *MS Office*.

3.3. Research Methods

To fulfil the objectives following methods will be adopted:

3.3.1. Study Initiation

Identification of study area followed by literature review.

3.3.2. Pre-Field Work

Delineation of study area followed by reconnaissance survey.

3.3.3. Field and Post-Field Work

Analysis and interpretation of four different years satellite data with the help of remote sensing and GIS.

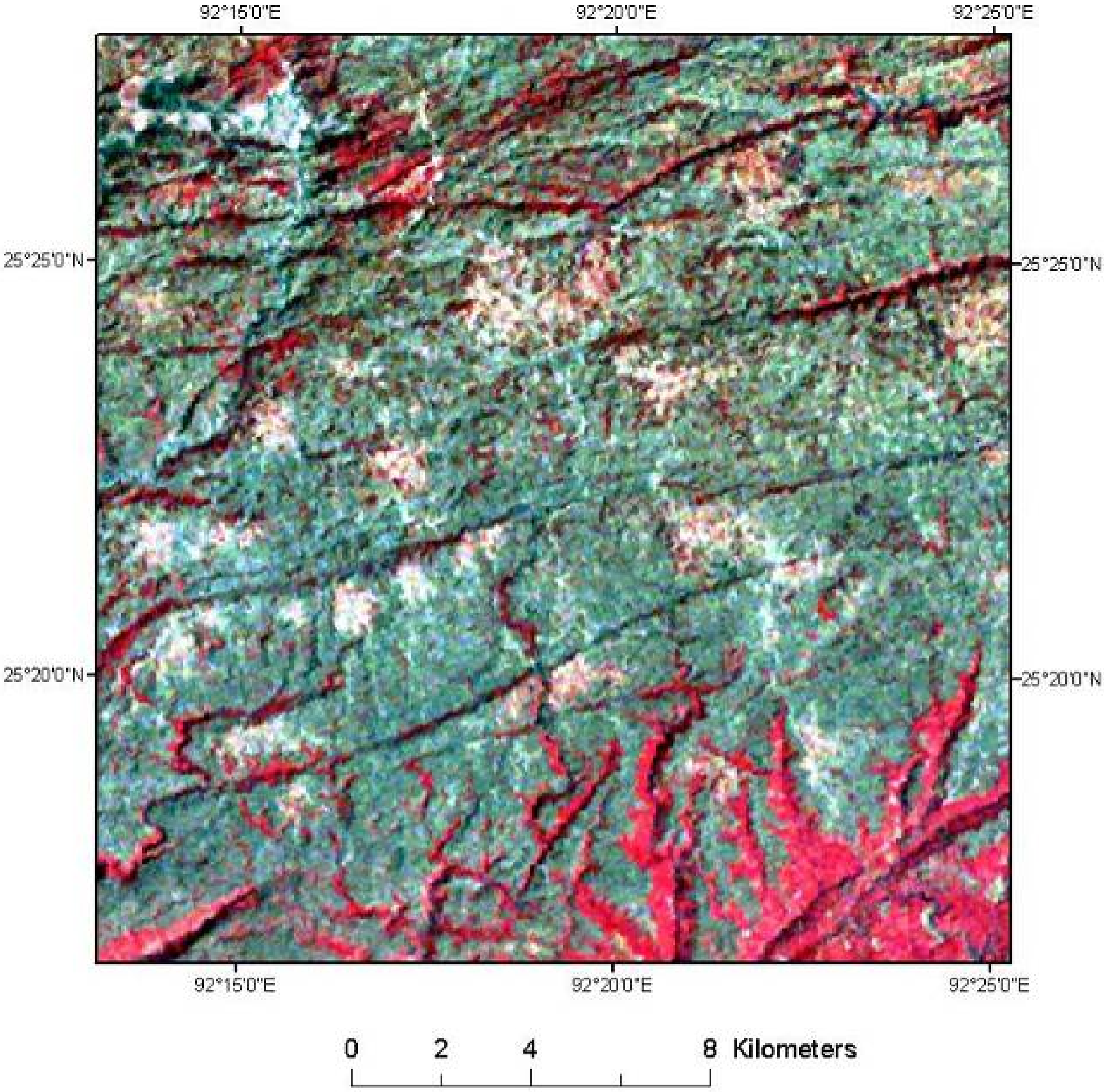

Figure 3.1: Landsat MSS FCC for the period 1975.

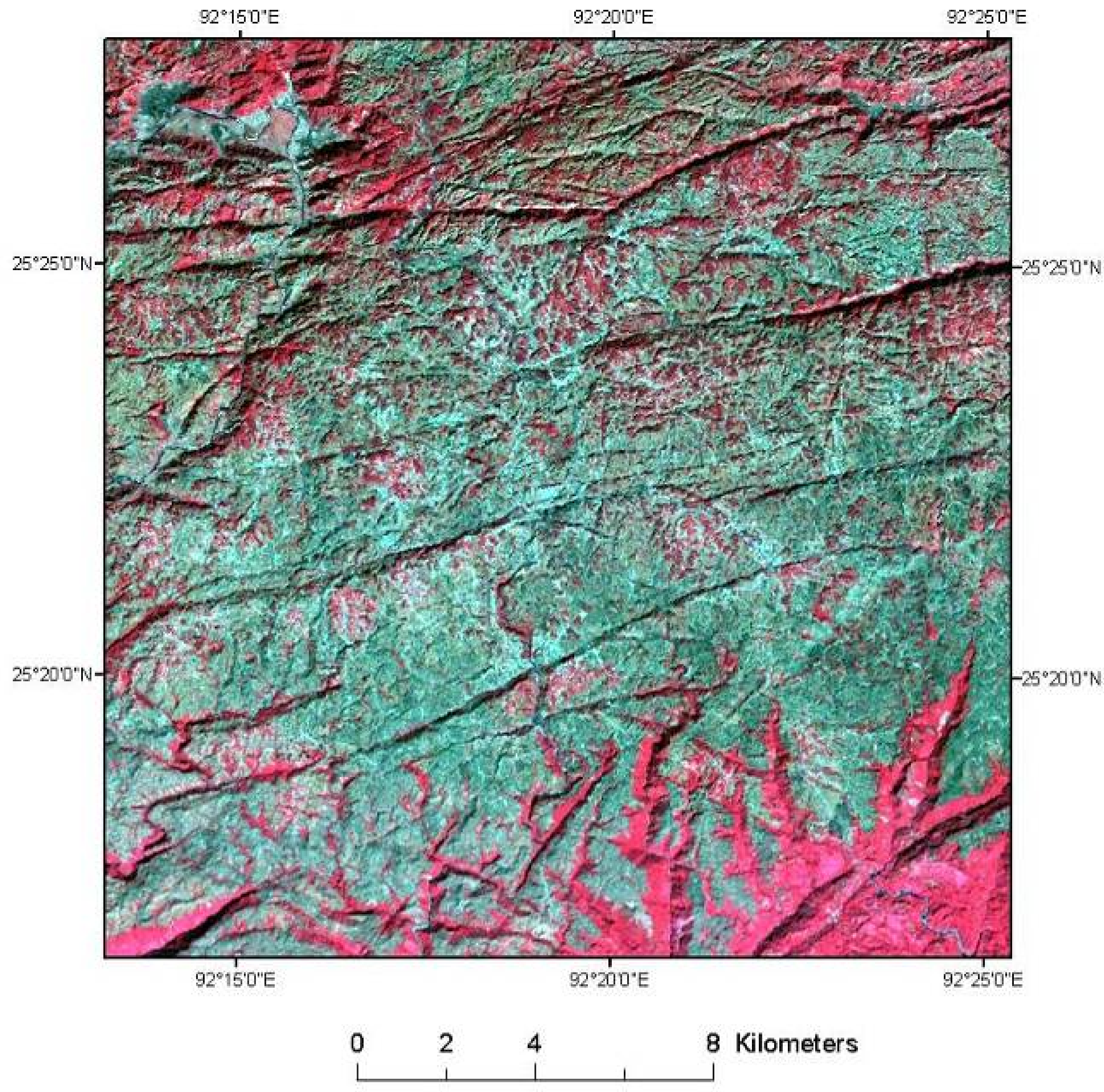

Figure 3.2: Landsat TM FCC for the period 1987.

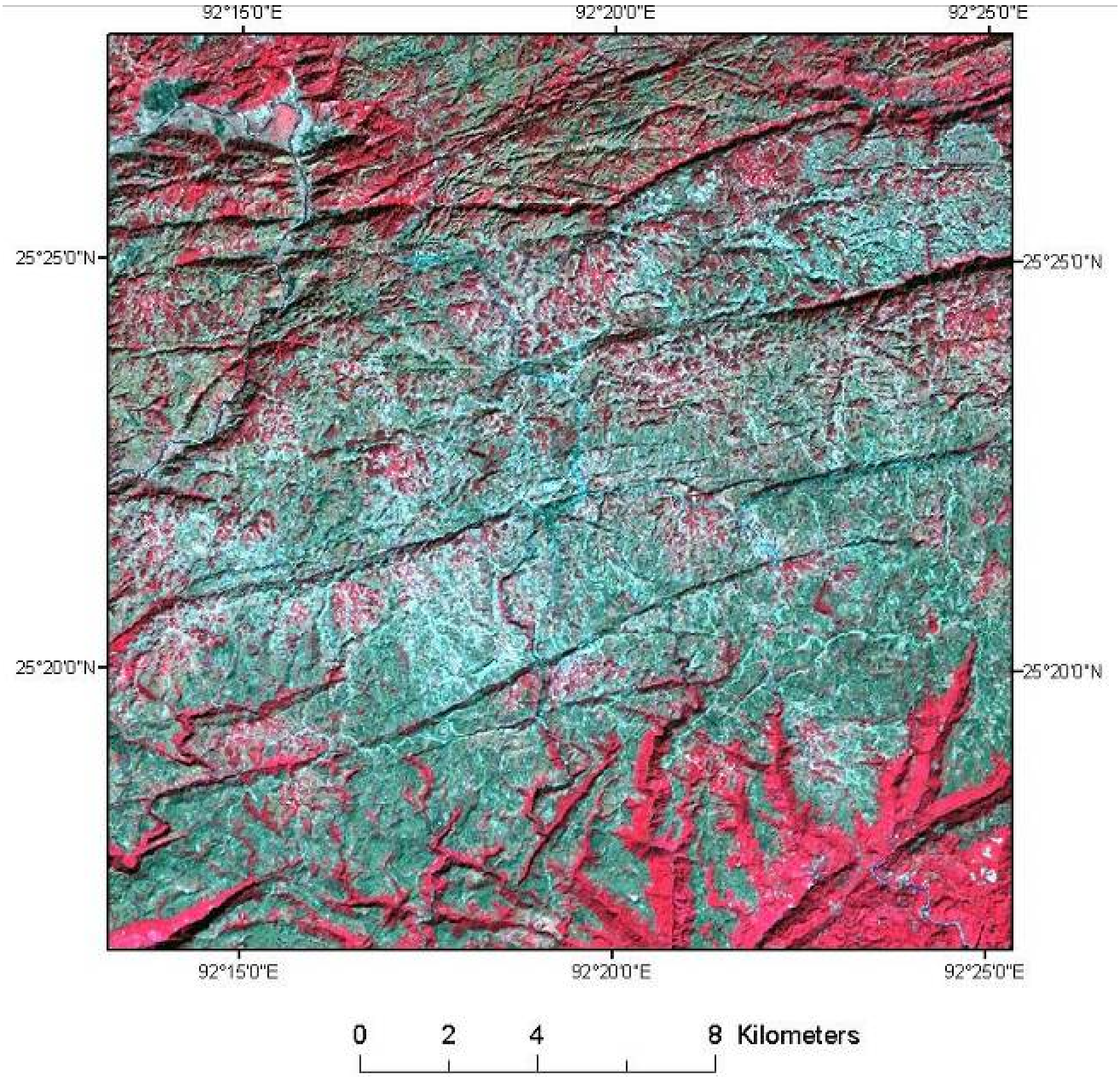

Figure 3.3: Landsat ETM $^{+}$ FCC for the period 1999.

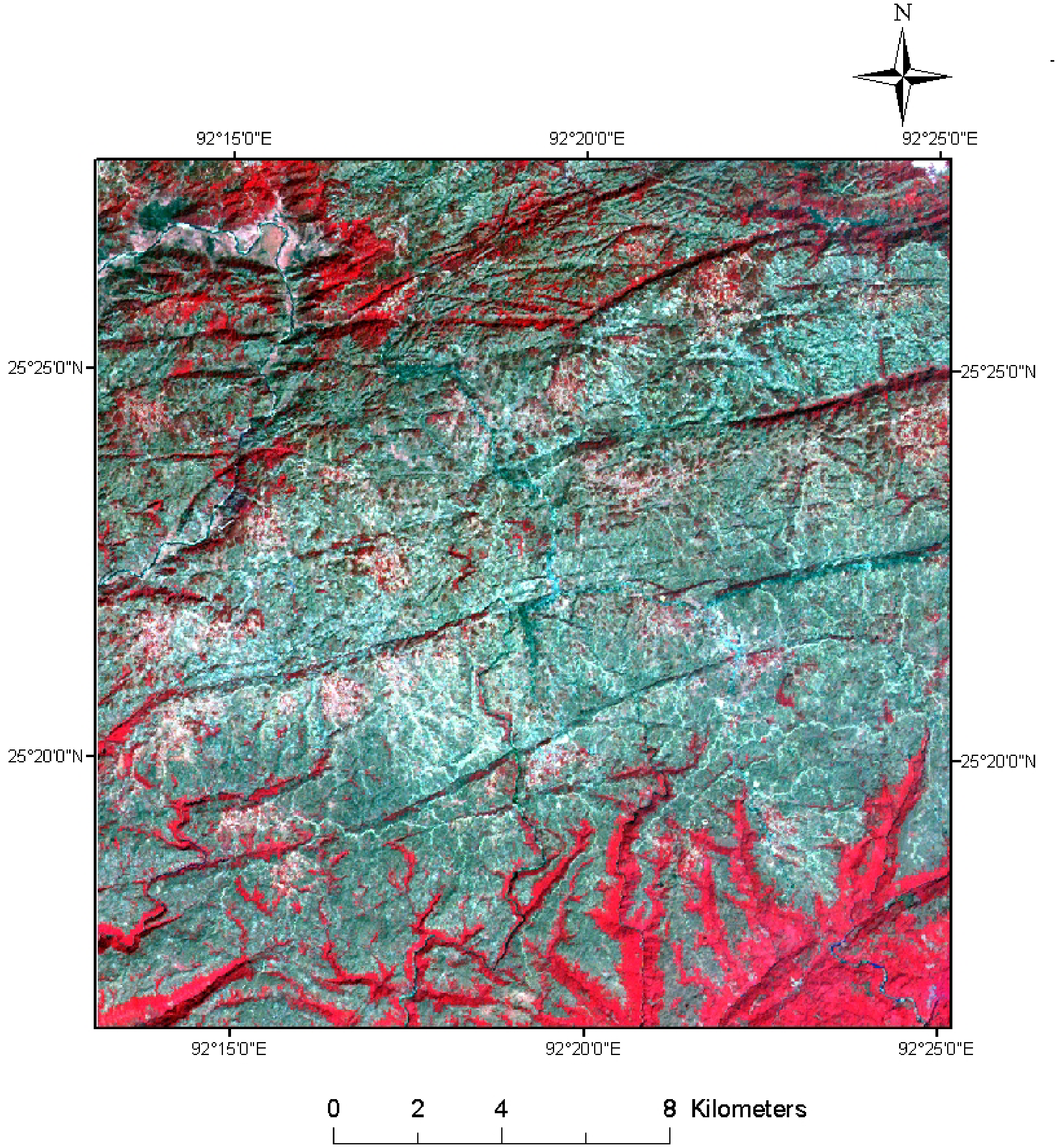

Figure 3.4: IRS-1D LISS-III FCC for the period 2001.

3.3.3.1. Radiometric Correction

First order corrections were done by dark pixel subtraction technique followed by Lilles and Kiefer (1999).

3.3.3.2. Visual Interpretation

Studying changes in land use pattern using remotely sensed data is based on the comparison of the time sequential data. Differences in surface phenomenon over time can be determined and evaluated by visual interpretation with local knowledge (Garg *et al.,* 1988; SAC, 1999). For the present purpose visual interpretation technique was used for land use/ land cover mapping for four different years remote sensing data of the study area.

3.3.3.3. Change Analysis

The land use/ land cover maps of 1975, 1987, 1999 and 2001 were converted into grid format using Intergraph MGE Grid Analyst. Maps of different time periods were overlaid to find changes. The increase or decrease in different land use/ land cover is obtained by intersecting and generating the matrices of change-no change for different years.

3.3.3.4. Forest Fragmentation Analysis

It was measured by calculating the amount of forest patches occurring in a landscape with respect to non-forest patches. In the programme, *Bio_CAP* the area was reclassified into three categories viz., non-forest, high fragmentation and low fragmentation.

3.3.3.5. Phytosociological Analysis

The community characteristics of vegetation in coal mining areas of Jaintia Hills district of Meghalaya were studied during the last week of October, 2004. To find out the impact of coal mining on vegetation distant gradient analysis was carried out. In this method, from the center of the study area, i.e., Lad Rymbai, structure and composition of vegetation is observed in four different zones. The radius of the first circle i.e., zone-I is 2 km. The distance from the periphery of the first circle to the periphery of the second circle is also 2 km and is considered as zone-II. Likewise, zone-III and zone-IV are delineated (Figure 3.5). In each circle 24 sample plots each for tree, shrub and herbs were laid. Each sample plot was supported by 3 replicas. The total number of sample plots for tree, shrub and herbs came to 72 each in each zone. The overall number of sample plots for tree, shrub and herb species was 288 each in the mining areas, i.e., in all the four zones. The vegetation characteristics of the mined areas were compared with that of an adjacent undisturbed forest, i.e., Tubre Sacred Grove. The total number of quadrats laid in the control site was 10.

For tree component a quadrat of 10m x 10m size was laid while for the shrub species it was 5m x 5m. For the herbaceous species the size of the quadrat was 1m x 1m. The species found in the quadrats were identified with the help of the herbaria of Botany Department, North-Eastern Hill University, Shillong and Botanical Survey of India, North-Eastern Circle, Shillong. The plants having CBH >15cm was considered as tree, stem diameter 5-15cm at basal level was considered as shrubs and stem diameter <5cm at basal level was considered as herbs.

Quantitative community characteristics such as frequency, density, basal area and important value index (IVI) of each component were determined by following the methods as outlined by Misra (1968) and Muller-Dombois & Ellenberg (1974).

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats of occurrence of a species}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats studied}}$$

Basal cover = Density x average basal area of individuals of a species

Basal area was calculated based on the measurement of CHB at 1.37m heights.

$$\text{Abundance} = \frac{\text{Number of individuals of a species}}{\text{Number of quadrats of occurrence of the species}}$$

Simpson Dominance Index (1949) = $(n_i / N)^2$

where, n_i = importance value index
N = total importance value of all species

The distribution pattern of the species was studied by using Whitford's index (Whitford 1948).

$$\text{Whitford's index} = \frac{\text{Abundance (A)}}{\text{Frequency (F)}};$$

if A/F ratio:< 0.025 :Regular distribution
0.025 - 0.05 :Random distribution
> 0.05 :Contagious or clumped distribution

Shannon-Weaver index of general diversity was calculated by using the formula

$$\bar{H} = - \sum (n_i / N) \ln (n_i / N)$$

where, $\bar{H}$ = Shannon-Weaver index
n_i = importance value index
N = total importance value of all species

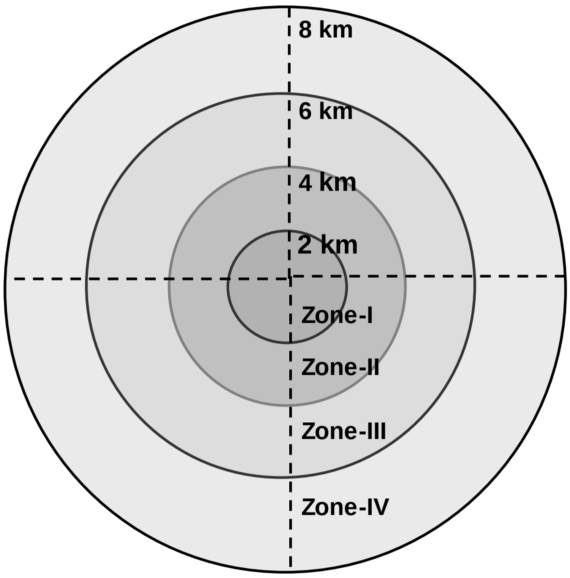

Figure 3.5: Conceptual framework of different coal mine impact zones.

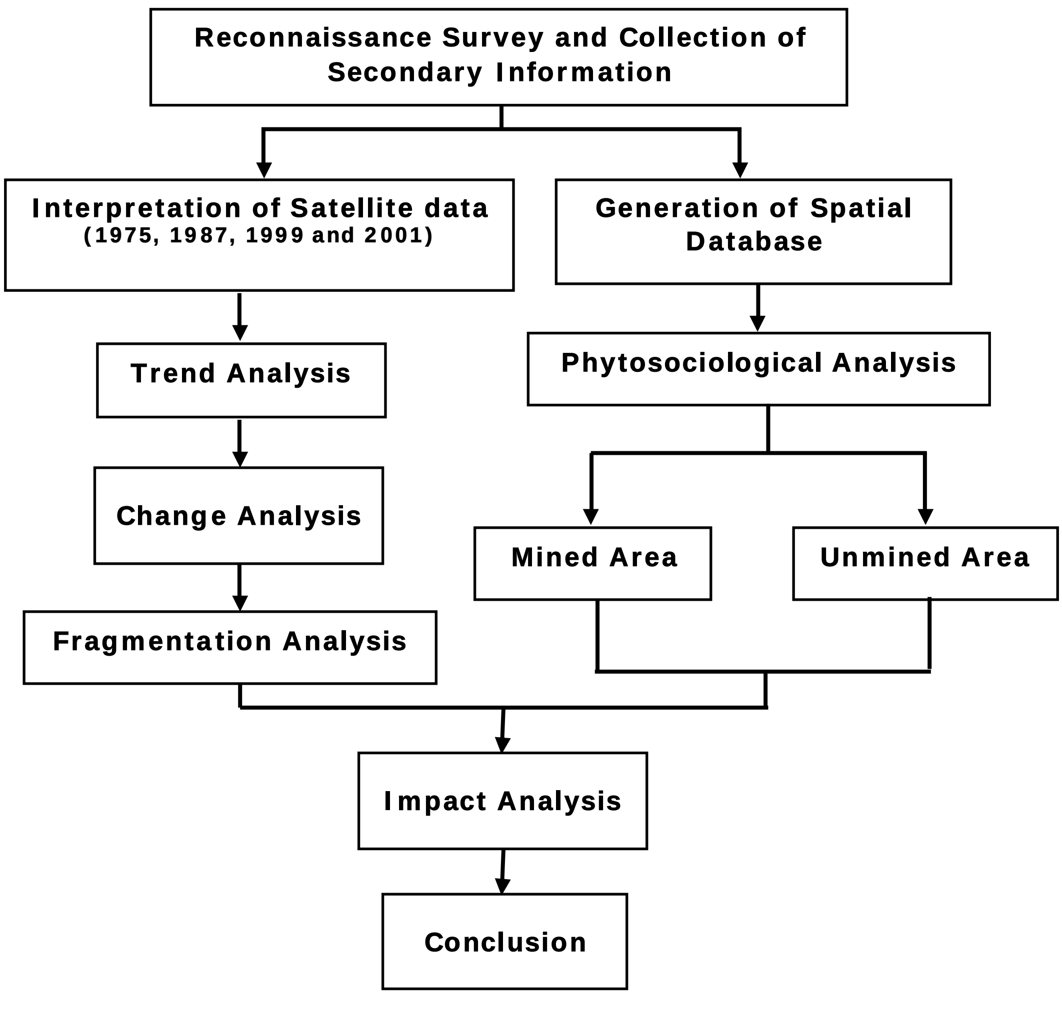

Figure 3.6: Paradigm for assessment of mining impact on vegetation.

4. Results and Discussion

Ecosystem disturbance may be defined as an event or series of events that alters the relationship of organisms and their habitat in time and space. Ecosystem disturbance by mining is an evitable fall out of industrialization and modern civilization. Mining of coal both surface and subsurface causes enormous damage to the flora, fauna, hydrological relations and soil biological systems. Destruction of the vegetal cover during mining operation is invariably accompanied by an extensive damage and loss to the system. The disturbed and haphazardly mixed infertile, consolidated and unconsolidated materials overlying the coal seams are known as overburdens. These overburdens when dumped in unmined areas in the vicinity of the coal mines create mine spoils. Nutrient deficient sandy spoils are generally hostile to plant growth. The dumping of spoils and coal destroys even the surrounding vegetation and leads to severe soil and water pollution. The Jaintia Hills district of Meghalaya has been extensively extracted in terms of coal. As a result of this, many parts of the district has been converted from lush green landscape into mine spoils. Large scale denudation of forest cover, scarcity of water, pollution of air, water and soil, and degradation of agricultural lands are some of the conspicuous environmental implications of coal mining in Jaintia Hills.

A detailed understanding of the impact of coal mining on vegetation and plant diversity on time and space is pre-requisite for the district. Keeping this objective in view, the first part of this chapter will discuss the plant community characteristics of the area and the impact of coal mining on them has been assessed by comparing certain community attributes of the mined areas with that of the adjacent umined area. The second part will deal with temporal impact of mining activities on vegetation. In order to achieve this objective the land cover types of dense forest, open forest and mining area were delineated. The area under crop, settlement and grassland/ non-forest were also taken into consideration to know the trend due to the impact of mining activities in different time periods.

4.1. Community Characteristics

4.1.1. Floristic Composition

There were variations in the composition of plant in the mined and unmined areas. The tree species showed a drastic reduction in their number in all zones of the mining sites (3-11) with that of the unmined sites (27). In the unmined site 27 tree species belonging to 22 genera and 19 families were registered. Four (4) tree species belonging to 4 genera and 4 families, 7 tree species belonging to 7 genera and 7 families, 3 tree species belonging to 3 genera and 3 families, and 11tree species belonging to 10 genera and 9 families were recorded in the mined areas of zone-I, zone-II, zone-III and zone-IV, respectively. It was apparent from the study that the number of tree species was more in the peripheral zone than the inner zones. There was not much variation in the number in first three zones of the area. The shrub species did not show much variation in the unmined and all the zones of the mined areas. In the unmined area, total 27 shrub species belonging to 22 genera and 18 families were found. Shrubs were represented by 19, 25, 22 and 34 species from 18, 25, 23 and 33 genera, and 13, 17, 16 and 21 families were recorded from zone-I, zone-II, zone-III and zone-IV, respectively. There was remarkable increase in the number of herbaceous species in the mined areas. In the unmined area total number of ground species recorded were 23 belonging to 21 genera and 15 families. In the mined areas herbaceous layer was composed of 39 species, 38 genera, 25 families in the zone-I, 41 species belonging to 41 genera and 26 families in the zone-II, 40 species from 39 genera and 23 families in zone-III, and 34 species belonging to 33 genera and 21 families in zone-IV (Table 4.1).

Table 4.1: Species, generic and family compositions in different zones

Species composition	Control	Zone-I	Zone-II	Zone-III	Zone-IV
Trees					
No. of species	27	4	7	3	11
No. of genera	24	4	7	3	10
No. of family	19	4	7	3	9
Shrubs					
No. of species	27	19	25	22	34
No. of genera	22	18	25	23	33
No. of family	18	13	17	16	21
Herbs					
No. of species	23	39	41	40	34
No. of genera	21	38	41	39	33
No. of family	15	25	26	23	21

Since the mined and unmined areas had similar climatic, edaphic and physiographic features the differences in species composition could be attributed to the mining activities. This is in agreement with the findings of Das Gupta (1999), Baig (1992), Jha and Singh (1990). Sarma (2002), while studying the impact of coal mining on the vegetation characteristics of the Nokrek Biosphere Reserve of Meghalaya outlined that the composition of vegetation reduces in the mined areas with that of the adjacent unmined areas. Lyngdoh *et al.* (1992) reported less number of species in the mine spoils of different ages to that the unmind sites. Iverson and Wali (1982) observed an increase in species richness with age in reclaimed coal mine spoils.

4.1.2. Density

The tree density in the mined areas ranged between 515 and 647 stems per ha while in the unmined area it was 1040 stems per ha. There was not much variation in the shrub density but density of herbaceous species was remarkably higher in the mined areas (154-178 individual/m^2) than the unmined area (32 individual/m^2) (Table 4.2).

The unmined area had greater plant density compared to that of the mined areas because of the acidic pH, moisture stress and nutrient property of litter. Low grow form, sparse density and ability to tolerate low nutrient levels and low moisture conditions are probably the adaptations to the harsh physical nature of substrate. Low nutrient habitats are usually colonized by species with low relative growth rates. These adaptations enable colonizing species to maximize the nutrient uptake and ensure high nutrient use efficiency in low nutrient environments (Baig, 1992). Lyngdoh (1995), Das Gupta (1999) and Sarma’s (2002) works lend support to the present findings. Bradshaw and Chadwick (1980) working on the colliery spoils reported that the number of species colonizing on the mined areas was influenced by its pH.

Table 4.2: Stand density as affected by mining in different zones

Species	Control	Zone-I	Zone-II	Zone-III	Zone-IV
Trees (individual/ha)	1040	561	515	603	647
Shrubs (individual/m^2)	1	2	1	1	2
Herbs (individual/m^2)	32	165	178	154	157

4.1.3. Dominance Pattern

The dominance were different for tree, shrub and herb component in mined and the unmined control area of the study area. In terms of importance value *Pinus kesiya* (IVI: 243.97-280.27) was the dominant tree species in the mining area and presented in all the zones, which was followed by the *Schima wallichii* (IVI: 10.05-46.36). In the control site *Camelia caudata* (IVI: 54.5), *Castanopsis purpurella* (IVI: 44.9) and *Quercus griffithii* (IVI: 30.7) were the dominant tree species.

In the shrub layer, *Eupatorium adenophorum* (IVI: 22.78-53.74) and *Melastoma nepalensis* (IVI: 23.36-48.86) were the two dominant species followed by *Lantana camara* (IVI: 23.93-49.44) in different zones of the mining area. Control site was dominated by *Psychotria erratica* (IVI: 16.13), *Cassia floribunda* (IVI: 14.52), *Shutaria vestida* (IVI: 14.52), and *Plectranthus striantus* (IVI: 14.52).

Among herbaceous species *Paspalum orbiculare* (IVI: 68.42-95.47) dominated all the zones of the mining area, which was followed by *Isachne himalaica* (IVI: 15.75-19.57). *Globba clarkii* (IVI: 38.73), *Selaginella semicordata* (IVI: 29.52) and *Panicum brevifolium* (IVI: 24.13) were the dominant ground species in the control site (Table 4.3).

The high importance value of *Pinus kesiya* in mining areas suggesting its ability to grow in the disturbed environments and its dominance in the harsh conditions. Higher importance value of *Schima wallichii* indicates the degraded environment. The higher importance value of *Paspalum orbiculare* suggests that it can multiply rapidly in the disturbed environments. This perennial grass by virtue of its stolon and rooting at each node can bind the soil particles, making the soil more stable. The dominance of one or two species explain the low diversity and high dominance in the mined affected areas.

Dominance-diversity curves have been used to interpret the dominance of species in the community in relation to resource apportionment and niche space (Whittaker, 1975). The curves (Figure 4.1, Figure 4.2, Figure 4.3) in the unmined sites resemble the log normal suggesting that there was more or less an even apportionment of resources among the members of the important species. The curves for the mined sites resemble with broken-stick series model (Poole, 1974). This could be attributed to the lesser number of species occurring in these areas and also represent a stress environment where conditions were not favourable for plant growth. Species diversity was low on these stands, but the species that grow here appear to have developed tolerance that enable them to grow in such an environment.

Table 4.3: Plant species with higher importance value index in control and mined areas

Species	Control	Zone-I	Zone-II	Zone-III	Zone-IV
Trees					
Pinus kesiya	-	264.47	280.27	246.05	243.93
Schima wallichii	-	-	10.05	46.36	18.91
Persea odoratissima	-	20.58	-	-	-
Quercus griffithii	30.7	-	-	-	
Camelia caudata	54.5	-	-	-	
Castanopsis purpurella	44.9	-	-	-	-
Shrubs					
Eupatorium adenophorum	-	53.74	27.55	22.78	40.52
Lantana camara	-	-	26.41	23.93	49.44
Melastoma nepalensis	-	25.28	48.86	37.86	23.36
Rubus ellipticus	-	-	23.15	-	-
Rubus khasiana	-	12.30	-	9.83	-
Shutaria vestida	14.52	-	-	-	-
Cassia floribunda	14.52	-	-	-	-
Psychotria erratica	16.13	-	-	-	-
Plectranthus striantus	14.52	-	-	-	-
Herbs					
Paspalum orbiculare	-	68.42	89.45	83.29	95.47
Gnaphalium pensylvanium	-	-	-	-	9.05
Plantago erosa	-	-	-	-	7.27
Borreria sp.	-	-	-	12.7	-
Isachne himalaica	-	15.75	16.29	19.57	-
Ageratum conyzoides	-	10.44	-	11.68	-
Borreria articularis	-	9.97	-	14.47	-
Selaginella semicordata	29.52	-	-	-	-
Panicum brevifolium	24.13	-	-	-	-
Globba clarkii	38.73	-	-	-	-

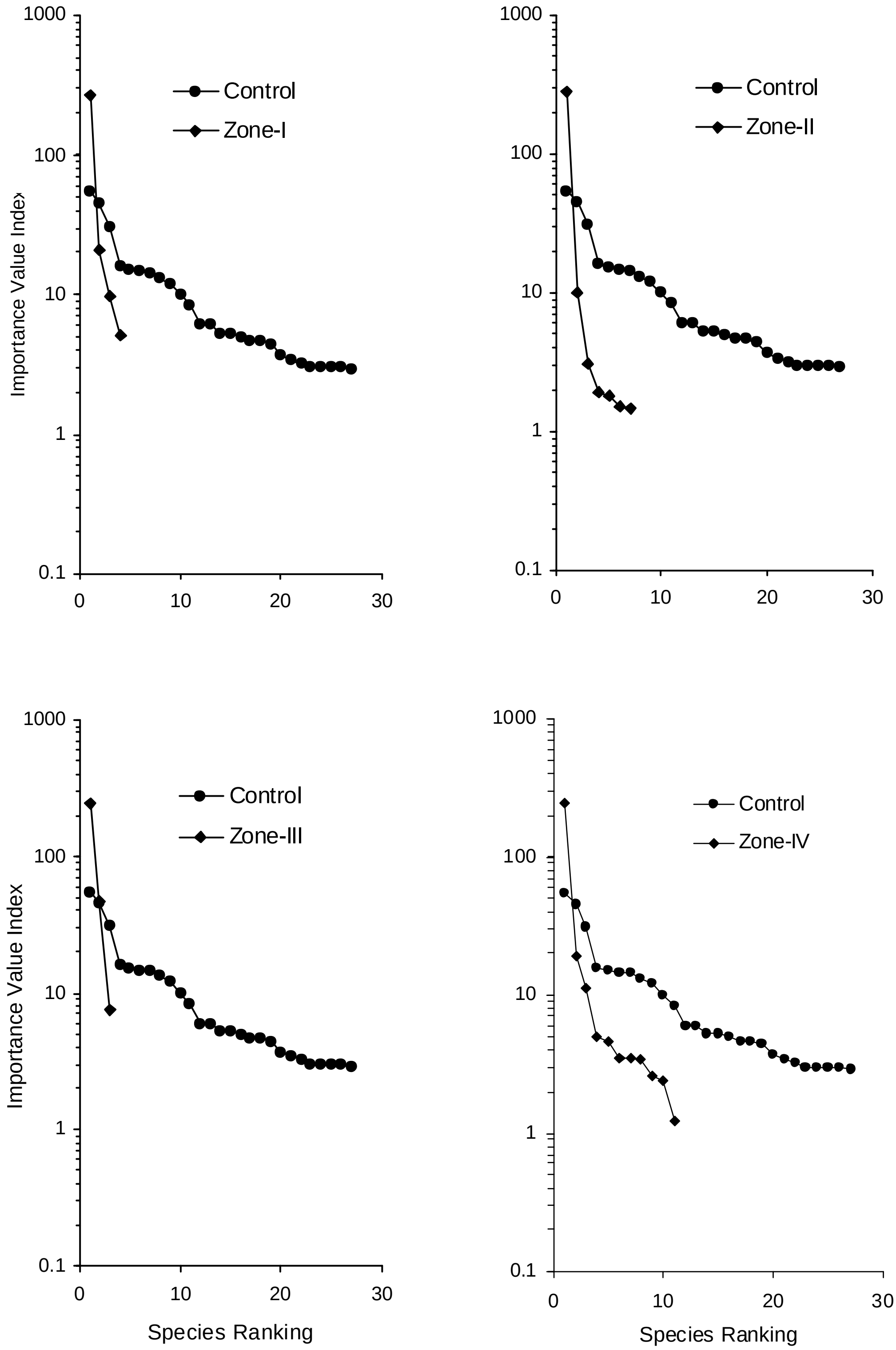

Figure 4.1: Dominance-diversity curves of trees in control and mined areas.

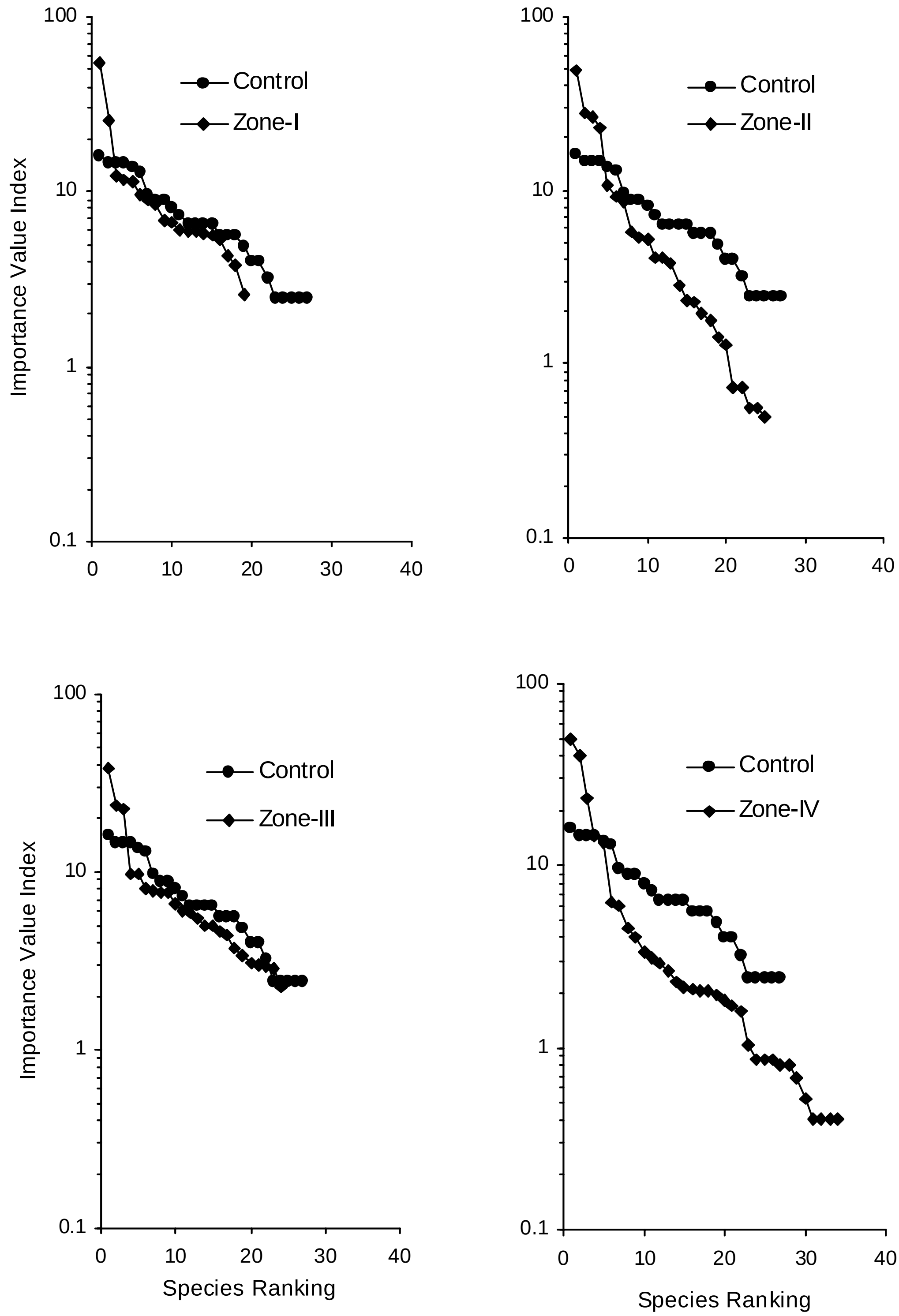

Figure 4.2: Dominance-diversity curves of shrubs in control and mined areas.

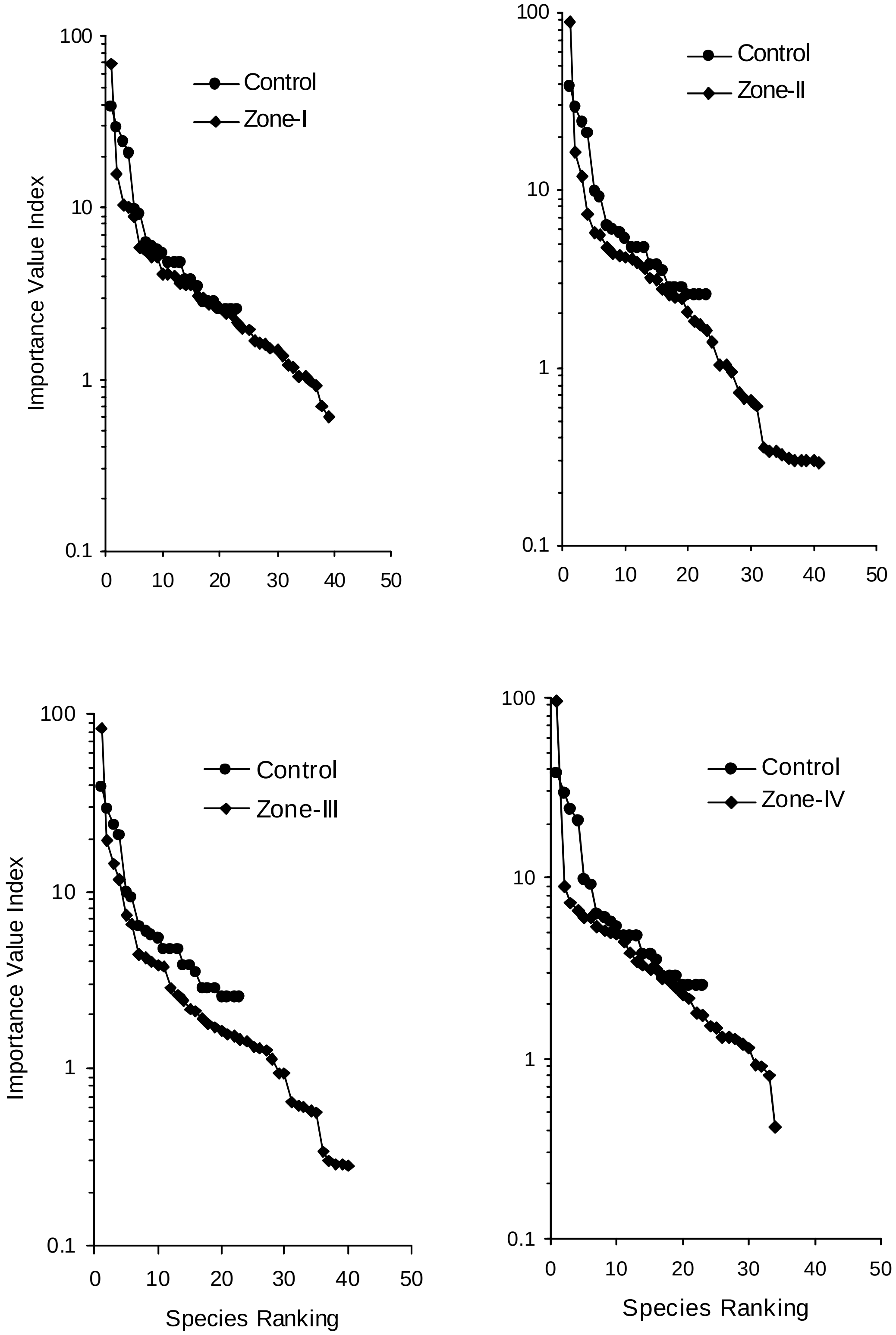

Figure 4.3: Dominance-diversity curves of herbs in control and mined areas.

4.1.4. Species Diversity

Shannon-Weaver diversity index for tree and shrub species were less in the mined areas as compared to that of the unmined area. Diversity in tree species was drastically reduced in the mined areas. There were not much differences in the diversity of ground vegetation both in mined and unmined areas (Table 4.4). The diversity index for herbaceous species increased with mining suggesting that mining operation enhanced the colonization of certain species in the newly created habitats due to mining. This is in agreement with the findings of Lyngdoh (1995), Das Gupta (1999) and Sarma (2002).

Table 4.4: Shannon-Weaver diversity index in control and mined areas

Species	Control	Zone-I	Zone-II	Zone-III	Zone-IV
Trees	2.8	0.47	0.34	0.54	0.85
Shrubs	3.13	2.59	2.51	2.84	2.56
Herbs	2.69	2.83	2.44	2.48	2.41

4.2. Impact of Coal Mining on Tree Population Structure

4.2.1. Density-Diameter Distribution

The trees of medium girth class (55-95cm) dominated in the mined areas in all the zones. In the control site the trees with low girth class (15-35cm) had the maximum individuals (Figure 4.4).

In the unmined site, it was found from the study that density of young and middle sized trees was higher than the older tree, indicating stable tree population structure. Such a tree population structure is represented by a normal case and suggests that the forest is growing and would continue to exist. However, in the mined areas, the tree density in all the girth classes was extremely low and did not follow any standard density diameter population curve (Rao *et al.,* 1990). This has been due to rampant and random clearing of forest areas for mining purpose, that have led to drastic change in tree population structure. Such a trend in population structure does not indicate the continued existence of the forest

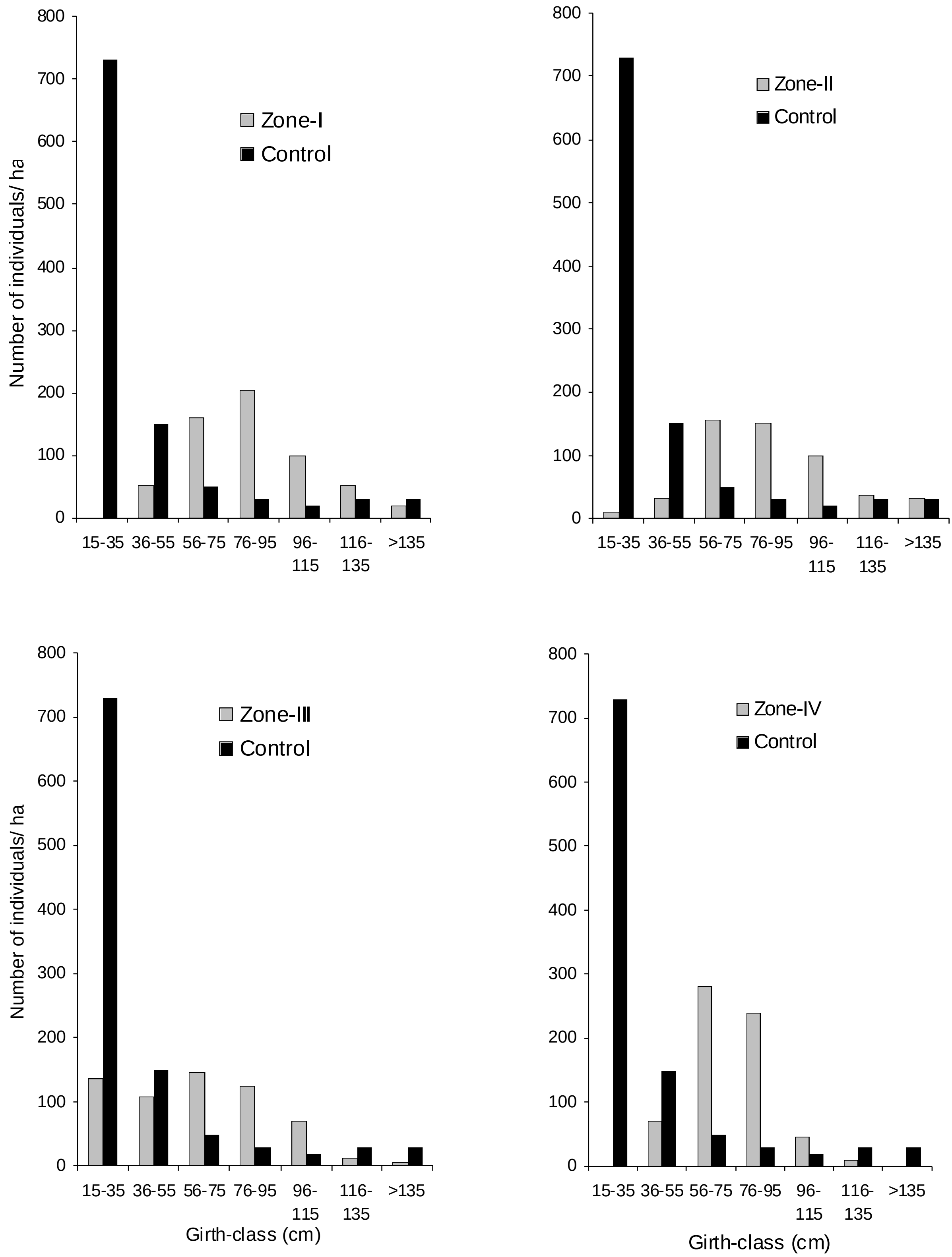

Figure 4.4: Density-diameter distribution of trees in different girth classes under control and mined areas.

4.2.2. Basal Cover

The basal area (m^2 ha^{-1}) in both mined and unmined areas showed no trend and were almost equally distributed. Comparatively low basal area in spite of high population density (individuals ha^{-1}) in the unmined site attributed that the trees dominated were of smaller in size (Figure 4.5). The higher basal area in the mined areas though it had low density, could be attributed to the existence of bigger trees and causing no damage to these trees during mining operations by the miners. This indicates the removal of younger trees during mining. Such a trend leads to the failure of the community to generate back naturally. Similar trend were also observed by Paijman (1970) in New Guinea, Newbery *et al.* (1992) in Malayasia and Parthasarathi and Karthikeyan (1997) in India for various disturbed forest stands.

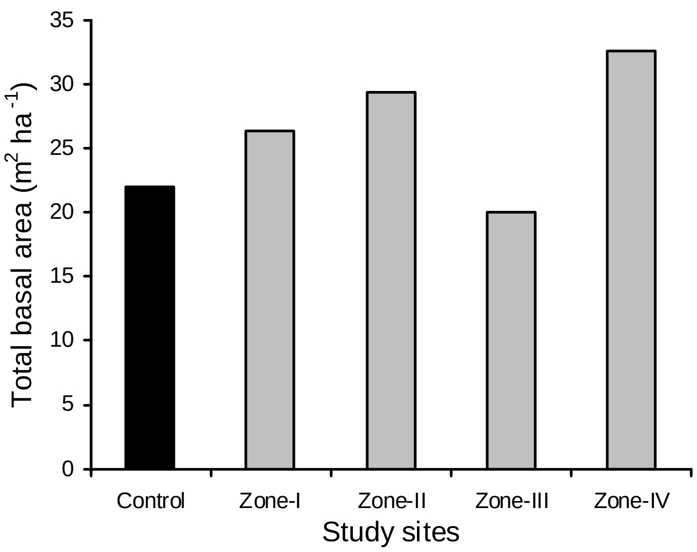

Figure 4.5: Basal area of tree species in control and mined areas.

4.3. Impact of Coal Mining on Species Distribution Pattern

Plant populations exhibit three patterns of spatial distribution, viz., contagious or clumped, random and regular or uniform. Patchiness, or the degree to which individuals are aggregated or dispersed, is crucial to the understanding of how species uses resources, and how it is used as a resource. Besides, the distribution pattern of species population is often related to its productive biology. Webb *et al.* (1967), Ashton (1972) and Austin *et al.* (1972) indicated that in the absence of major disturbance, soil and water conditions play major roles in controlling species distribution pattern.

In the unmined area most of the tree and shrub species showed contagious distribution pattern (85 and 89%). In the mined areas all the component of the plant species represented contagious pattern of distribution (Table 4.5). The contagious distribution pattern of species indicated the mosaicness of the forest stand. The contagious of the species suggests the increase in fragmentation of the natural vegetation due to mining. Similar species distribution pattern was observed by Sarma (2002) in coal mining areas of Nokrek biosphere reserve of Meghalaya.

Table 4.5: Proportion (%) of tree species under different distribution pattern in control and mined areas

Species	Control	Zone-I	Zone-II	Zone-III	Zone-IV
Tree					
Regular	-	-	-	-	-
Random	15	-	-	-	-
Contagious or clumped	85	100	100	100	100
Shrub					
Regular	-	-	-	-	-
Random	11	-	-	-	-
Contagious or clumped	89	100	100	100	100
Herbs					
Regular	-	-	-	-	-
Random	-	-	-	-	-
Contagious or clumped	100	100	100	100	100

Table 4.6: Overall community structure of control and coal mined areas

Species	Control	Zone-I	Zone-II	Zone-III	Zone-IV
Trees					
No. of species	27	4	7	3	11
No. of genera	24	4	7	3	10
No. of family	19	4	7	3	9
Density (individuals ha^{-1})	1040	561	515	603	647
Basal area (m^2ha^{-1})	21.94	26.36	29.38	20.06	32.61
Shannon-Weaver diversity index	2.8	0.47	0.34	0.54	0.85
Simpson dominance index	0.085	0.783	0.87	0.697	0.67
Shrubs					
No. of species	27	19	25	22	34
No. of genera	22	18	25	23	33
No. of family	18	13	17	16	21
Density (individuals/m^2)	1	2	1	1	2
Shannon-Weaver diversity index	3.13	2.59	2.51	2.84	2.56
Simpson dominance index	0.049	0.113	0.12	0.08	0.13
Herbs					
No. of species	23	39	41	40	34
No. of genera	21	38	41	39	33
No. of family	15	25	26	23	21
Density (individuals/m^2)	32	165	178	154	157
Shannon-Weaver diversity index	2.69	2.83	2.44	2.48	2.41
Simpson dominance index	0.097	0.138	0.22	0.198	0.24

Table 4.7: Density, basal area, importance value index and distribution pattern of trees, shrubs and herbs in control stands

Trees	Family	TI	BA	IVI	A/F
*Pithecellobium monadelphum (*Roxb.) Koster	Mimosaceae	2	0.03	5.3	0.200
Castanopsis tribuloides (Sm.) DC	Fagaceae	2	0.21	13.2	0.200
Diospyros kaki Thunb.	Ebenaceae	2	0.02	4.6	0.200
Rhus acuminata DC.	Anacardiaceae	3	0.04	8.3	0.075
Quercus griffithii Hk.f&Th ex DC	Fagaceae	7	0.32	30.7	0.028
Schima wallichii (DC.)Korth	Theaceae	1	0.00	3.0	0.100
Eurya acuminata DC.	Theaceae	2	0.01	4.4	0.200
Syzygium tetragonum (Wt.) Kurz	Myrtaceae	2	0.01	6.0	0.050
Sapindus rarak DC.	Sapindaceae	1	0.01	3.4	0.100
Podocarpus nerrifolia D.Don.	Podocarpaceae	1	0.05	5.3	0.100
Camellia caudata Wall.	Theaceae	38	0.11	54.5	0.078
Beilschmedia roxburghiana Nees	Laraceae	3	0.21	14.4	0.300
Castanopsis purpurella (Miq.) Balak.	Fagaceae	8	0.61	44.9	0.032
Styrax serrulatum Roxb.	Styraceae	1	0.00	2.9	0.100
Cinnamomum granduliflerum (Wall.) Meissn.	Lauraceae	2	0.21	15.1	0.050
Pyrularia edulies A. DC	Santalaceae	2	0.02	4.6	0.200
Ficus nerifolia J.E.Sm.	Moraceae	1	0.05	4.9	0.100
Schefflera hypoleucea (Kurz) Harms	Araliaceae	1	0.00	3.0	0.100
Lindera latifolia Hk.f.	Lauraceae	6	0.06	16.0	0.038
Lithocarpus elagans (Bl.) Hatus ex Soep	Fagaceae	5	0.10	14.7	0.056
Eurya cerasifolia (D.Don) Kobuski	Theaceae	4	0.06	12.0	0.044
Coffea khasiana Hook.f.	Rubiaceae	4	0.01	9.9	0.044
Itea macrophylla Wall	Itaceae	1	0.00	3.0	0.100
Picresema sp.	Simaroubiaceae	1	0.02	3.7	0.100
Citrus latipes (Swingle)Tanaka	Rutaceae	2	0.01	6.0	0.050
Ficus hirta var Roxb (Mig.) King	Moraceae	1	0.00	3.0	0.100
Dysoxylum gobara (Buch.-Ham) Merr.	Meliaceae	1	0.01	3.2	0.100
		104	**2.19**	**300**	

Shrubs	Family	TI	IVI	A/F
Rubus ellipticus Smith	Rosaceae	5	7.26	0.125
Rubus khasiana Cordat.	Rosaceae	3	5.65	0.075
Embelia vestita Roxb.	Myrsinaceae	4	6.45	0.100
Viburnum foetidum Wall.	Caprifoliaceae	8	12.90	0.050
Cassia floribunda Cav.	Fabaceae	10	14.52	0.063
Shutaria vestida W. & A.	Rubiaceae	10	14.52	0.063
Psychortia erratica Hook.f.	Rubiaceae	10	16.13	0.040
Psychortria curviflora Wall.	Rubiaceae	7	13.71	0.028
Erythroxylum kunthianum Wall. Ex Kurz	Erythroxylaceae	1	2.42	0.100
Prinsepia utilis Royle	Rosaceae	3	5.65	0.075
Jasminium dispermum Wall.	Oleaceae	4	6.45	0.100
Rubus assamensis Focke	Rosaceae	1	2.42	0.100
Rhynchotecum vestitum Wall. Ex Cl.	Gesneriaceae	3	4.03	0.300
Lasianthus sikkimensis Hook.f.	Rubiaceae	5	8.87	0.056
Polygonum molle D.Don	Polygonaceae	6	9.68	0.067
Ficus clavata Wall ex Miq.	Moraceae	3	5.65	0.075

Measa indica (Roxb.) Wall	Myrsinaceae	4	6.45	0.100
Lasianthus lucidus Bl.	Rubiaceae	3	4.03	0.300
Aralia thomsonii Seem.	Araliaceae	1	2.42	0.100
Euonymus lowsonii Clarke & Prain	Celastraceae	4	6.45	0.100
Corylopsis himalayana Griff.	Hamamelidaceae	1	2.42	0.100
Embelia subcoriaceae (Clarks) Mez.	Myrsinaceae	1	2.42	0.100
Breynia retusa (Dennst) Alst.	Euphobiaceae	4	8.06	0.044
Boehmeria sidaefolia Wedd.	Urticaceae	4	4.84	0.400
Solanum aculeatissimum Jacq.	Solanaceae	2	3.23	0.200
Plectranthus striatus Benth.	Lamiaceae	10	14.52	0.063
		124	**200**	

Herbs	**Family**	**TI**	**IVI**	**A/F**
Lophatherum gracile Brongn.	Poaceae	15	9.12	0.375
Isachne himalaica Hook.f.	Poaceae	31	20.95	0.124
Selaginella semicordata (Wall ex. Hk.Et.Grev.)	Selaginallaceae	44	29.52	0.090
Hedychium ellepticum Smith	Zingiberaceae	17	9.84	0.425
Globba clarkii Baker.	Zingiberaceae	73	38.73	0.149
Begonia palmata D.Don	Begoniaceae	4	3.49	0.400
Impatiens khasiana Hk..f.	Balsaminaceae	6	6.35	0.150
Impatiens banthamii V.Steenis	Balsaminaceae	5	3.81	0.500
Commelina paludosca Bl.	Commelinaceae	4	5.71	0.100
Panicum brevifolium L.	Poaceae	55	24.13	0.611
Murdannia gigantean (Vahl.) Bruck.	Commelinaceae	2	2.86	0.200
Aeginetia indica Linn.	Orobanchaceae	2	2.86	0.200
Carex filicina Nees.	Cyperaceae	1	2.54	0.100
Crassocephalum crepidioides (Benth.) Moore	Asteraceae	1	2.54	0.100
Achyrospermum wallichianum (Benth.) Hk.f.	Lamiaceae	8	4.76	0.800
Elatostema dissectum Wedd.	Urticaceae	10	5.40	1.000
Elsholtzia blanda (Benth.) Benth.	Lamiaceae	12	6.03	1.200
Arisaema tortuosum (Wall.) Schott.	Araceae	1	2.54	0.100
Dianella ensata (Thunb.) R.J.Handerson	Liliaceae	1	2.54	0.100
Cyanotis vaga (Lour.) J.A.&J.H.Schult.	Commelinaceae	5	3.81	0.500
Balanophora dioica R.Br.	Balanophoraceae	8	4.76	0.800
*Murdannia nudiflora (*Linn.) Brenan	Commelinaceae	2	2.86	0.200
Sonerila khasiana Clarke	Melastomaceae	8	4.76	0.800
		315	**200**	

TI= Total Individual IVI= Importance Value Index A= Abundance F=Frequency

Table 4.8: Density, basal area, importance value index and distribution pattern of trees, shrubs and herbs in zone-I

Trees	**Family**	**TI**	**BA**	**IVI**	**A/F**
Camellia caudata Wall	Theaceae	10	0.160	9.84	0.200
Pinus kesiya Royle. Ex Gordon.	Pinaceae	367	18.098	264.47	0.051
Persea odoristimma (nees) Koster.	Lauraceae	23	0.556	20.58	0.137
Helecia nilagirica Bedd.	Proteaceae	4	0.162	5.10	0.320
		404	**18.98**	**300**	

Shrubs		TI	IVI	A/F
Circium sp.	Asteraceae	112	9.62	0.180
Clerodendrum wallichii Merr.	Verbenaceae	61	8.90	0.070
Eupatorium adenophorum Spreng	Asteraceae	1185	53.74	0.440
Urena lobata Linn.	Malvaceae	65	6.88	0.160
Ficus clavata Wall ex Miq.	Moraceae	55	5.99	0.180
Lasianthus lucidus Bl.	Rubiaceae	80	6.60	0.290
Lantana camara Linn.	Verbenaceae	174	11.54	0.310
Lindera caudata Benth.	Lauraceae	61	5.39	0.310
Melastoma nepalensis Lodd.	Melastomaceae	410	25.28	0.180
Plectranthus striatus Benth.	Lamiaceae	76	5.92	0.380
Padocarpus neriifolia D.Don	Podocaraceae	38	3.77	0.344
Persea duthei (King ex Hk.f) Koster.	Lauraceae	82	8.56	0.130
Rhus acuminata DC.	Anacardiaceae	22	4.28	0.090
Rubus ellipticus Smith	Rosaceae	20	2.59	0.290
Rubus khasianas Cordat.	Rosaceae	119	12.30	0.100
Senecio cappa Buch.-Ham.ex D.Don	Asteraceae	44	5.60	0.144
Sida rhombilolia Linn.	Malvaceae	133	11.44	0.150
Solanum aculeatissimum Jacq.	Solanaceae	52	5.88	0.170
Symplocos pyrifolia Wall. Ex G.Don	Symplocaceae	40	5.73	0.100
		2829	**200**	

Herbs	Family	TI	IVI	A/F
Ageratum conyzoides Linn.	Asteraceae	370	10.44	0.130
Borreria articularis (L.f) F.N. Williams	Rubiaceae	390	9.97	0.166
Bidens pilosa (Bl.) Sherff	Asteraceae	154	5.59	0.150
Breynia retusa (Dennst) Alst.	Euphorbiaceae	31	2.17	0.160
Centella asiatica (Linn.) Urban	Apiaceae	250	5.13	0.50
Commelina paludosca Bl.	Commelinaceae	213	5.77	0.250
Crossouphalum sp.	Asteraceae	30	1.69	0.270
Crotalaria anagyroides HBK.	Fabaceae	95	3.98	0.170
Cyperus flavidus Tetz.	Cyperaceae	79	3.53	0.180
Emilia sonchifolia (Linn.) DC.	Asteraceae	21	0.97	0.600
Eupatorium adenophorum Spreng.	Asteraceae	394	8.89	0.230
Asplenium phyllitides D.Don	Aspleniaceae	79	3.05	0.250
Floscopa scandens Lour.	Commelinaceae	11	1.05	0.220
Gnaphalium pensylvanicum Willd.	Asteraceae	43	2.75	0.140
Hedera nepalensis K.Koch.	Araliaceae	13	1.22	0.190
Hedychium coccineum Smith	Zingiberaceae	28	2.46	0.100
Hodgsonia macrocarpa (Bl.) Cogn.	Cucurbitaceae	19	1.59	0.170
Isachne himalaica Hook.f.	Poaceae	1324	15.75	1.130
Lobelia angulata Forst.	Campanulaceae	38	2.39	0.160
Lycopodium cernum Linn.	Lycopodeaceae	45	2.61	0.170
Linderbergia muraria (Roxb.) Bruhl	Scrophulariaceae	23	1.95	0.144
Melastoma nepalensis Lodd.	Melastomaceae	14	0.91	0.44
Oxalis anaphelein L.	Oxalidaceae	70	4.09	0.100
Oxalis corniculata L.	Oxalidaceae	129	4.11	0.260
Pouzolzia hirta (Bl.) Hassk.	Urticaceae	14	0.60	1.120
Paspalum orbiculare Forst.	Poaceae	7283	68.42	2.590
Persea duthei (King ex Hk.f.) Koster.	Lauraceae	29	1.36	0.430
Plantago erosa Wall.	Plantaginaceae	109	3.62	0.270

Polygonum barbata L	Polygonaceae	30	2.00	0.180
Potentilla fulgens Wall.	Rosaceae	43	1.48	0.630
Girardinia palmate (Forsk) Gaud.	Urticaceae	82	1.65	1.640
Pratia begonifolia (Wall.) Lindl.	Campanulaceae	26	1.17	0.520
Rubus ellipticus Smith.	Rosaceae	50	2.97	0.140
Scutelleria discolor Benth.	Lamiaceae	8	0.70	0.360
Senecio cappa Buch.-Ham. Ex D.Don	Asteraceae	10	1.04	0.200
Smithia ciliata Royle	Fabaceae	46	1.50	0.680
Solanum aculeatissimum Jacq.	Solanaceae	107	5.20	0.110
Viola palmaris Ging.	Violaceae	98	3.53	0.240
Unidentified		91	2.68	0.460
		11889	**200**	

TI= Total Individual IVI= Importance Value Index A= Abundance F=Frequency

Table 4.9: Density, basal area, importance value index and distribution pattern of trees, shrubs and herbs in zone-II

Trees	**Family**	**TI**	**BA**	**IVI**	**A/F**
Pinus kesiya Royle. Ex Gordon.	Pinaceae	355	20.90	280.27	0.049
Schima wallichii (DC.) Korth	Theaceae	9	0.10	10.05	0.180
Saurauria punduana Wall.	Saurauiceae	1	0.01	1.49	0.720
Rhus acuminata DC.	Anacardiaceae	1	0.07	1.80	0.720
Exbucklandia populnea	Hammamalidaceae	2	0.03	3.07	0.360
Macaranga denticulate Muell.-Arg.	Verbenaceae	2	0.04	1.91	1.440
Helecia nilagirica Bedd.	Proteaceae	1	0.01	1.47	0.720
		371	**21.16**	**300**	

Shrubs	**Family**	**TI**	**IVI**	**A/F**
Castanopsis indica A.Dc.	Fagaceae	39	5.83	0.440
Circium sp.	Asteraceae	18	2.83	0.810
Clerodendrum wallichii Merr.	Verbenaceae	57	8.66	0.290
Eupatorium adenophorum Spreng	Asteraceae	271	27.55	0.290
Eurya acuminata DC.	Theaceae	76	10.67	0.280
Ficus clavata Wall ex Miq.	Moraceae	1	0.50	0.720
Lantana camara Linn.	Verbenaceae	274	26.41	0.370
Lindera caudata Benth.	Lauraceae	7	1.29	1.260
Macaranga denticulate Muell.-Arg.	Verbenaceae	2	0.56	1.440
Melastoma nepalensis Lodd.	Melastomaceae	533	48.86	0.250
Mahonia pycnophylla (Fedde) Takeda	Berberidaceae	10	2.35	0.450
Nellia thyrsiflora D.Don	Rosaceae	9	1.41	1.620
Padocarpus neriifolia D.Don	Podocaraceae	5	0.74	3.600
Persea duthei (King ex Hk.f) Koster.	Lauraceae	2	0.56	1.440
Plectranthus striatus Benth.	Lamiaceae	37	5.27	0.540
Rhus acuminata DC.	Anacardiaceae	5	0.74	3.600
Rubus ellipticus Smith	Rosaceae	153	23.15	0.110
Saurauia punduana Wall.	Saurauiaceae	18	4.14	0.260
Schima wallichii (DC.) Korth	Theaceae	8	1.79	0.640
Senecio cappa Buch.-Ham.ex D.Don	Asteraceae	65	9.14	0.330
Sida rhombilolia Linn.	Malvaceae	24	4.06	0.480
Smilax aspera L.	Smilacaceae	11	1.97	0.880
Solanum aculeatissimum Jacq.	Solanaceae	20	3.82	0.400
Symplocos spicata Roxb.	Symplocaceae	24	5.38	0.210

Urena lobata Linn.	Malvaceae	9	2.29	0.410
		1678	**200**	

Herbs	**Family**	**TI**	**IVI**	**A/F**
Ageratum conyzoides Linn.	Asteraceae	160	5.73	0.450
Anaphalis adnata DC.	Asteraceae	41	1.72	1.180
Borreria articularis (L.f) F.N. Williams	Rubiaceae	60	1.03	1.080
Borreria sp.	Rubiaceae	363	12.07	0.240
Bidens pilosa (Bl.) Sherff	Asteraceae	87	4.32	0.370
Breynia retusa (Dennst) Alst.	Euphorbiaceae	42	2.57	0.470
Carytia japonica L.	Vitaceae	3	0.30	2.160
Centella asiatica (Linn.) Urban	Apiaceae	64	4.14	0.270
Commelina paludosca Bl.	Commelinaceae	199	7.43	0.320
Crassocephalum sp.	Asteraceae	55	3.23	0.400
Crotalaria anagyroides HBK.	Fabaceae	14	0.67	2.520
Cyperus flavidus Tetz.	Cyperaceae	71	3.63	0.420
Drymaria cordata (Linn.) Roem. & Schult.	Caryophyllaceae	178	4.75	0.890
Emilia sonchifolia (Linn.) DC.	Asteraceae	54	1.82	1.560
Eriosaema himalaicum Ohashi	Fabaceae	8	0.34	5.760
Eupatorium adenophorum Spreng.	Asteraceae	118	3.16	1.330
Asplenium phyllitides D.Don	Aspleniaceae	87	2.08	2.510
Floscopa scandens Lour.	Commelinaceae	1	0.29	0.720
Gnaphalium pensylvanicum Willd.	Asteraceae	100	4.42	0.430
Hedera nepalensis K.Koch.	Araliaceae	2	0.30	1.444
Hedychium coccineum Smith	Zingiberaceae	3	0.30	2.160
Hedyotis tenelliflora Bl.	Rubiaceae	10	0.36	7.200
Hodgsonia macrocarpa (Bl.) Cogn.	Cucurbitaceae	13	0.94	1.040
Isachne himalaica Hook.f.	Poaceae	976	16.29	0.730
Lantana camara Linn.	Verbenaceae	2	0.30	1.440
Melastoma nepalensis Lodd.	Melastomataceae	289	5.61	1.450
Nepenthus khasiana L	Nepenthaceae	4	0.31	2.880
Osbeckia capitala Benth.	Melastomataceae	64	2.46	0.940
Oxalis corniculata L.	Oxalidaceae	33	1.38	1.490
Pouzolzia hirta (Bl.) Hassk.	Urticaceae	13	0.66	2.340
Paspalum orbiculare Forst.	Poaceae	9290	89.45	1.800
Persea duthei (King ex Hk.f.) Koster.	Lauraceae	8	0.34	5.760
Plantago erosa Wall.	Plantaginaceae	145	3.93	1.040
Polygonum barbata L	Polygonaceae	25	1.04	2.000
Potentilla fulgens Wall.	Rosaceae	69	2.50	1.010
Pratia begonifolia (Wall.) Lindl.	Campanulaceae	95	4.10	0.480
Rubus sp.	Rosaceae	7	0.61	1.260
Senecio cappa Buch.-Ham. Ex D.Don	Asteraceae	25	1.60	0.720
Smithia ciliata Royle	Fabaceae	21	0.72	3.780
Solanum aculeatissimum Jacq.	Solanaceae	5	0.32	3.600
Viola palmaris Ging.	Violaceae	30	2.75	0.270
		12834	**200**	

TI= Total Individual IVI= Importance Value Index A= Abundance F=Frequency

Table 4.10: Density, basal area, importance value index and distribution pattern of trees, shrubs and herbs in the zone-III

Trees	**Family**	**TI**	**BA**	**IVI**	**A/F**
Pinus kesiya Royle. Ex Gordon.	Pinaceae	357	13.848	246.05	0.050
Schima wallichii (DC.) Korth	Theaceae	67	0.516	46.36	0.057
Ligustrum robustum (Roxb.) Warb.	Oleaceae	10	0.076	7.54	0.288
		434	**14.44**	**300**	

Shrubs	**Family**	**TI**	**IVI**	**A/F**
Castanopsis indica A.Dc.	Fagaceae	46	7.70	0.070
Clerodendrum wallichii Merr.	Verbenaceae	59	7.59	0.120
Datura stromonium Linn.	Solanaceae	17	3.06	0.150
Eurya acuminata DC.	Theaceae	36	5.97	0.090
Eupatorium adenophorum Spreng	Asteraceae	345	22.78	0.430
Ficus clavata Wall ex Miq.	Moraceae	28	4.59	0.120
Lasianthus lucidus Bl.	Rubiaceae	79	8.07	0.200
Lyonia ovalifolia var. ovalifolia (Wall.) Drude	Ericaceae	24	3.40	0.210
Lantana camara Linn.	Verbenaceae	333	23.93	0.250
Lindera caudata Benth.	Lauraceae	11	2.27	0.166
Melastoma nepalensis Lodd.	Melastomaceae	527	37.86	0.166
Nellia thyrsiflora D.Don	Rosaceae	20	2.96	0.230
Padocarpus neriifolia D.Don	Podocaraceae	13	2.87	0.120
Persea duthei (King ex Hk.f) Koster.	Lauraceae	20	3.70	0.120
Plectranthus striatus Benth.	Lamiaceae	43	6.07	0.120
Rhus acuminata DC.	Anacardiaceae	29	4.39	0.150
Rubus ellipticus Smith	Rosaceae	76	7.92	0.190
Rubus khasianas Cordat.	Rosaceae	85	9.85	0.120
Senecio cappa Buch.-Ham.ex D.Don	Asteraceae	49	6.61	0.120
Sida rhombilolia Linn.	Malvaceae	21	3.01	0.240
Schima wallichii (DC.) Korth	Theaceae	42	5.52	0.150
Solanum aculeatissimum Jacq.	Solanaceae	41	4.98	0.210
Symplocos spicata Roxb.	Symplocaceae	27	5.04	0.090
Urena lobata Linn.	Malvaceae	79	9.81	0.100
		2050	**200**	

Herbs	**Family**	**TI**	**IVI**	**A/F**
Ageratum conyzoides Linn.	Asteraceae	231	11.68	0.140
Anaphalis adnata DC.	Asteraceae	7	1.43	0.200
Ainsliaea latifolia (D.Don) Sch.	Asteraceae	23	2.13	0.340
Borreria articularis (L.f) F.N. Williams	Rubiaceae	358	14.47	0.150
Bidens pilosa (Bl.) Sherff	Asteraceae	28	1.62	0.810
Breynia retusa (Dennst) Alst.	Euphorbiaceae	15	1.51	0.430
Crotalaria anagyroides HBK.	Fabaceae	14	0.95	1.122
Centella asiatica (Linn.) Urban	Apiaceae	44	2.86	0.390
Commelina paludosca Bl.	Commelinaceae	146	7.35	0.222
Crossouphalum sp.	Asteraceae	25	2.14	0.370
Cyperus flavidus Tetz.	Cyperaceae	69	4.46	0.250
Drymaria cordata (Linn.) Roem. & Schult.	Caryophyllaceae	368	6.62	1.840
Emilia sonchifolia (Linn.) DC.	Asteraceae	1	0.28	0.720

Eupatorium adenophorum Spreng.	Asteraceae	2	0.57	0.360
Asplenium phyllitides D.Don	Aspleniaceae	93	3.86	0.550
Floscopa scandens Lour.	Commelinaceae	2	0.29	1.444
Gnaphalium pensylvanicum Willd.	Asteraceae	40	1.73	1.150
Hedera nepalensis K.Koch.	Araliaceae	2	0.29	1.444
Impatiens khasiana Hk..f.	Balsaminaceae	55	2.42	0.810
Isachne himalaica Hook.f.	Poaceae	1254	19.57	1.000
Lophatherum gracile Brongn.	Poaceae	23	1.58	0.660
Leucus ciliata L.	Lamiaceae	23	1.30	1.040
Lobelia angulata Forst.	Campanulaceae	11	0.65	1.980
Lycopodium cernum Linn.	Lycopodiaceae	44	2.59	0.500
Oxalis corniculata L.	Oxalidaceae	34	1.13	2.720
Polygonum barbata L	Polygonaceae	7	0.61	1.260
Pouzolzia hirta (Bl.) Hassk.	Urticaceae	20	1.28	0.900
Paspalum orbiculare Forst.	Poaceae	7721	83.29	2.320
Persea duthei (King ex Hk.f.) Koster.	Lauraceae	3	0.58	0.540
Plantago erosa Wall.	Plantaginaceae	136	4.24	0.810
Polygonum viscosum D.Don	Polygonaceae	3	0.30	2.160
Potentilla fulgens Wall.	Rosaceae	8	0.62	1.444
Pratia begonifolia (Wall.) Lindl.	Campanulaceae	84	4.05	0.420
Rubus sp.	Rosaceae	13	0.94	1.040
Scutelleria discolor Benth.	Lamiaceae	11	1.47	0.320
Senecio cappa Buch.-Ham. Ex D.Don	Asteraceae	25	1.32	1.130
Smithia ciliata Royle	Fabaceae	53	3.77	0.270
Solanum aculeatissimum Jacq.	Solanaceae	31	1.92	0.620
Viola palmaris Ging.	Violaceae	7	0.34	5.040
Unidentified		18	1.81	0.360
		11052	**200**	

TI= Total Individual IVI= Importance Value Index A= Abundance F=Frequency

Table 4.11: Density, basal area, importance value index and distribution pattern of trees, shrubs and herbs in the zone-IV

Trees	**Family**	**TI**	**BA**	**IVI**	**A/F**
Pinus kesiya Royle. Ex Gordon.	Pinaceae	398	22.25	243.93	0.060
Schima wallichii (DC.) Korth	Theaceae	23	0.37	18.91	0.080
Saurauria punduana Wall.	Saurauiceae	21	0.50	11.06	0.610
Rhus javanica Linn.	Anacardiaceae	1	0.03	1.24	0.720
Rhus acuminata DC.	Anacardiaceae	3	0.04	3.48	0.240
Plangium chinensis L.	Cornaceae	2	0.04	2.37	0.360
Litsea citrata Bl.	Lauraceae	4	0.05	4.60	0.180
Lindera caudata Benth.	Lauraceae	5	0.09	4.98	0.230
Myrica esculanta Buch.-Ham. Ex D.Don	Myricaceae	3	0.03	3.42	0.240
Macaranga denticulate Muell.-Arg.	Verbenaceae	3	0.04	2.57	0.540
Helecia nilagirica Bedd.	Proteaceae	3	0.04	3.47	0.240
		466	**23.48**	**300**	

Shrubs	**Family**	**TI**	**IVI**	**A/F**
Castanopsis indica A.Dc.	Fagaceae	15	1.60	1.200
Circium sp.	Asteraceae	32	6.24	0.120
Clerodendrum wallichii Merr.	Verbenaceae	14	2.31	0.400

Datura stromonium Linn.	Solanaceae	14	1.94	0.633
Elaegnus sp.	Eleagnaceae	4	0.87	0.720
Eupatorium adenophorum Spreng	Asteraceae	920	40.52	0.740
Eurya acuminata DC.	Theaceae	71	5.99	0.510
Ficus clavata Wall ex Miq.	Moraceae	1	0.41	0.720
Lasianthus lucidus Bl.	Rubiaceae	2	0.81	0.360
Lantana camara Linn.	Verbenaceae	1071	49.44	0.460
Lyonia ovalifolia var. ovalifolia (Wall.) Drude	Ericaceae	18	2.07	0.810
Lindera caudata Benth.	Lauraceae	5	0.53	3.600
Itea macrophylla Wall.	Iteaceae	75	3.14	13.500
Macaranga denticulate Muell.-Arg.	Verbenaceae	18	2.07	0.810
Melastoma nepalensis Lodd.	Melastomaceae	370	23.36	0.280
Nellia thyrsiflora D.Don	Rosaceae	20	2.88	0.400
Girardinia palmata (Forsk) Gaud.	Urticaceae	2	0.81	0.360
Persea duthei (King ex Hk.f) Koster.	Lauraceae	7	1.72	0.320
Prunus acuminata (Wall.) Dietr.	Rosaceae	1	0.41	0.720
Rhus acuminata DC.	Anacardiaceae	23	3.35	0.344
Prinsepia utilis Royle	Rosaceae	4	0.87	0.720
Rubus ellipticus Smith	Rosaceae	4	0.87	0.720
Rubus khasianas Cordat.	Rosaceae	125	14.81	0.111
Saurauia punduana Wall.	Saurauiaceae	11	1.84	0.500
Schima wallichii (DC.) Korth	Theaceae	1	0.41	0.720
Senecio cappa Buch.-Ham.ex D.Don	Asteraceae	169	13.22	0.280
Sida rhombilolia Linn.	Malvaceae	1	0.41	0.720
Smilax myrtillus DC.	Smilacaceae	13	2.65	0.260
Solanum aculeatissimum Jacq.	Solanaceae	32	4.01	0.360
Symplocos spicata Roxb.	Symplocaceae	9	1.03	1.620
Thysanolaena maxima (Roxb.) O. Ktze.	Poaceae	30	2.08	2.400
Triumfetta tomentosa Bojer	Tiliaceae	10	0.69	7.200
Urena lobata Linn.	Malvaceae	20	2.13	0.900
Wendlandia wallichii W.&A.Prodr.	Rubiaceae	25	4.53	0.180
		3137	**200**	

Herbs	Family	TI	IVI	A/F
Ageratum conyzoides Linn.	Asteraceae	132	6.00	0.560
Anaphalis adnata DC.	Asteraceae	61	3.14	0.900
Borreria articularis (L.f) F.N. Williams	Rubiaceae	49	2.67	0.980
Barreria sp.	Rubiaceae	95	4.93	0.570
Bidens pilosa (Bl.) Sherff	Asteraceae	139	4.95	1.000
Breynia retusa (Dennst) Alst.	Euphorbiaceae	43	2.24	1.240
Centella asiatica (Linn.) Urban	Apiaceae	31	2.13	0.890
Commelina paludosca Bl.	Commelinaceae	118	6.62	0.380
Crossouphalum sp.	Asteraceae	76	4.39	0.550
Cyperus flavidus Tetz.	Cyperaceae	90	6.00	0.333
Dicranopteris linearis (Burm.f) Undewood	Gleicheniaceae	20	0.92	3.600
Drymaria cordata (Linn.) Roem. & Schult.	Caryophyllaceae	72	2.50	2.070
Emilia sonchifolia (Linn.) DC.	Asteraceae	55	3.09	0.810
Eupatorium adenophorum Spreng.	Asteraceae	96	3.83	1.080
Asplenium phyllitides D.Don	Aspleniaceae	64	2.80	1.280
Gnaphalium pensylvanicum Willd.	Asteraceae	224	9.05	0.450
Hedychium coccineum Smith	Zingiberaceae	41	1.48	3.280
Hedyotis tenelliflora Bl.	Rubiaceae	45	1.14	8.100
Isachne himalaica Hook.f.	Poaceae	75	1.78	6.000
Lobelia angulata Forst.	Campanulaceae	10	1.20	0.800
Elsholtzia blanda (Benth.) Benth.	Lamiaceae	23	1.32	1.840
Melastoma nepalensis Lodd.	Melastomaceae	77	3.29	1.130

Osbeckia capitala Benth.	Melastomaceae	136	5.30	0.810
Oxalis corniculata L.	Oxalidaceae	55	3.46	0.620
Paspalum orbiculare Forst.	Poaceae	9125	95.47	4.320
Plantago erosa Wall.	Plantaginaceae	107	7.27	0.270
Polygonum barbata L	Polygonaceae	27	1.73	1.220
Potentilla fulgens Wall.	Rosaceae	19	0.91	3.420
Pratia begonifolia (Wall.) Lindl.	Campanulaceae	74	5.12	0.370
Rubus sp.	Rosaceae	7	0.81	1.260
Smithia ciliata Royle	Fabaceae	43	1.50	3.440
Smilax aspera L.	Smilacaceae	18	1.27	1.440
Viola palmaris Ging.	Violaceae	5	0.42	3.600
Unidentified		21	1.30	1.680
		11273	**200**	

TI= Total Individual IVI= Importance Value Index A= Abundance F=Frequency

4.4. Change Detection

4.4.1. Land Use/ Land Cover Distribution and Changes

In order to put any change into a proper perspective, it is useful to establish the state of the environment in the selected base year. The aerial extent of each land use/ land cover class in the different years i.e., 1975, 1987, 1999 and 2001 was analysed in order to get an overview of changes in magnitude so as to justify the change analysis (Figure 4.6, Figure 4.7, Figure 4.8, Figure 4.9).

It was found that most of the areas were dominated by grassland/ non-forest (64.7 to 66.1 percent) during the course of the study. The forest area covered about 25 percent of the total area during 1975. This had decreased to about 16 percent in the year 2001. The coal mining areas occupied a considerable portion that ranged between 3 to more than 10 percent of the area. The settlement area ranged between 4 and 7 percent and the crop area was found quite less (1.5-2.7 percent) (Table 4.12).

Table 4.12: Area (km^2) under different land use/ land cover categories in different years

Years	Mining area	Dense forest	Grassland/ Non-forest	Open forest	Settlement	Cropped area
1975	13.76 (3.26%)	95.12 (22.5%)	271.23 (64.65%)	11.69 (2.76%)	17.63 (4.17%)	11.21 (2.65%)
1987	28.86 (6.78%)	65.04 (15.7%)	272.39 (64.71%)	24.16 (5.68%)	23.48 (5.52%)	6.57 (1.54%)
1999	40.21 (9.05%)	51.64 (12.23%)	273.01 (66.07%)	18.95 (4.38%)	28.49 (6.75%)	6.88 (1.52%)
2001	45.24 (10.75%)	51.52 (12.34%)	273.36 (64.98%)	14.12 (3.35%)	29.20 (6.94%)	6.83 (1.62%)

During the entire study period there were changes in the land cover and land uses. Mining was initiated in the area in early 1970s. As a result of what lots of the area were converted into mining areas. The forests were mostly victimized due to mining activity (13 to 45 km^2). There was gradual decrease of forest both dense and open during the course of time. The total forest area lost during the study period was 40.53 km^2, which was about 40 percent of the total forest area. There was loss of 43.5 km^2 dense forest area from the study area, which was 45.7 percent of the total area under dense forest. There was increase of 2.43 km^2 open forest area during the study period. This was due to the conversion of the dense forest to the open forest (95 to 65 km^2). There were not much variation in dense forest during the year 1999 and 2001. But area under open forest had reduced during this period (Figure 4.10).

As the mining operation started, there was lots of demand of manpower to work in the coalfields. Development of the infrastructure started in this period (Figure 4.11). Dense forest areas were targeted to accommodate these facilities. During this period a considerable portion of the dense forest area were converted into non-forest like, settlement, roads and grasslands. Grasslands were outcome of the mining. When extraction and supply of coal was over the areas kept fallow. In course of time those areas were covered with grasses that could grow in the harsh edaphic conditions. No other plant species could grow in that area and it became completely abandoned (Figure 4.12). The local people also inclined towards the mining activities and most of the agricultural fields were converted into mining areas. It was found that there was not much impact on the grassland and existing non-forest areas of the region since the mining was introduced.

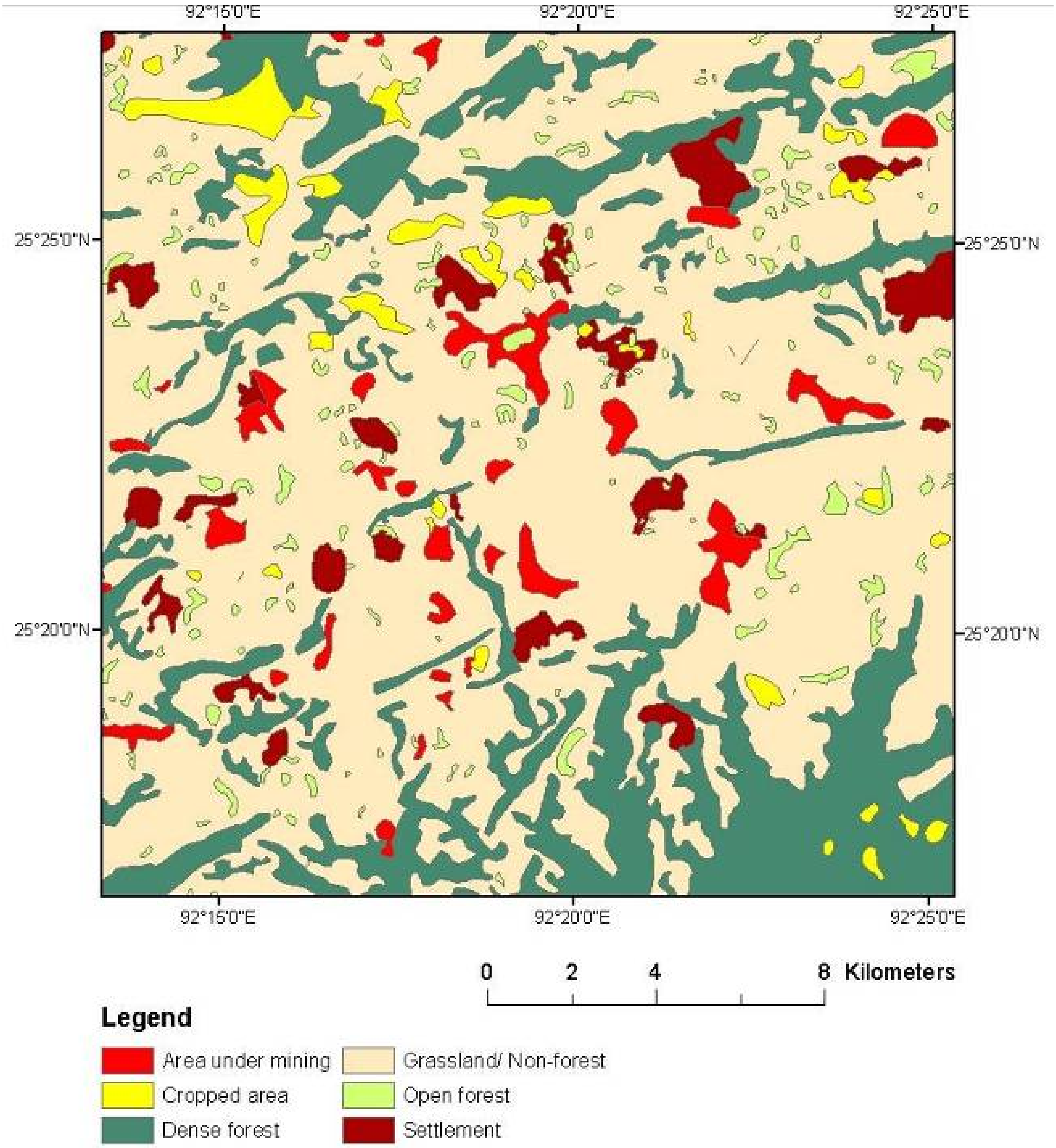

Figure 4.6: Land use/ land cover in 1975.

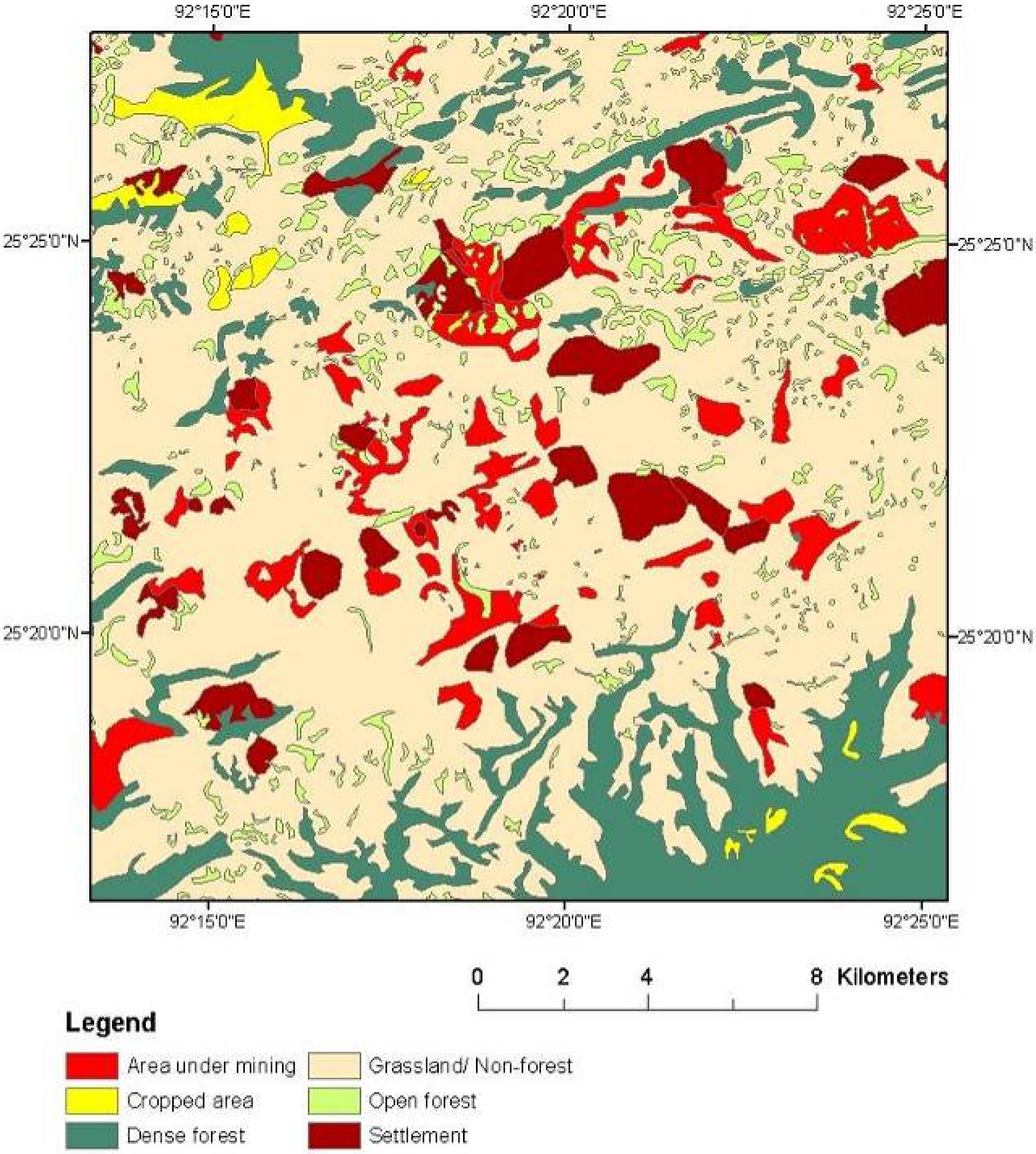

Figure 4.7: Land use/ land cover in 1987.

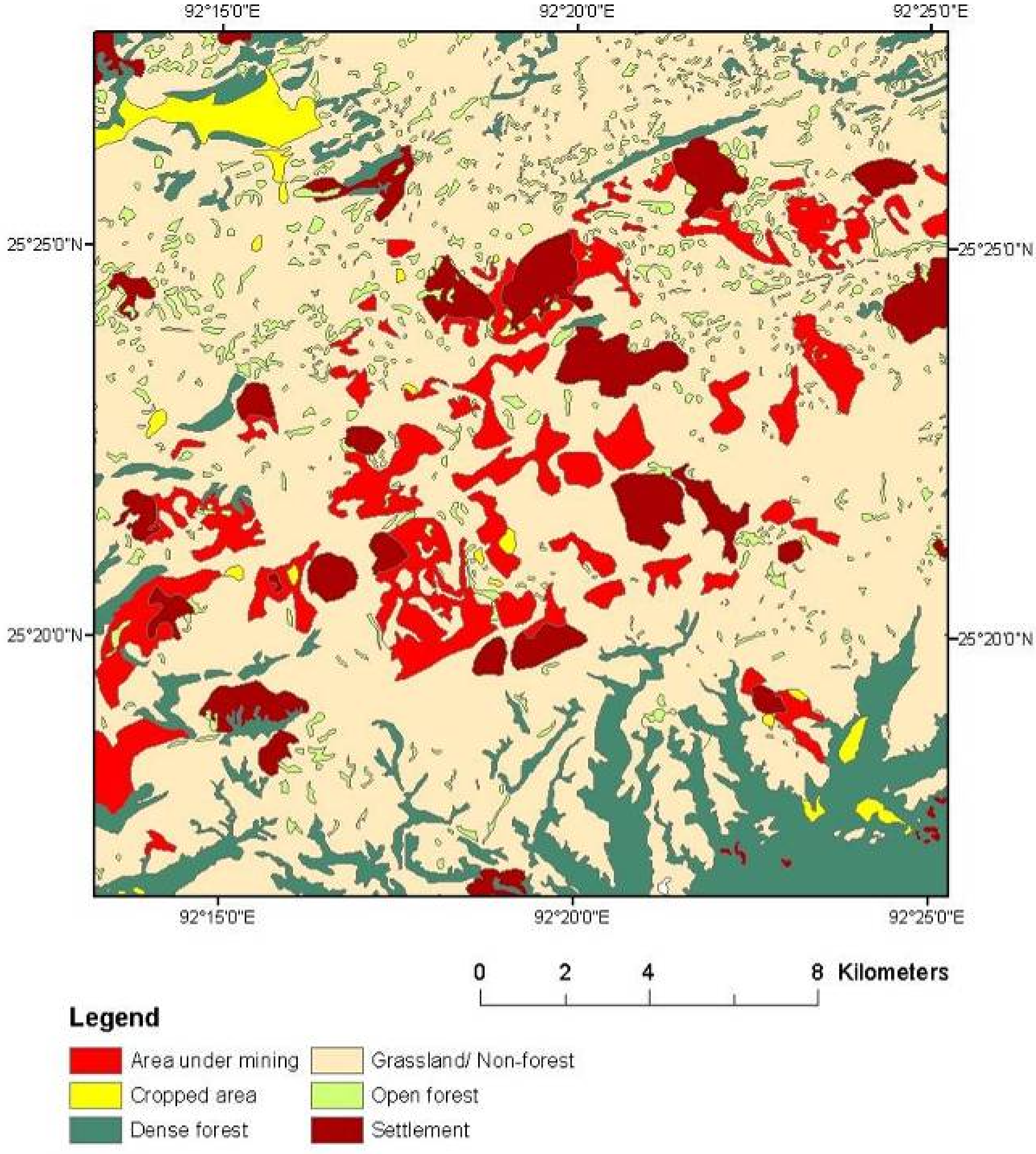

Figure 4.8: Land use/ land cover in 1999.

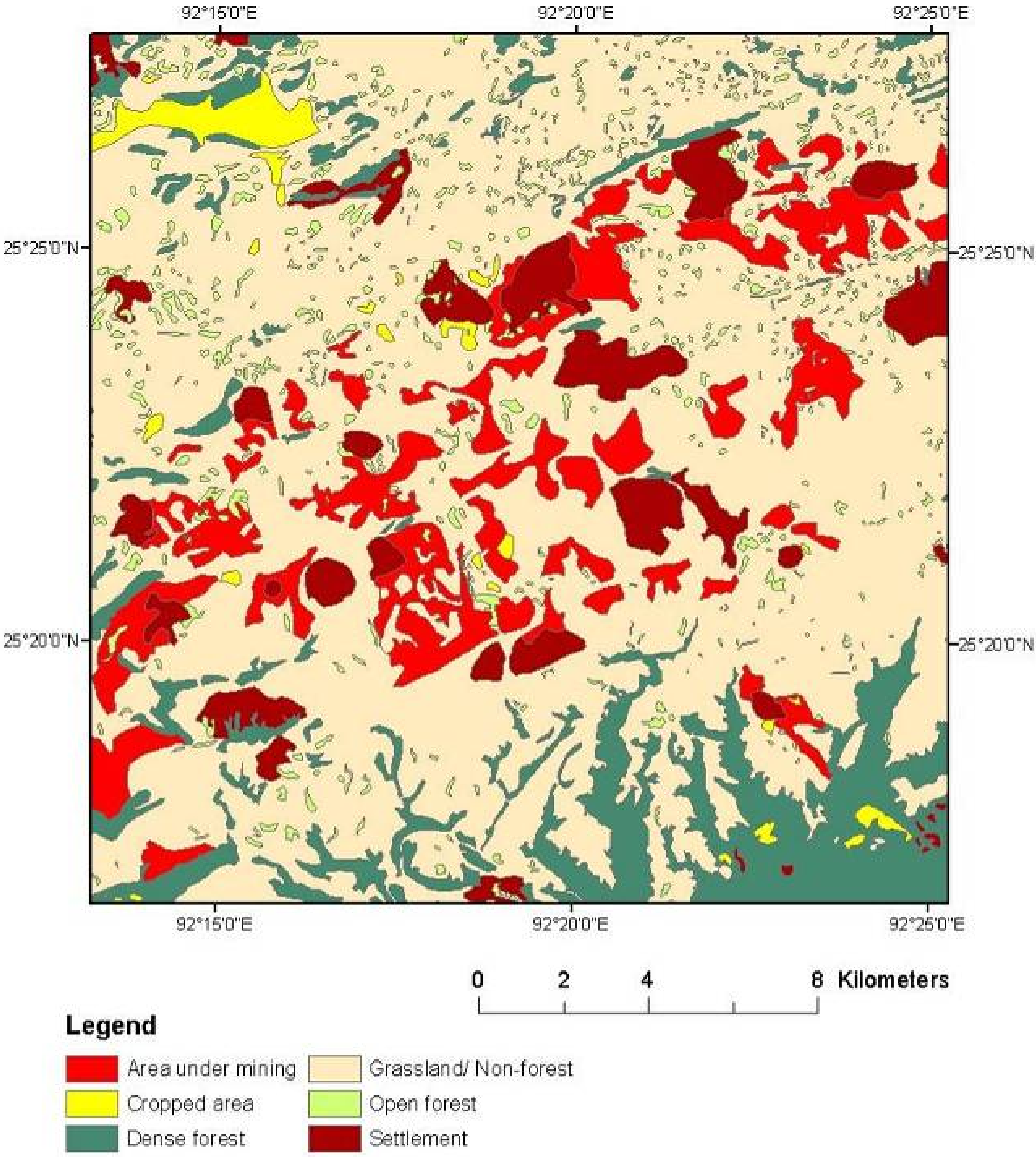

Figure 4.9: Land use/ land cover in 2001.

Prakash and Gupta (1998) studied the land use/ land cover changes of Jharia coal field of India and concluded that there were gradual decrease and threat to the vegetation present in the area where mining was prominent. Ghosh (1998) emphasized that due to the consequences of mining activities there were thorough change in the natural topography of the region.

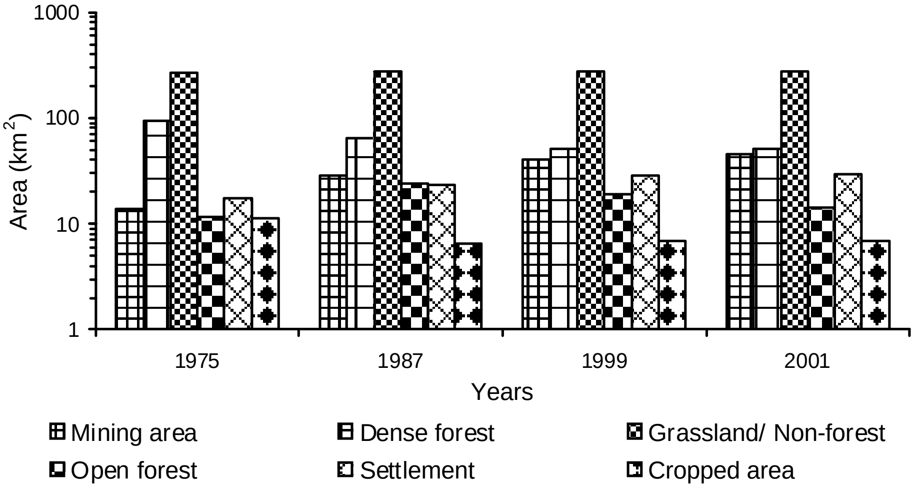

Figure 4.10: Area under different land use/ land cover categories in different years.

(a) **(b)**

Figure 4.11: Mining operation attracted people from far-flung areas. Growth of urban centre (a) and hamlets (b) around mines are the result of mining.

(a) **(b)**

Figure 4.12: Unsuccessful forest plantations were carried out by the Govt. Departments on the mine spoils.

4.4.2. Changes in different land use/ land cover categories from 1975 to 2001

To understand the land use dynamics related to vegetation and mining, successive land cover change maps of 1975 and 1987, 1987 and 1999 and 1999 and 2001 has been prepared. Seven classes of changes i.e., dense forest to open forest, dense forest to mining, dense forest to non-forest, open forest to mining, open forest to non-forest, no change and others are considered (Figure 4.14, Figure 4.15, Figure 4.16).

It was found from the change analysis that there was impact of mining to different land uses, which were directly or indirectly related to vegetation. About 6 km^2 of the dense forest of the study area were changed to the open forest during 1975 to 1987. This rate of change was not maintained in the proceeding years. More than 6 km^2 area of open forest converted into non-forest during that period. The changes of about 25 percent of the total area could tell how much stress was going on to the landscape during 12 years of time. During 1987 to 1999 changes occurred in about 20 percent of the total area. About 4 km^2 of the dense forest were converted into open forest during this period. The change of open forest area to the non-forest recorded a considerable portion (12.87 km^2). During the years 1999 and 2001 about 7 percent of the total area undergone changes. During this period about 3 percent of the area were converted into non-forest either from dense forest or open forest (Table 4.13). The changes that occurred due to the direct or indirect impact of mining are represented in Figure 4.13.

Prakash and Gupta (1998) while studying the change analysis of the Jharia coal field found that there were changes in different land uses. They concluded that there was general decrease in the vegetation cover. But after the change detection analysis it was apparent that due to the initiation of afforestation activities there were increase in the vegetation cover in the study area. The classification done for the change analysis for the study were open cast mining, new plantation level out area and area of no change. Rathore and Wright (1993) emphasized that the mining and changes were correlated to each other.

Table 4.13: Changes in land use/ land cover in different years

Change type	**1975-87**	**1987-99**	**1999-2001**
Dense to open Forest	5.92 (1.41%)	3.68 (0.88%)	0.86 (0.21%)
Dense forest to mining	0.61 (0.15%)	0.09 (0.02%)	0.06 (0.01%)
Dense forest to non-forest	29.35 (6.99%)	19.25 (4.58%)	4.64 (1.11%)
Open forest to mining	0.22 (0.05%)	0.41 (0.1%)	0.12 (0.03%)
Open forest to non-forest	6.53 (1.55%)	12.87 (3.07%)	5.51 (1.31%)
No change	318.16 (75.75%)	335.81 (79.96%)	390.35 (92.94%)
Others	59.19 (14.09%)	47.86 (11.4%)	18.46 (4.4%)
Total	**420 (100%)**	**420 (100%)**	**420 (100%)**

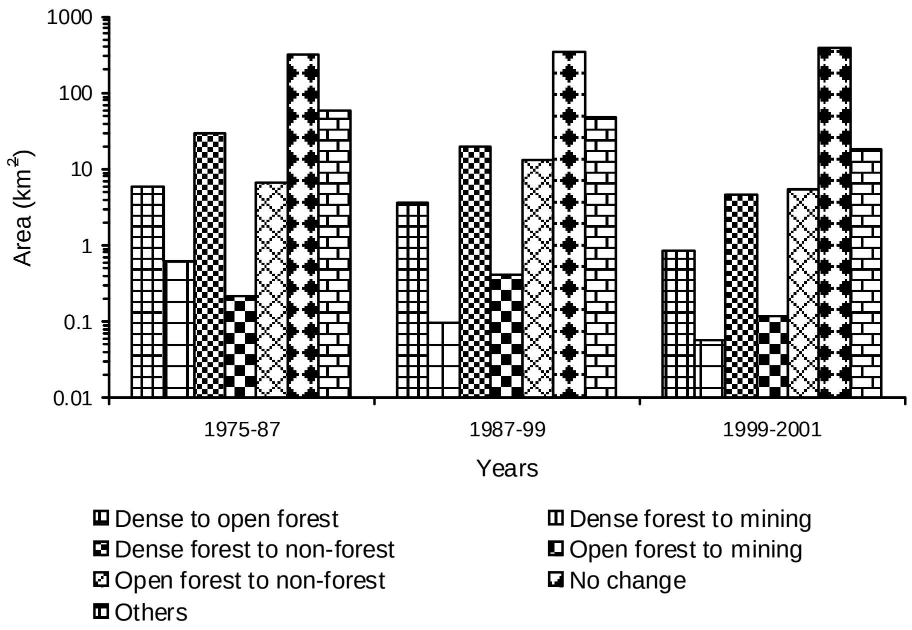

Figure 4.13: Changes in different land use/ land cover categories in different years.

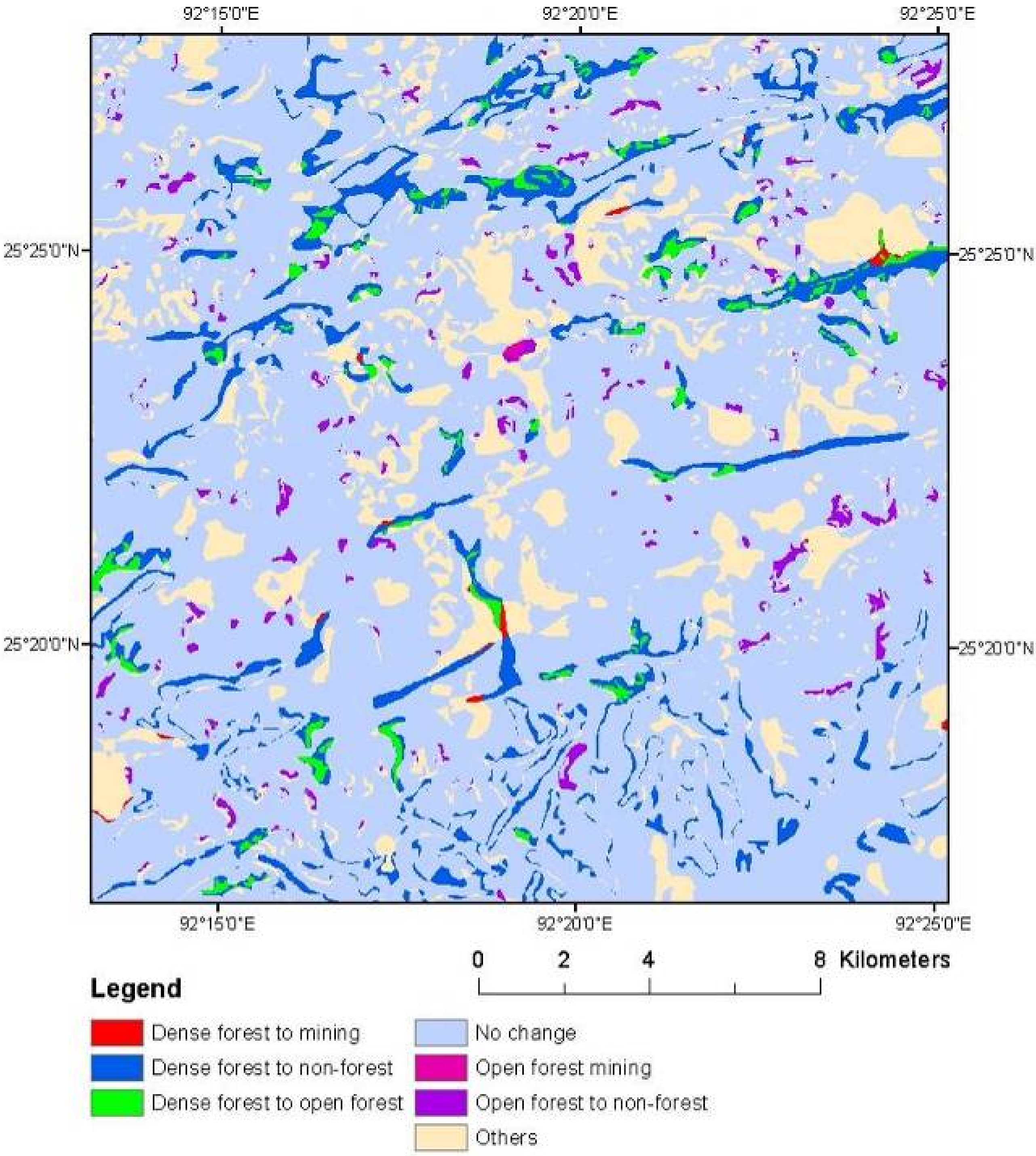

Figure 4.14: Changes of land use/ land cover from 1975 to 1987.

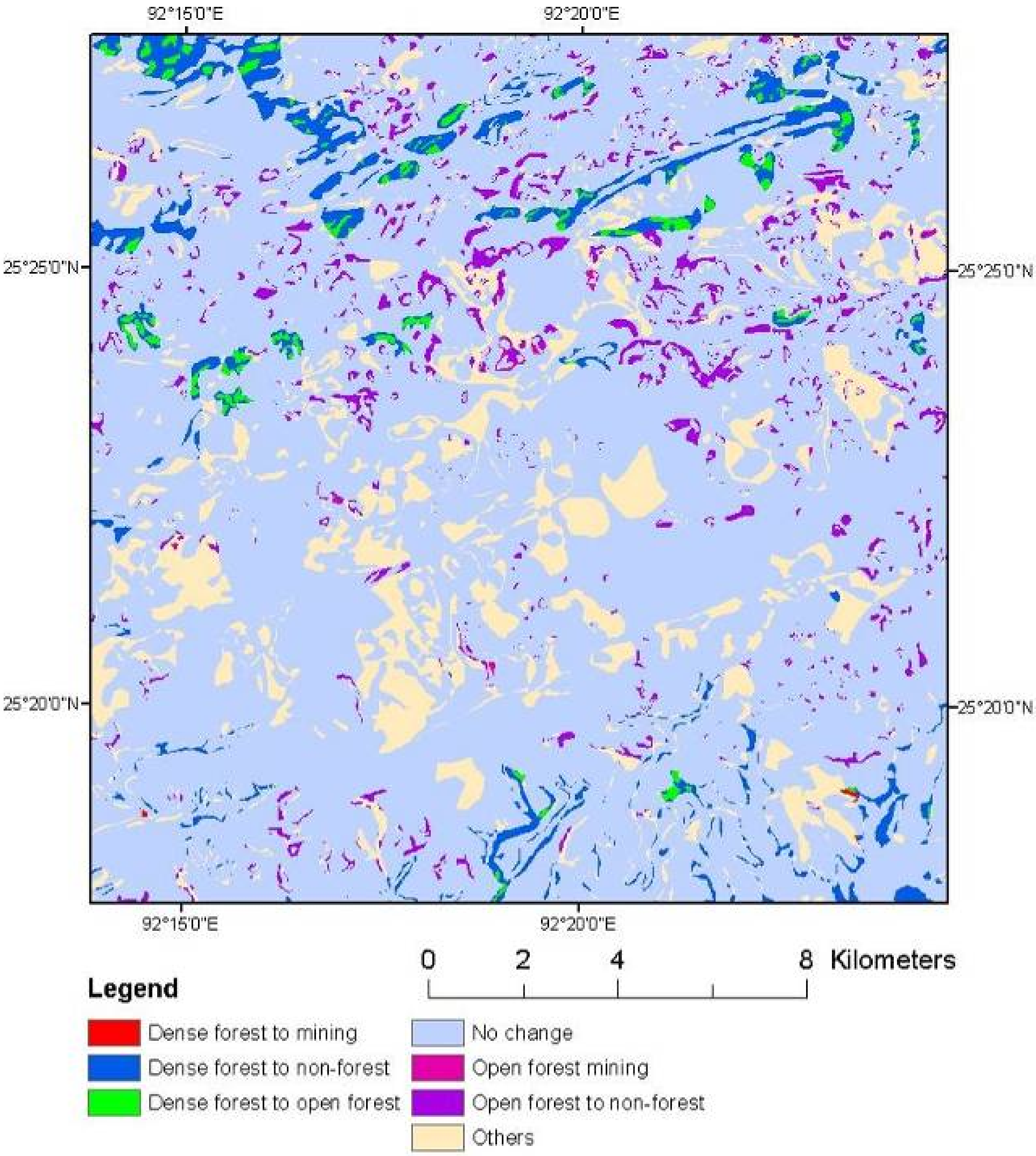

Figure 4.15: Changes of land use/ land cover from 1987 to 1999.

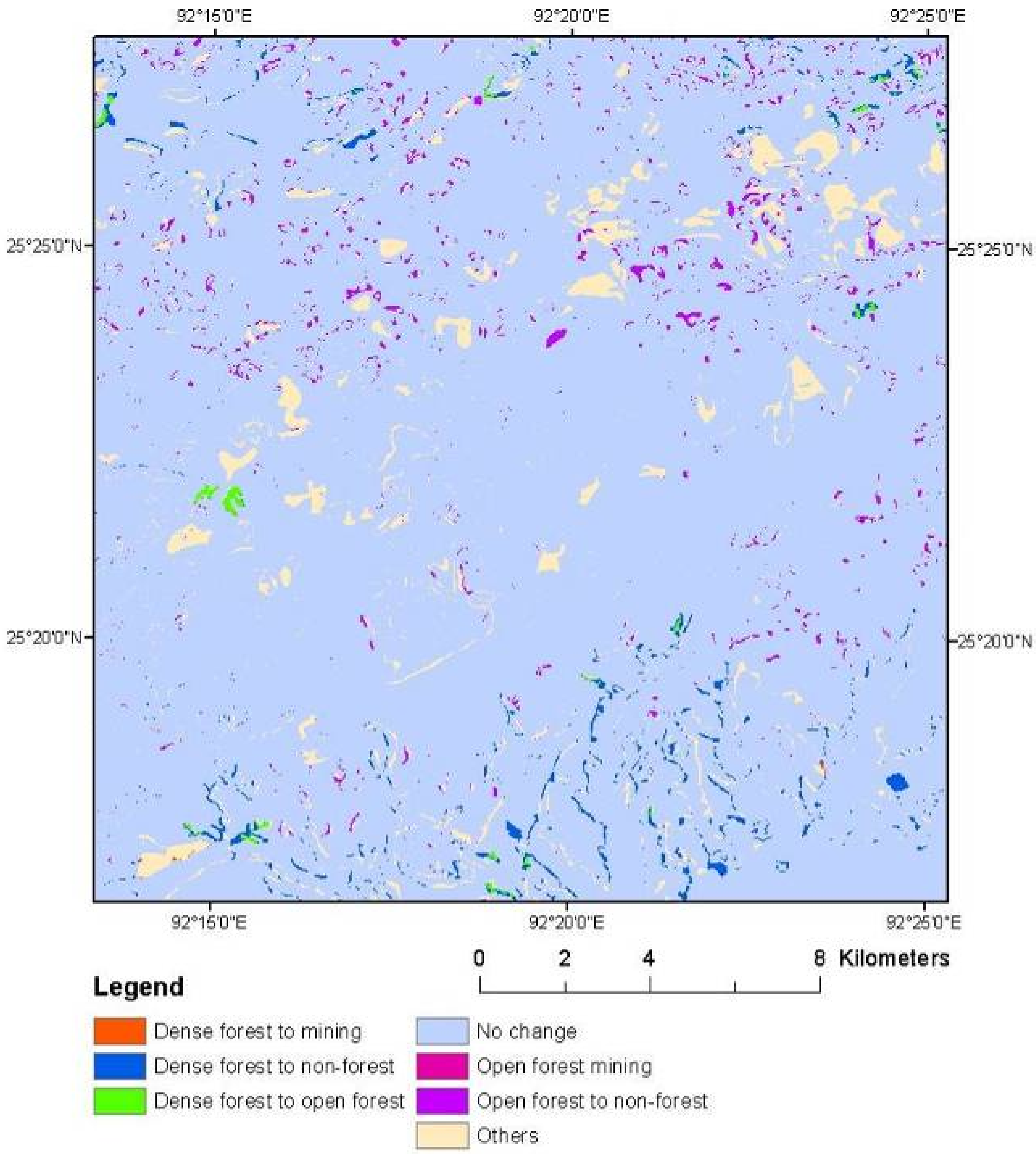

Figure 4.16: Changes of land use/ land cover from 1999 to 2001.

4.4.3. Forest Fragmentation

Forest fragmentation occurs when large, continuous forests are converted into smaller blocks, either by roads, clearing for agriculture, urbanization, or other human developments. The forest fragmentation maps of four different years have been prepared for the present study to delineate the areas, which are under risk due to the impact of coal mining. The degree of fragmentation is classified as non-forest area, high fragmentation area and low fragmentation area (Figure 4.18, Figure 4.19, Figure 4.20, Figure 4.21).

A considerable portion of the study area were dominated by non-forest (68.4-75 percent). It was apparent from the maps that high fragmentation areas were located close to the mines. During the year 1975 and 2001 more than 20 km^2 area of low fragmentation were converted either to highly fragmented or non-forest areas. As expected there was increasing trend for the areas under high fragmentation. In case of the year 1999 to 2001 there were loss of high fragmentation area of about 9 km^2 and those areas were converted to the non-forest area. More than 68 km^2 (16 percent) area were identified as the areas at risk. The area under non-forest was more in 2001 than the past years (Table 4.14). The areas under different fragmentation classes are represented in Figure 4.17.

Table 4.14: Area (km^2) and proportion (%) of different fragmentation classes in different years

	1975	**1987**	**1999**	**2001**
Low fragmentation	74.58 (17.76%)	56.49 (13.45%)	37.37 (8.90%)	36.92 (8.79%)
High fragmentation	57.05 (13.58%)	76.29 (18.17%)	77.44 (18.44%)	68.23 (16.24%)
Non-forest	288.37 (68.66%)	287.22 (68.39%)	305.19 (72.66%)	314.85 (74.96%)
Total	**420 (100%)**	**420 (100%)**	**420 (100%)**	**420 (100%)**

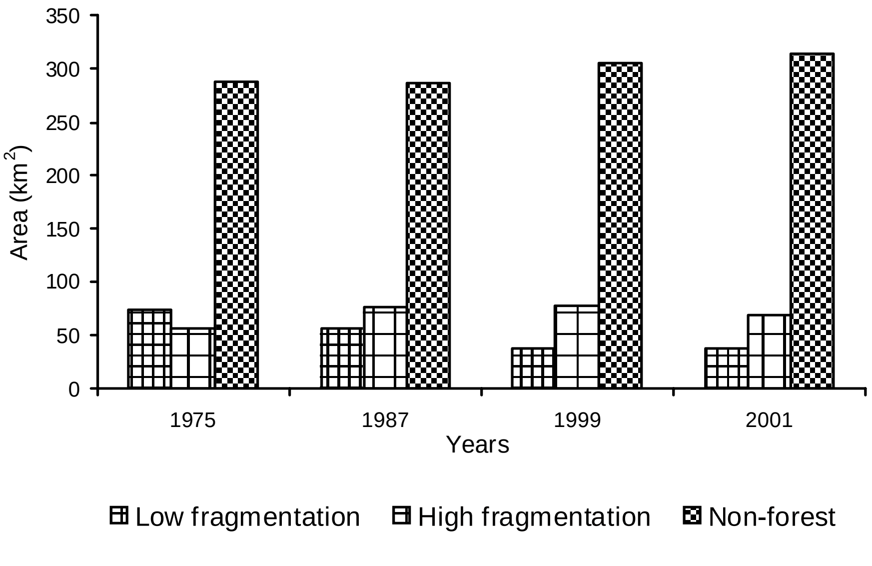

Figure 4.17: Areas under different fragmentation classes in different years.

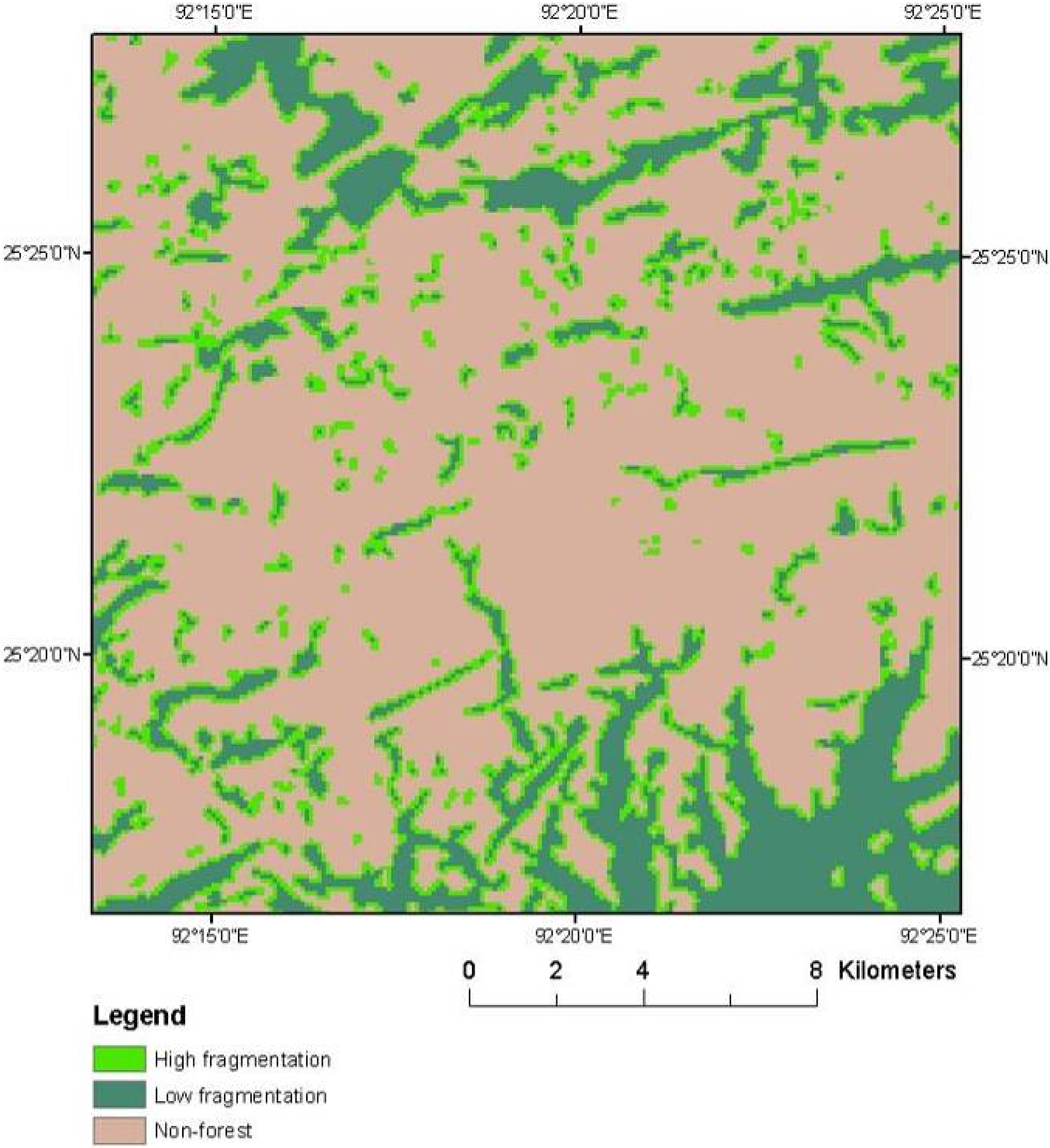

Figure 4.18: Forest fragmentation in 1975.

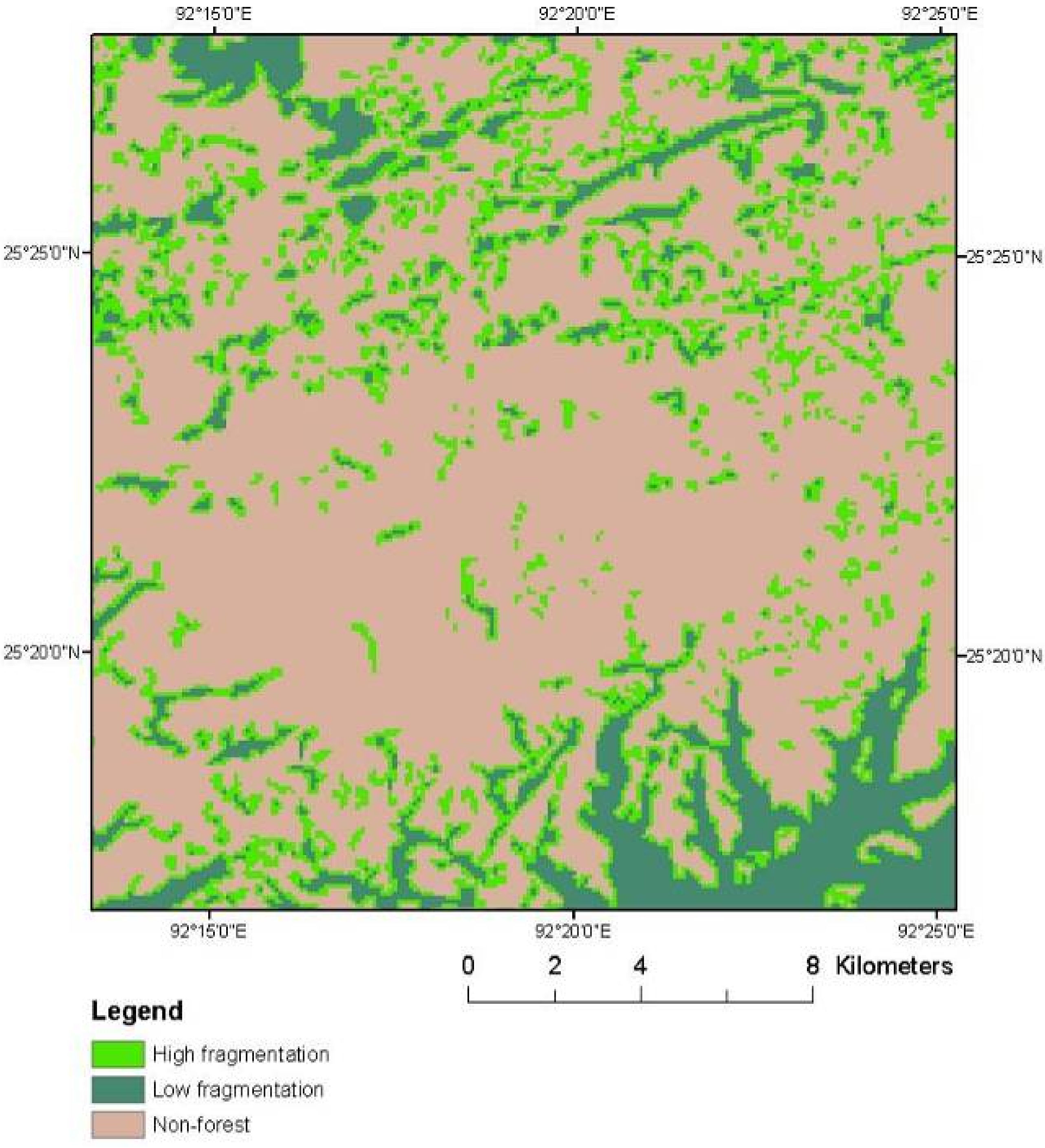

Figure 4.19: Forest fragmentation in 1987.

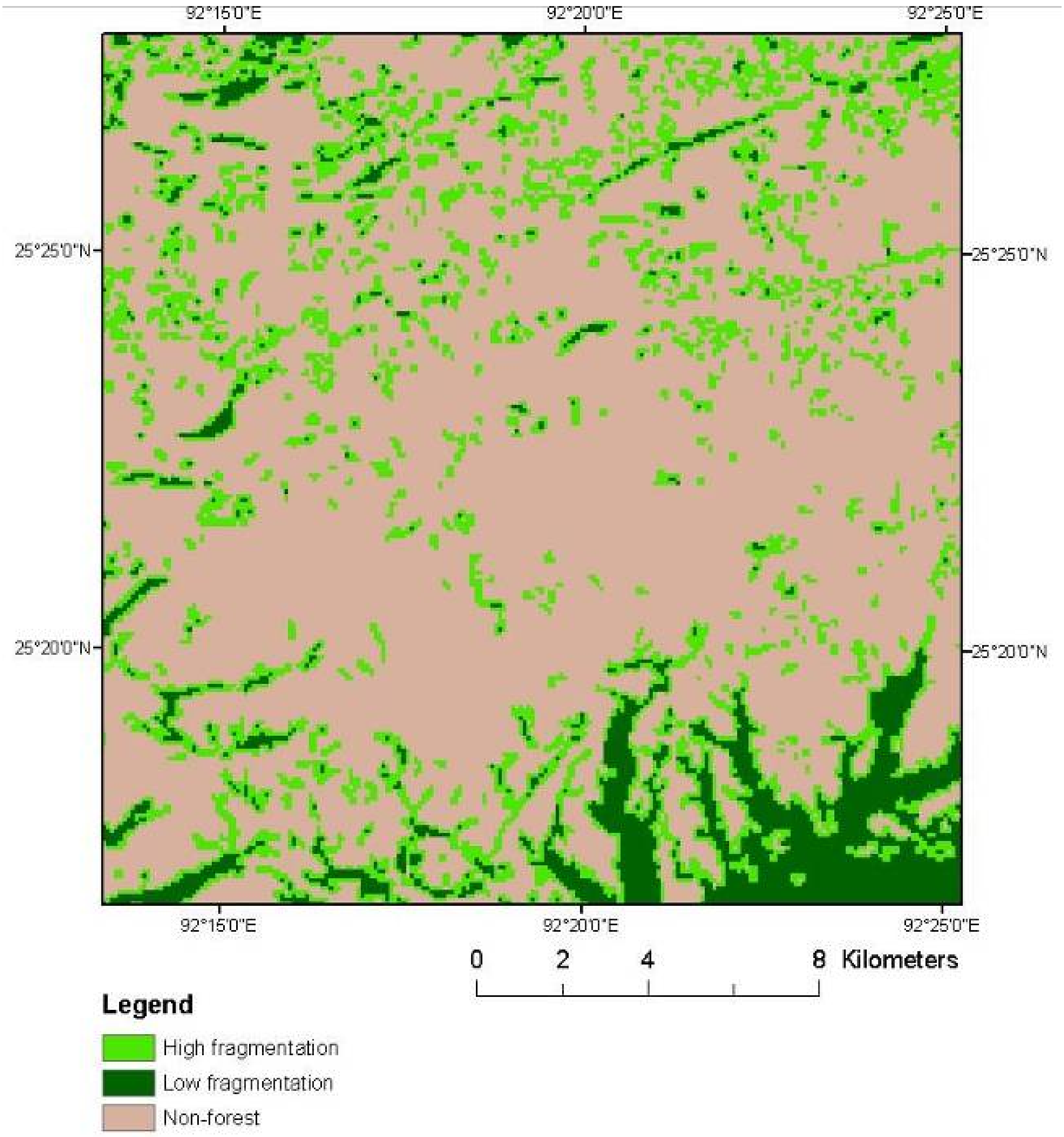

Figure 4.20: Forest fragmentation in 1999.

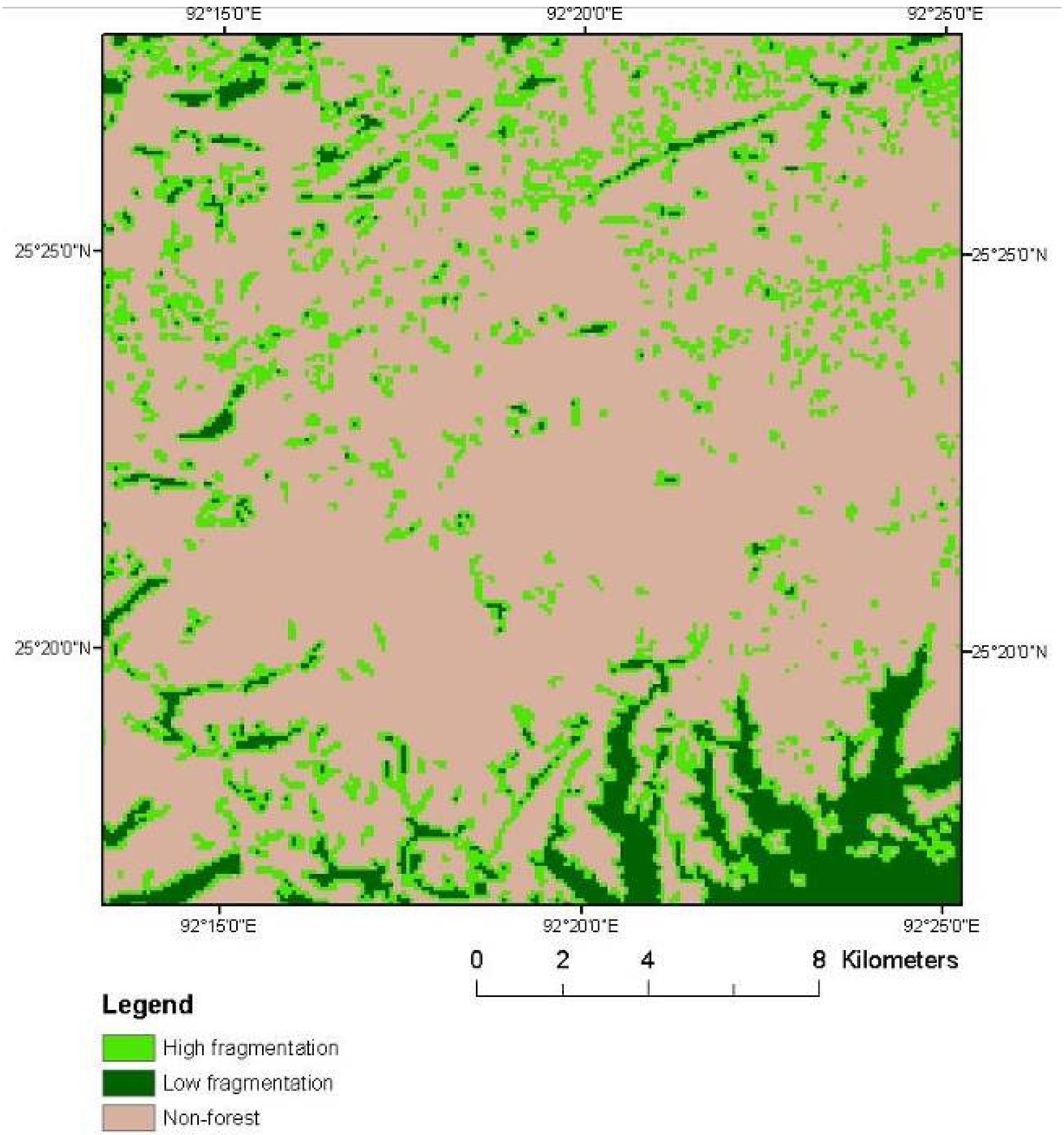

Figure 4.21: Forest fragmentation in 2001.

5. General Discussion and Conclusions

5.1. Discussion and Conclusions

Jaintia Hills district of Meghalaya has a total coal deposit of about 40 million tonnes. The district has been most extensively exploited for coal. Although only 7 percent coal deposits are found in the district, it contributes more than 74 percent of the total coal production in Meghalaya. The coalfields of the Jaintia Hills district are small and highly dispersed. Coal is mostly found in Bapung, Lakadong, Jarain-Shkentalang, Lumshnong, Malwar-Musiang-Lamare, Sutnga, Ioksi, Chyrmang and Mutang. The unscientific extraction of coal in unorganized sector is going on since long and the area affected by coal mining is increasing day by day.

Due to extensive coal mining, large areas of the district have been turned into degraded land, creating unfavourable habitat conditions for plants and animals. Mining of coal has caused massive damage to the landscape and biological communities. It was found that the number of tree and shrub species decreased due to mining. The unfavourable habitat conditions prevailing in the coal-mined areas have reduced the chances of regeneration of many a species, thereby reducing the number of species in the mined areas. Although the number of trees and shrubs have decreased, the number of herbaceous species colonizing the mined areas were found to be higher than in unmined areas. Similar observations were made by several workers in the coal mining areas in different parts of the world (Cornwell, 1971; Fyles *et al.,* 1985; Game *et al.,* 1982; Singh and Jha, 1987; Jha and Singh, 1990). The density of tree species decreased considerably in the mined areas. The density of the shrub species did not vary much. Lyngdoh (1995) and Das Gupta (1999) in Jaintia Hills, and Sarma (2002) in Garo Hills district of the state had similar observations. This could be due to the better ability of herbs to adapt to the disturbed sites. Some herbaceous species invaded the newly created habitats. *Nepenthes khasiana* was documented from the mined areas (Figure 5.1). Meghalaya is the only home for this endangered species. Due to indiscriminate mining throughout the district this rare species is highly threatened.

Figure 5.1: The *Nepenthes khasiana* (pitcher plant), an endangered species, threatened due to indiscriminate mining.

The Khasi pine, *Pinus kesiya* was the dominant tree species in the study area. The high importance value index of *Pinus kesiya* in mining areas suggests its ability to grow in the disturbed environments. The importance value index of *Schima wallichii* was next to *Pinus kesiya*, which indicates the degraded environment of the area. The dominant shrub species in the mined areas were *Eupatorium adenophorum, Melastoma nepalensis and Lantana camara.* The dominant herbaceous species in the mining area was *Paspalum orbiculare*, which suggests that it can multiply rapidly in the disturbed environments. The characteristics of this perennial grass by virtue of its stolon and rooting at each node can bind the soil particles, making the soil more stable. This grass plays an important role in soil stabilization. This is in agreement with the findings of Ries and Hofman (1983), who observed that perennial grasses were well-suited to grow on the mine spoils.

Dominance-diversity curves for the mined sites resembled with broken-stick series model. This could be attributed to the lesser number of species occurring in these stressed environments where conditions are not favourable for plant growth. Species diversity was low on these sites, but the species that grow here appear to have developed tolerance.

Shannon-Weaver index of diversity for tree species was much lower in the mined areas compre to control. This suggests dominance of one or two species in the mined area. The Shannon-Weaver diversity index for the shrub species was lower in the mined areas than the control. There were not many differences in the diversity of herbaceous vegetation in both the areas. The diversity index for herbaceous species increased with mining proximities suggesting that mining operation favoured colonization of certain species in the newly created habitats. Similar observation was made by Lyngdoh (1995), Das Gupta (1999) and Sarma (2002).

The trees of medium girth class (55-95cm) dominated the mined areas. Unmined area had more individuals of lower girth class (15-35cm) even though trees of all girth classes were present in the area. In unmined areas, it was found that density of smaller and middle sized trees was higher than the old trees. This indicates a stable tree population structure. Such population structure is represented by a normal case and suggests that the forest is growing and would continue to exist. However, in the mined areas, the tree density in all the girth classes was extremely low and did not follow any standard density diameter population curve. This has been due to rampant and random clearing of forest areas for mining purpose that has led to drastic change in tree population structure. Such a trend in population structure does not indicate the continued existence of the forest.

The basal area in the unmined areas was found lower than the mined area. This was due to the dominance of low girth class trees, which had regenerated in the unmined area. The higher basal area in the mined areas could be attributed to the existence of bigger trees. Bigger trees are normally spared during mining operations by the miners. This indicates the removal of younger trees during mining activities. Such a trend leads to the failure of the community to generate back. Paijman (1970) and Parthasarathi and Karthikeyan (1997) made similar observations in New Guinea and India, respectively.

In the unmined area both trees and shrubs showed contagious distribution pattern. All species in the mined areas showed contagious pattern of distribution. The contagious distribution pattern of species indicated the mosaiced structure of the forest stand. The contagious of the species suggests the increase in patchiness of the natural vegetation due to mining. This is in agreement with the findings of

Rao *et al.* (1990), who observed that due to disturbance contagiousness increased. Webb *et al.* (1967), Austin *et al.* (1972) and Ashton (1972) indicated that in the absence of major disturbances, soil and water conditions play significant roles in controlling such distribution pattern.

The mining of coal initiated in Jaintia Hills district of Meghalaya in the early 1970s. As the mining operation started, there was lots of demand of manpower to work in the coalfields. Development of the infrastructure started in this period. Dense forest areas were targeted to accommodate these facilities. During this period a considerable portion of the dense forest were converted into non-forest like, settlement, roads and grassland. Grasslands were outcome of the mining. When extraction and supply of coal was over the areas kept fallow. In course of time those areas were covered with grasses that could grow in the harsh edaphic conditions. No other plant species could grow in that area and it became completely abandoned. The local people also inclined towards the mining activities and most of the agricultural fields were converted into mining areas. The decrease in cropped area might also be due to the loss of nutrient in the soil as a result of the dumping of the waste materials in and around the mining. It was found that there was not much impact on the grassland and existing non-forest areas of the region since the mining was introduced. There was gradual decrease of forest both dense and open during the course of time. There was an increase in the open forest during 1975 and 1987. This was due to the conversion of the dense forest into the open forest. There were not much variation in dense forest during the year 1999 and 2001. But area under open forest had reduced during this period.

The study on the impact of coal mining on land use changes have been carried out world wide (Koster and Slob, 1994; Schejbal, 1995; Prakash and Gupta, 1998; Ghosh, 1998; Rathore and Wright, 1993). The change analysis of different components showed that there was decrease in the change of dense forest to open forest as time passed, also dense forest to mining. During the initial stage mining was carried out mostly in the dense forest areas of the state. These forest areas got fragmented and existed as the open forest. The conversion of the dense forest into non-forest also showed the decreasing trend. The reason may be the same. There was gradual increase in the change of open forest to mining and non-forest areas. This could be concluded that there was lots of impact on the open forest areas in recent years.

The area under low fragmentation decreased significantly as the time passed. The high fragmentation area, which were the areas at risk increased as the activity of coal mining had increased since its inception. More than 68 km^2 (16 percent) area were identified the areas at risk. The areas of non-forest also increased from the starting. There was loss of about 9 km^2 area of high fragmentation in three years period from 1999 to 2001 and was converted into non-forest area. Goretti (1998), Koster and Slob (1994) and Schejbal (1995) concluded that the vegetation got lost due to the spread out of waste materials haphazardly in the areas of coal mining, which were very unhealthy for its growth.

5.2. Review of Results and Discussion

In executing this study, the different vegetation community characteristics, tree population structure, distribution pattern, land use/ land cover distribution and changes, change analysis of different land uses related to forest and mining and forest fragmentation were analysed to achieve the objectives of the study. The result of the study shows that:

- There were more or less same impact on the community characteristics of vegetation due to coal mining in the first three impact zones. The impact was less in the fourth zone.

- Number of tree and shrub species got reduced and herbaceous species increased in number in the mined areas as compared to the unmined area.
- *Pinus kesiya* was dominant tree species followed by the *Schima wallichii, Eupatorium adenophorum, Melastoma nepalensis and Lantana camara. Paspalum orbiculare* was the dominant herbaceous species in all the zones of the mined.
- Dominance-diversity curves showed the broken stick model in the mine areas.
- Shannon-Weaver index of diversity was low in all the zones of mining areas compared to unmind area in case of trees and shrubs. Herbaceous species had higher value in the mined areas.
- Dominance-diameter distribution curves showed that most of the trees in the mined areas were of medium girth classes. Unmined area had more individuals of lower girth class even though trees of all girth classes were present in the area.
- Basal area found lesser in the unmined area as compared to the mined areas.
- Distribution pattern of the vegetation found was contagious in the mined area. In the unmined area also most of the species showed contagious pattern of distribution.
- There was loss of 40.5 km^2 (40 percent) of forest area in 26 years.
- Dense forest lost about 48 percent.
- Increase in the open forest areas.
- Increase in mining area from 13.76 km^2 to 45.24 km^2. The rate of increase was 1.2 km^2 per year.
- Settlement area increased from 17.63 km^2 to 29.20 km^2.
- Cropped area reduced about 5 km^2 during the period 1975 to 1987.
- There were not much temporal changes in the grassland and non-forest areas.
- The trend of change from dense forest to open forest decreased.
- Decrease in dense forest to mining and non-forest areas.
- Increasing trend of open forest to non-forest, i.e., from 6.5 km^2 during 1975 to 1987 to 5.5 km^2 in three years during 1999 to 2001.
- Area under low fragmentation decreased with time.
- Area under non-forest increased with time.
- More than 68 km^2 i.e., more than 16 percent of the total study area were under high fragmentation and identified the areas as risk.
- There was loss of about 9 km^2 high fragmentation area in three year period from 1999 to 2001 and was converted into non-forest area.

5.3. Summary and Recommendations

Extensive coal mining has led to shrinking of land base and creation of a landscape dotted with mine spoils. The pitfalls of such activities are felt in the impairment of vegetation in these ecosystems. The present study analyses the plant community characteristics in the mine affected areas and impact of coal mining on vegetation during different periods of time.

It was found that there were more or less same impact in the inner zones of the mining impact areas delineated for the present study. The impact was less in the outer most zone. Mining of coal has caused damage to the landscape and the biological communities in enormous ways. The number of tree and shrub species drastically decreased in their number due to mining. The unfavourable habitat conditions prevailing in the coal-mined areas has reduced the chances of regeneration of species, thereby, reducing the number of species in the mined areas. The number of herbaceous species colonizing in the mined areas were found to be higher than in the unmined areas. Species like *Pinus kesiya, Schima wallichii, Persea odoratissima, Eupatorium adenophorum, Lantana camara, Melastoma nepalensis, Rubus ellipticus, Rubus khasiana, Paspalum orbiculare, Plantago erosa, Gnaphalium pensylvanium, Isachne himalaica, Ageratum conyzoides, Borreria articularis* dominate in mined areas and these species can grow in the degraded environment. The Shannon-Weaver index of diversity for trees and shrubs was lower in the mined areas. On the other hand, the diversity index for herbaceous species increased with mining proximities suggesting that mining operation favoured colonizing of certain species in newly created habitats.

The mining of coal initiated in Jaintia Hills district of Meghalaya in early 1970s. Since then the mining has been increasing and the area affected by coal mining is increasing day by day. A considerable portion of the forest area was converted into non-forest. The dense forest areas converted into the open forests and there was gradual decrease of these two forest types during the course of time. The area under low risk i.e., low fragmentation area, decreased significantly with time. The area under non-forest increased with time. About 68 km^2 of the study area (16 percent) were identified as the areas at risk. These high fragmentation areas are located in the proximity to mining.

The present study revealed that coal mining has adversely affected the vegetation in the coal mining areas of Jaintia Hills district. Such habitats do not permit proper plant growth and development.

The present study led to the conclusions that phytosociological analysis can be used as important tools for predicting the suitability of mine spoil habitats for the plant growth. The information gathered on various aspects of vegetation and colonization of plants in mined areas would be helpful in revegetating the mined areas. The change analysis can be useful in finding out the change of trend of different land use/ land covers. To understand the land use dynamics related to vegetation and mining this method can be applied. It helps to delineate the vegetation areas under risk due to mining activities.

It is evident from the above discussion that the mining activities in Jaintia Hills district is detrimental to the vegetation and general environment of the district. It is advisable that such activities have to be strictly regulated to avoid further damage and scientific mining has to be taken up in a proper manner to minimize the damage to the vegetation as well as the environment. Appropriate rehabilitation measures using the plants that grow in the mine areas need to be taken up in the mine-affected areas. The findings of the study could be quite useful while formulating the Management Plan for the district.

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