COAL MINING AND ITS IMPACT ON ENVIRONMENT OF NOKREK BIOSPHERE RESERVE, MEGHALAYA

ABSTRACT

By

KIRANMAY SARMA

DEPARTMENT OF GEOGRAPHY

SUBMITTED

IN PARTIAL FULFILMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN GEOGRAPHY OF NORTH-EASTERN HILL UNIVERSITY, SHILLONG

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ABSTRACT

Meghalaya 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 and sillimanite causing large scale destructions and deterioration of the environment of the state. The coal mining brings about significant physical, chemical and biological changes in the environment. These include, serious water pollution and damage to aquatic plants and fishes, air pollution, reduction in vegetal cover and biodiversity, reduction in discharge of streams, alteration in landscape structure due to land disturbance, alteration of soil physico-chemical properties, accelerated soil erosion, particularly loss of nutrient-rich top soil and production of silt and habitat fragmentation. The Nokrek Biosphere Reserve is a unique area with a number of rare and endangered species of plants and animals. The whole buffer area of the Biosphere Reserve is degraded and disturbed due to large-scale coal mining, shifting cultivation and other human activities. Uncontrolled and unscientific mining operation within the Biosphere Reserve has been detrimental to the fragile ecosystem. This has resulted in large scale degradation of the landscape, soil, water and forest causing serious threat to the existence of the ecosystem.

STATEMENT OF THE PROBLEM

The Nokrek Biosphere Reserve (NBR) has many distinct and unique bio-physical features that need to be conserved. The whole buffer area of the Biosphere Reserve is degraded and disturbed due to large-scale coal mining, shifting cultivation and other human activities. Mining operation has been carried out indiscriminately within the Biosphere Reserve even on steep and fragile slopes without any concern for ecological and environmental consequences. Uncontrolled and unscientific mining operation within the Biosphere Reserve has been detrimental to the fragile ecosystem. This has resulted in large-scale degradation of the landscape, soil, water and forest causing serious threat to the existence of the ecosystem. An understanding of the impact of coal mining on the landscape, vegetation, soil and water quality of the Biosphere Reserve is a pre-requisite for the effective management of NBR and preparing a viable management plan of the Biosphere Reserve.

STUDY AREA

In the western part of Meghalaya, an area of 820 sq. km covering all the three districts of Garo Hills viz., East Garo Hills, West Garo Hills and South Garo Hills has been designated as Nokrek Biosphere Reserve. The Biosphere Reserve is lying between 25°18'39" N and 25°36'7" N latitudes and 90°13'30" E and

91°37'17" E longitudes. The Biosphere Reserve is located in the Tura Range, which is a part of Meghalaya Plateau, having an average altitude of 600 m. The highest point in this region is the Nokrek Peak (1412m) lying within the Biosphere Reserve. The core area of the Biosphere Reserve is Nokrek National Park, which is spread over an area of 47.48 sq. km.

OBJECTIVE OF THE STUDY

The objectives of the study are as follows:

I. To identify, map and determine the extent of the coal mining area in the Nokrek Biosphere Reserve.

II. To characterize land degradation and landforms due to coal mining.

III. To assess the impact of coal mining on: (i) vegetation, (ii) soil characteristics and (iii) water quality.

METHODOLOGY

Pre-field phase

- Selection of the problem and consultation of literature.
- Identification, mapping and determination of area under coal mining in the NBR by using topographical sheets and satellite imageries, following manual interpretation method.
- Collection of general information on climate, soil, vegetation, geology etc.

Field-work phase

- Selection of three coal mining areas from the NBR- Budugiri, Budu Wathegiri and Faramgiri.

- Vegetation and soil studies were done in two stands of unmined and mined while water samples were collected from three stands i.e., upstream, down stream and mining stands. Composite soil samples were collected in three depths, i.e., 0-10 cm, 10-20 cm and 20-30 cm while for vegetation study tree, shrub and ground vegetation (herb) were considered. Study was carried out for two years considering three seasons viz., pre-monsoon, monsoon and post-monsoon.

- The method applied for vegetation study in the field carried out following the methods described in Mishra (1968) and Martin (1995).

- Field photographs have been taken.

Post-field work phase

- Geomorphology:
  -For different geomorphic analysis toposheet no. 78 K/2, 78 K/3, 78 K/6, 78 K/7, 78 K/10 and 78 K/11 have been used.

- Water:
  -pH, Conductivity, Sodium, Potassium, Nitrate, Sulphate, Phosphate, Hardness, Dissolved Organic Matter, Dissolved Oxygen

- Soil:
  -pH, Moisture, Texture, Nitrogen, Phosphorous, Soil Organic Matter, Soil Organic Carbon, C/N

- Vegetation:
  -Floristic composition,
  -Density,
  -Population Structure: Density Distribution Diametre, Basal Cover Distribution Pattern, Dominance, Species Diversity, Distribution Pattern (Regular, Random and Contagious), Impact on Regeneration

PLAN OF WORK

The present thesis on "Coal mining and its impact on environment of Nokrek Biosphere Reserve, Meghalaya" has been divided into following five chapters.

CHAPTER-I: INTRODUCTION

i. General Introduction
ii. Objectives
iii. Review of Literature
iv. Study Area

CHAPTE-II: GEOLOGY AND LOCATION OF COAL MINING SITES

i. Geological setting of the area
ii. Location of coal mines

CHAPTER-III: GEOMORPHOLOGY OF NOKREK BIOSPHERE RESERVE

i. Analysis of various geomorphic attributes viz., relief, slope and drainage analysis for the entire Biosphere Reserve

ii. Detailed drainage basin study for seven selected drainage basin

CHAPTER-IV: IMPACT OF COAL MINING ON VEGETATION, SOIL AND WATER QUALITY

i. Impact of coal mining on vegetation
ii. Impact of coal mining on soil
iii. Impact of coal mining on water quality

CHAPTER-V: GENERAL DISCUSSION

FINDINGS

In the entire Garo Hills, the total reserve of coal has been estimated to be 359 million tonnes and a considerable portion of it is found in the southern part of Nokrek Biosphere Reserve. The unscientific extraction of coal in unorganized sector within the Biosphere Reserve is going on and the area of coal mining in this region is increasing day by day since the beginning of mining in 1985. The annual extraction of coal from the Biosphere Reserve has been estimated to be in the tune of 4,32,000 tonnes. Coal mining activity started within the Nokrek Biosphere Reserve from the Darrangiri area. At present, coal is being extracted from 18 mining sites. These are: Darenggiri, Jatragiri, Rongragiri, Khamalgiri, Rongmagiri, Budu Wathegiri, Budugiri, Gopgiri, Khibalamagiri, Khakijagiri, Faramgiri, Anchenggiri, Rongphakgiri, Rongmigiri, Rongrugiri, Ruabangagiri, Bandarigiri and Rongdianchengiri. The thickness of the seam of coal ranges from 0.45 m to 2.00 m. The Nokrek Biosphere Reserve is formed over the gneissic rock with old inlier, Sela group and Jaintia and Simsang Series with ultra-basic in deep shades rocks. Coal beds are of Lower Eocene geological horizon, which are mostly found along with Jaintia and Simsang series.

The geomorphological analysis of Nokrek Biosphere Reserve revealed that if coal mining is extended further inside the Biosphere Reserve the land degradation could reach to an alarming stage. As evident from the results of slope, relief and drainage density analysis substantial areas of the Biosphere Reserve falls under 9° to 22°, <100m to 200m and 5-9 km per sq. km categories respectively, which are highly vulnerable to erosion losses. Mining activities in such areas is bound to accelerate the above processes. The studies relating to drainage suggest that the coal mining activities at upper catchment would directly effect the streams and rivers in the higher order, which may be located far from the actual mining.

Extensive coal mining activities in the buffer zone of Nokrek Biosphere Reserve have led to the degradation of land and creation of landscape dotted with mine spoils. The impact of such activities on the vegetation, soil and water qualities of Nokrek Biosphere Reserve was significant.

The total number of species was much less in the mined areas than unmined areas. Trees and shrubs showed a drastic reduction in their species composition due to coal mining. The density of trees, shrubs and herbs in mined areas were significantly lower than the unmined areas at all the three sites. The basal area of trees follows the same trend as density. The dominance of plant species was shared by many species both at unmined and mined sites. Fifteen species among tree, 4 among shrubs and 28 among herb species only were found in mined sites, while 27 tree species, 4 shrub species and 16 herb species were found only in the unmined sites. Shannon's diversity index for tree species was low in the mined sites which indicates adverse impact of mining. The number of species regenerating (i.e., seedling and sapling) was more in the unmined sites than the mined sites. The seedling and sapling density were also quite high in the unmined areas. Many species which were found in the unmined areas and were native to the locality could not regenerate due to mining resulting into the local extinction. However, certain species colonized the areas following mining. The colonization of these secondary successional species is an agreement with the intermediate disturbance hypothesis that justifies the higher species diversity due to the disturbances of mild intensity.

All the soil physico-chemical characteristics were adversely affected due to mining. The soil became more acidic in the mined areas and the soil moisture regime of the soil got depleted. The nitrogen, phosphorus and soil organic matter were less in the mined areas than that of unmined areas. The C/N ratio was drastically reduced due to the mining. The deterioration in soil physico-chemical properties would have detrimental effect on the soil flora, fauna and micro-organisms. The impact of mining was felt even upto the depth of 30 cm suggesting that coal mining would adversely affect even the growth of higher plants.

The water quality was also affected due to mining. The water in mined areas was highly acidic and the conductivity increased due to mining. The hardness of the water, calcium and magnesium concentration increased in the mined areas. The concentration of chloride, phosphate, nitrate, sulphate, sodium and potassium increased due to mining. The D.O. content was very low in the water passing through the mined areas. The impact of pollutants from mining was more acute during post and pre monsoon seasons than the monsoon season. The above results indicate that the coal mining alters the water quality of the water bodies to the extent that could be detrimental to the survival of aquatic life in the stream and rivers, even further downstream.

The present study revealed that coal mining has adversely affected the vegetation, soil characteristics and water quality in the coal mined areas of Nokrek Biosphere Reserve. The information gathered on various aspects of vegetation and colonization of plants in mined areas would be helpful in revegetating the mined areas. The studies on the physico-chemical properties of soil and water is useful in the assessment of the status of ecosystem health of the Biosphere Reserve.

From the above discussion it is evident that the mining activities in the buffer zone of Nokrek Biosphere Reserve is detrimental to the flora, fauna and general environment of the Biosphere Reserve. Therefore, such activities within the Biosphere Reserve have to be strictly regulated to avoid further damage to the Biosphere Reserve. Scientific mining has to be taken up in a restricted manner so that with a minimum damage to the Biosphere Reserve. Appropriate rehabilitation measures using the plants that grow in the mined areas need to be taken up in the mined affected areas. The findings of the study could be quite useful while formulating the Biosphere Reserve Management Plan.

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Dedicated to my revered father
Shri Damudar Sarma
and my mother
Late Damayanti Devi

THE NORTH-EASTERN HILL UNIVERSITY
DECEMBER 2002

I Kiranmay Sarma, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the North-Eastern Hill University for the degree of Doctor of Philosophy in Geography.

Kiranmay Sarma 9/12/2002

(KIRANMAY SARMA)

9/12/02

(Prof. S. SINGH)
HEAD
Department of Geography
North-Eastern Hill University

R. K. Rai

~~(Prof. R.K. RAI)~~
SUPERVISOR
Department of Geography
North-Eastern Hill University
NEHU, SHILLONG-793 014

9/12/2002

(Dr. S.K. BARIK)
JOINT SUPERVISOR
Department of Botany
North-Eastern Hill University

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Kiranmay Sarma

(KIRANMAY SARMA)

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CHAPTER-I

INTRODUCTION

The term 'coal' is believed to have originated from the Sanskrit word 'kaal', meaning black. In ancient times, coal was known as burning rock and was believed to possess supernatural power (Sharan *et al.* 1994). It was known to the Chinese before Christian era and the Greeks knew about its use in the 4th century. It was used as a domestic fuel in England in the 9th century. The invention of the steam engine in England and the consequent industrial revolution in the 18th century gave a great impetus to coal mining. The demand for coal was further increased when coke made from bituminous coal began replacing charcoal in the iron ore melting 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).

Most coal seams originated from the accumulation and decay of terrestrial plants, abundantly present during the Carboniferous period. As decomposition took place, the vegetation lost the oxygen and hydrogen atoms from its rich carbohydrate food reserves, leaving deposits of high percentage of carbon. In this way pit bogs were formed. As time passed, layers of sand and mud transported by running water settled over some of the pit deposits. The pressure of these overlying layers, movement of earth's crust, and often volcanic heat compressed and hardened the deposits, thus producing coal. In order to produce 30 cm of coal, in an average 4.5-6 m of plant residues are required. Coal is an organic compound rich in carbon. It is called mineral fuel to distinguish it from such other fuels as woods, charcoal, or dung. In a strict sense, coal is not a mineral, because of its organic origin. However, they are classed as minerals because they have been produced by geological processes over a long period of time (Brown *et al.* 1975).

Today coal faces strong competition from alternative fuels and its use as fuel is fast diminishing. But it has remained a vital energy source in the world for over two centuries. During 1060 to 1860 A.D., it was estimated that cumulative production of coal amounted to 7×10^9 metric tonnes on a world's scale. The world wide production of coal in 1977 was 3.7×10^9 billion metric tonnes. Thus, the coal mined during the 110 years period from 1860 to 1970 was approximately 19 times that of the preceding eight centuries (Hubbert 1973).

India is the fifth largest coal producing country in the world. The coal production in India was about 154.30 million tonnes in 1985-86 and it was expected that the production level would reach 417 million tonnes by 2000 A.D. (Coal India 1986).

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 prehistoric days man has been interested about the 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 records of mining activities of man.

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). Mining activities at Raniganj in West Bengal, Jharia in Bihar and Singrauli in Madhya Pradesh for coal, Bichhri, Khetri and Zawar in Rajasthan, Malanjkhand in Madhya Pradesh and Agnigundala in Andhra Pradesh for lead, zinc, copper and cadmium, and Neyveli in Tamil Nadu for lignite are the examples of large scale mining operations in India. Though mining and use of minerals in India date back to the Indus Valley Civilization, coal mining was first taken up in India in 1774 by Sumner and Heatly in Raniganj coal field (Tandon 1990).

Natural resources have been over-exploited for almost two centuries, without any concern for the environment. This has resulted in the reduction of forest areas, greater soil erosion, air, water and land pollution, and damage to various species (UNESCO 1985). The unscientific mining of minerals poses a serious threat to the environment (Dadhwal 1999). Environmental pollution caused due to mining plays an important role on the productivity of the mine itself. Besides, mining operations seriously affect the environmental health by way of altering the bio-geochemical cycles and polluting the water resources, air and soil.

Coal contains a significant amount of irondisulphides ($FeSO_4$) 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 ferric sulphate (Fe_3SO_4) and sulphuric acid (H_2SO_4) in the presence of bacteria. The H_2SO_4 thus formed, lowers the pH of the soil and water in the terrestrial and aquatic environment, respectively, which affects the population and activity of organisms inhabiting those environments. Chemicals released from the coal mines, mine overburden and tailings also contain high concentrations of metals such as Cu, Cd, Fe, Hg and Zn which also affect the organisms adversely.

The contaminated water and wastes that are discharged from the mines retard various microbe mediated processes in the contaminated ecosystems. The release of metals into such systems also affects microbial population and their overall activity. The accumulation of these toxic wastes in water bodies and soils pose a threat to the aquatic and soil microflora and microfauna, which in turn, results into a reduced population of these organisms and a decline in biological activity. The microorganisms are responsible for the breakdown of organic matter and release of nutrients. They are regarded as the principal agents of mineral cycling in soil and water bodies because of their roles in transformation of elements like carbon, nitrogen, phosphorus and potassium. Thus, the microflora and microfauna influence the availability of nutrients in the systems, which consequently regulate the structure and function of the ecosystems.

While digging pits and tunnels during the mining operation, the pieces of soil rocks above the coal seams are thrown haphazardly outside the pit creating coal mine spoils that cause large-scale destruction to the surrounding land and vegetation often beyond replenishment. 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). Coal mine spoils represent extremely rigid substrata for plant growth and development. Among the factors which hinder the growth of plant species on these spoils, acidity merits special attentions. Extreme acidity is caused due to the oxidation of iron pyrites (FeS_2) (Chadwick 1973, Caruccio 1975). Continued acidification for many years may lead to die back of well established vegetation (Costigan *et al.* 1980). The physical factors which limit plant establishment and survival include high temperature, moisture stress (Richardson 1975), soil particle size (Down 1974), surface instability leading to erosion (Brierley 1956, Down 1975) and compaction (Hall 1957, Richardson 1975).

Soil fertility is also a major factor regulating plant growth. The two limiting nutrients on coal mine spoils are nitrogen and phosphorus (Willium 1975, Wittwer *et al.* 1981). The shortage of organic matter is attributed to the absence of litter. Organic matter is often found in the upper few centimeters of mine spoils (Schafer *et al.* 1979).

In the north-east India, coal mining was initiated by Medlicott (1869, 1874) followed by La Touch (1882, 1883, 1884, 1889,1890). This was followed by preliminary excavations by Fox (1935-38) in Garo Hills and some mining works were undertaken by Arogyaswami and Desikachari (1949-50) in southern Khasi Hills. Coal fields of

Garo Hills were reexamined by Arogyaswami, Sen, Rao and Puri in 1949-50. 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 last century. Since most of the coal deposits are small and isolated and it was not amenable for scientific mining to be conducted in the organized sector, coal mining operations were left to the Khasi 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 1970 (Directorate of Mineral Resource 1992).

The state of Meghalaya is rich in mineral resources. Besides coal, other mineral resources that occur in large quantities include limestone, sillimanite and clay. 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 the 6th Schedule of Indian constitution, very little governmental control can be exercised on the lands in Meghalaya. The coal mines belong to the land owners who do the mining operations according to their convenience. 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 systems like land, water, air and vegetation (Tiwari 1996).

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 (Guha Roy 1991). The coal deposits are found along the southern fringe of the Shillong plateau extending over a length of 400 km. The deposits of coal in the Garo Hills Districts are Cretaceous origin. In the hills of Meghalaya, the coal bearing sedimentary formations are sub-horizontal to gentle deep 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 in Meghalaya are: Laitryngew, Cherrapunjee, Laitduh, Mawbehlarkar, Mawsynram, Lumdidon, Langrin, Pynursla, Lyngkyrdem, Mawlong-Shella-Ishamati in Khasi Hills, Bapung, Lakadong, Sutnga, Jarain, Musiang-Lamare and Ioski in Jaintia Hills and West Darrangiri, Siju, Pyndengru-Balphakram, Selsela Block in Garo Hills.

The major deposits of coal occurrence in the state are West Darrangiri (127 million tonnes), Siju (125 million tonnes), Pyndengru-Balphakram (107 million tonnes) of Garo Hills, Langrin (97.61 million tonnes) of Khasi Hills and Bapung (33.66 million tonnes) of Jaintia Hills. The West Darrangiri coal deposit of which a considerable portion is located within the Nokrek Biosphere Reserve of Garo Hills has the highest reserve of coal in the state (22.56%) and the Bapung coal deposit of Jaintia Hills

District is the most extensively exploited coal deposit. Out of the total production of 34,60,000 tonnes of coal in Meghalaya, the largest contribution comes from Jaintia Hills having 27,86,000 tonnes in 1991 (Meghalaya Statistics 1996).

In Garo Hills the total reserve of coal has been estimated to be 359 million tonnes, which is more than 60 percent of the total coal deposits of the state. Out of this West Darrangiri area alone comprises about 35 percent of the total coal deposits in the Garo Hills districts of which a considerable portion is spread to the southern part of the Nokrek Biosphere Reserve. In this part of the Biosphere Reserve, which falls within the buffer zone, unsystematic exploitation of coal in unorganized sector is going on. At present coal is being exploited by landholders operating as small-scale ventures with primitive skills and techniques. In the area the coal seams being comparatively thin, ranging from 0.45 m to 2.00 m, the mining is done manually by a method known as "rat-hole mining". The 'rat-hole' method of coal mining employed by the private operators involves manual excavation, which is crude, uneconomical and unscientific. In this method, small tunnels are dug into the seam sideways and coal is brought out by wheel-barrows. The coal is either dumped near the mine head or by the road side for transportation by trucks. While digging, some strict rules are followed by the miners which are imposed by the village heads to safe guard the environment. To check the area from subsidence there must be at least 9 m distance from one bifurcation to another from the main tunnel. This serves as the pillars to support the soils above. Violation of rules results in punishment by the village heads. Sometimes,

Plate 1 Coal mines in Nokrek Biosphere Reserve: The photographs showing the entry/exit path of the mines. Rat-hole mining method–a crude mining technique is the sole method of coal extraction in the Biosphere Reserve.

Plate 2 Sites showing the piling of extracted coal inside the Nokrek Biosphere Reserve.

these pillars are also cut down, as a result of which, the soil covering the coal seams sinks down forming subsidence. This type of underground mining can also have an adverse impact on the surrounding water bodies causing acid drainage (Buonicore *et al.* 1980).

STATEMENT OF THE PROBLEM

The Nokrek Biosphere Reserve (NBR) has many distinct and unique bio-physical features that need to be conserved. It is a unique area with a number of rare and endangered species of plants and animals. The NBR is one of the richest sites for citrus genetic diversity. The vegetation of the Biosphere Reserve comprises tropical to subtropical evergreen forest, semi evergreen forest, tropical moist deciduous forest, bamboo brakes, grasslands and riverine forest. All these forests are rich in bamboo, grass, medicinal plant, climber and orchid diversity. The whole buffer area of the Biosphere Reserve is degraded and disturbed due to large-scale coal mining, shifting cultivation and other human activities. Mining operation has been carried out indiscriminately within the Biosphere Reserve even on steep and fragile slopes without any concern for ecological and environmental consequences. Uncontrolled and unscientific mining operation within the Biosphere Reserve has been detrimental to the fragile ecosystem. This has resulted in large-scale degradation of the landscape, soil, water and forest causing serious threat to the existence of the ecosystem. An understanding of the impact of coal mining on the landscape, vegetation, soil and water quality of the Biosphere Reserve is a pre-requisite for the effective management of NBR and preparing a viable management plan of the Biosphere Reserve. Keeping this objective in view the present study was undertaken during 2000-2002 to assess the impact of coal mining in the geomorphology, vegetation, soil and water quality of the NBR.

REVIEW OF LITERATURE

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 Garo Hills Districts are Cretaceous origin (Guha Roy 1991). Many studies have been done on the geology of Meghalaya. Geological work was initiated by Oldham (1858) after the inception of Geological Survey of India (G.S.I.) in 1851. Medlicot (1869) also did substantial work on Meghalaya geology. In the post independence period large areas of Meghalaya have been mapped by G.S.I. The compiled geological framework of Meghalaya is given by Anon (1974), Murthy *et al.* (1976a, 1976b) and Mazumder (1986).

The Meghalaya plateau, is a '3rd order' modulation of earth's surface (Fairbrige 1968). Land degradation appraisal studies involve geomorphic characterization of the terrain for which different geomorphic attributes have been studied. Many works have been done in the field of geomorphology in the course of times. The works of Horton (1932, 1945), Schumm (1956), Choreley (1966), Gregory (1977), Knington (1984), Petts & Foster (1985), Schumm *et al.* (1987) are worth mentioning in this regard. In India, the works of Rai (1980), Mukhopadhyay (1980, 1982), Sharma (1980), Goswami (1982), Basu (1979), Barman (1986), Bora (1990) have been outstanding.

Natural resources have been over-exploited without any concern for the environment. As a result of which reduction of forest areas, greater soil erosion, air and water pollutions and damage to various species has occurred (UNESCO 1985). The unscientific mining of coal poses a serious threat to the environment (Dadhwal 1999). The coal mining activities have brought in the desired effect of economic growth but on the other hand, affected the environment in a variety of ways, which contributed to its degradation. Mining of coal causes massive damage to landscape and biological communities (Down and stock 1977). 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 plant growth.

Ecology of mined lands has been the subject of extensive study the world over (Bradshaw *et al.* 1986, Brenner *et al.* 1994). In India Banerjee (1981), Singh & Jha (1987), Valdiya (1988), Saxena (1979), Mann & Chatterjee (1979), Prasad (1989), Jha (1989, 1990, 1992), Jha & Singh (1990, 1991), 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 (1997) and Das Gupta (1999).

Mining of minerals causes considerable damage to the ecosystem because of the excavations and dumping of mine waste on the adjacent site, which form the 'spoil'. These spoils present a special habitat where conditions are extremely unfavourable for plant growth and establishment. Intensive studies on mine spoil ecology have been undertaken in different parts of the globe. The development of ecosystem on china-clay wastes was studied by Dancer *et al.* (1977), Marrs & Bradshaw (1980) and Marrs *et al.* (1980, 1981). Studies on reclamation of china-clay wastes were carried out by Marrs and Bradshaw (1982). Establishment of vegetation on asbestos wastes was studied by Moore and Zimmermann (1977). Iron mine tailings were studied by Leisman (1957), Shetron and Duffek (1970) and Martinik (1977). Floristic diversity of lead mining wastes was studied by Clark & Clark (1981), lead and zinc by Kimmerer (1984) and copper mining wastes by Goodman & Gemmell (1978) and Veeranjaneyulu & Dhanaraju (1990).

Several studies related to the floristic composition as well as the physical and chemical properties of colliery spoils in different parts of the world have been done by a number of workers, viz., Brierley (1956), Barnhisel & Massey (1969), Doubleday (1971), Down (1973, 1974, 1975a, 1975b), Williams (1975), Williams & Chadwick (1977), Dennington & Chadwick (1978), Game *et al.* (1982), Fyles *et al.* (1985), Singh & Jha (1987), Jha & Singh (1990a, 1990b, 1992) and others.

Certain soil physico-chemical characteristics such as, texture, water holding capacity, pH, electrical conductivity, soluble Ca, Mg and Na content, cation exchange capacity, exchangeable cations, gypsum, and calcium carbonate equivalents are crucial for predicting the plant growth potential on mine overburdens (Power 1978). Richardson (1958), Bradshaw *et al.* (1975) and Bell & Ungar (1981) found high temperature and low moisture of surface coal mine spoils to be important factors limiting plant growth.

Byrnes & Miller (1973), Down (1974) and Richardson *et al.* (1971) reported that in mined areas, the soil becomes water-logged due to high clay content. The soils become compact forming crusts which often restrict seedling growth and entry of water and air into the soil system. Power *et al.* (1978) found that the soil bulk density in the mined areas of the Northern Great Plain of USA was 10-30% lower than the soil found in unmined areas. Pederson *et al.* (1980) reported that soils with high bulk density and low porosity had low infiltration rates. Lyngdoh (1995) reported lower bulk density in mine spoils in comparison to the unmined control site. Uma Shankar *et al.* (1993) reported higher proportion of sand in the affected mine sites in relation to the unaffected control site. The sloppy topography of the coal mine spoils makes the dumps vulnerable to erosion (Johnson & Bradshaw 1977). Curtis (1973) demonstrated that the severe erosion from the mine spoils increases silting and acidity of the streams flowing nearby.

Ludeke (1973) found that light loam soil holds more available water than heavy clay soil. Similarly uniform fine sand mine tailings have more water holding capacity than the silty-clay overburden. Generally, the water holding capacity of the soils in mined areas gets reduced and creates severe water problem. Though the availability of water is serious problem at the soil surface, its effect on plants depends upon their tolerance to moisture stress (Bell & Ungar 1981).

Substantial amount of water is required for mining purposes. Water has an important role in controlling dust pollution, arising out of mining. Water is also an important need of a washery unit. Water is lost in the disposal of sludges originating from ash residues of liquification plants and scrubber equipment of pollution control devices. Significant amount of water is lost through evaporation during fugitive dust control of roads at mining sites. In underground mining Probstein & Gold (1978) estimated the quantity of water used in Appalachian underground mines. In Meghalaya no such pumping facility is available to pump out the mine water (Rai 1997).

Soil pH is a major determinant in controlling plant growth, particularly on improvised lands such as mine spoils. Acute acidity acts as a severe constraint for root and shoot development (Johnson & Bradshaw 1977). The pH of coal mine spoils ranges from 1.5 to 8.0. Most workers have reported it to be in the range of 3.5. Exposure, abundance and neutralizing properties of certain minerals along with their combustion bring about such a variation in pH (Gemmel 1977). Bradshaw & Chadwick (1980) obtained high pH value in freshly formed coal mine spoils.

Soil temperature plays an important role in the establishment of plants. Black (1968) reported high soil water evaporation rate and poor availability due to altered temperature conditions in coal mine spoils. Barren spoils especially the dark shales, common on mine sites lose heat through convection and evaporation with a consequential rise in soil temperature. As the barren soil dries, evaporation decreases and surface temperature continues to rise. Temperature as high as 67°C have been recorded in dark mine waste (Deely & Borden 1973). High temperature and low moisture of surface mine spoils limit plant growth (Richardson 1958, Bradshaw *et al.* 1975 and Bell & Ungar 1981) and reduce the activities of the decomposers (Wieder *et al.* 1983).

During mining of coal from the earth, many metals are seen to gain access to both terrestrial and aquatic ecosystems. Water soluble B, Cu, Fe, Ni, Sr and Zn contents were found to be greater in mine spoils compared to unmined spoils in Northern Dakota (Wali & Freeman 1973). Kimber *et al.* (1978) found Fe, Al, Cu, Mn, Ni, Zn and Pb in high concentration in coal waste tip. The toxic levels of Fe, Al, and Mn (Berg & Vogel 1973) and Cu, Ni and Zn (Massey & Barnhisel 1972) can be found on different coal mine spoils.

Johnson & Bradshaw (1979) reported that nitrogen and phosphorus are the two principal limiting nutrients for plant growth in lands affected by mining. Potassium, calcium and magnesium have also been reported to be critical for growth of plants in such lands.

Coal mining causes massive damage to landscape and biological communities (Down 1979). In coal mined areas, the nutrient cycles are incomplete and mostly open due to the disruption of the ecosystems (Likens *et al.* 1970, Stark 1977, O' Niell *et al.* 1977). This leads to nutrient deficiency for plant growth in the mined areas. Litter layer which is an exchange site for nutrients is also lost from the system during soil and wind erosion. Thus nutrient holding capacity of coal mine spoils is drastically reduced. Therefore, a major disadvantage of the surface mined land sites is the low fertility of the spoil materials (Jha & Singh 1990a, 1992).

Nitrogen deficiency is a major factor limiting the growth of plants on spoils (Davidson & Jeffries 1966), Fitter & Bradshaw 1974, Handley *et al.* 1978, Bradshaw & Chadwick 1980). Although the establishment of a stable, self sustaining ecosystem depends on the effective cycling of several major elements, the accumulation of nitrogen and the formation of effective cycling is particularly important. Nitrogen deficiency in coal mine spoils could be due to its great susceptibility to leaching losses (Richardson & Dicker 1972, Gemmel 1973) and it could also be due to its non-availability even though there are considerable amounts of nitrogen available to plants in the coal and carbonaceous shales of coal mine spoils (Cornwell & Stone 1968, Palmer *et al.* 1985). Wittwer *et al.* (1981) found nitrogen and phosphorus as limiting growth factors in south eastern Kentucky mine spoils. The acidity and pyretic content of coal mine spoils influence their availability to plants (Gemmel 1977). Iverson & Wali (1982) observed phosphorus as a major limiting nutrient during the colonization, an early succession process of surface mined land in North Dakota. Phosphorus deficiency leads to stunted plant growth (Safaya & Wali 1979). Phosphorus is universally deficient in U.S. mine spoils (Bauer *et al.* 1977, Power *et al.* 1978a). Potassium content in mine spoils is normally high. This could be due to low leaching losses of potassium. However, when structural deterioration and breaking down of clay mineral takes place, due to regeneration of acidity and other factors, rapid release of potassium may result (Gemmel 1977). However, Schafer & Nielsen (1979) working on mine spoils at Colstrip, Montana reported that potassium, calcium and magnesium are concentrated in the upper soil layer while sodium is found below these three nutrients. In a study at Oklahoma, Johnson *et al.* (1982) reported that most mine spoils had adequate levels of nutrients for good plant growth after 10-70 years of disturbance. The concentrations of nitrogen, phosphorus, potassium and calcium were twice as high as that of forest soils.

Floristic composition is considered to be one of the major distinguishing characters of any community and its knowledge is important in understanding the ecosystem functions. Similarly, in drastically disturbed ecosystems, for example, the coal mined affected areas, this knowledge helps in understanding natural succession in these areas. Natural succession on coal mine spoils is a subject of both practical and ecological interest. Wali & Freeman (1973) and Imes & Wali (1977, 1978) pointed out that an adequate understanding of natural succession processes should be included in the efforts to reclaim degraded lands. They opined that without this knowledge no desired plant cover could be possible.

Various studies have been conducted to analyse the vegetation which occurs naturally on coal mine spoils (Brierley 1956, Hall 1957, Cornwell 1971, Bell & Ungar 1981, Brenner 1984). Russel & La Roi (1986) found low vegetation cover (i.e., less than 10%) and very low species richness in rocky mine spoils. The species richness increased substantially in finer textured spoils, with higher water and nutrient holding capacities.

Gibson *et al.* (1985) studied species composition of 49 reclaimed coal strip mines ranging in age from 10 to 70 years and reported that structural characteristics of the vegetation were similar to mature upland forests on the older and favourable sites. Johnson *et al.* (1982) found that the average mine spoils had 80% and 55% trees as compared to upland and flood plain forests respectively. In some cases stagnation of succession may take place as reported by Schafer & Nielsen (1979) for a 50 year old spoil. Stagnated herb/shrub/annual grass seral stage occurred due to sandy texture.

In some mining sites even after several years of abandonment, species diversity, abundance and density were very low. Vegetation was sparse and scattered, and in some cases, vegetation development did not occur all together (Glenn-Levin 1979, Wali & Freeman 1973). Species diversity in abandoned mined areas in Western Dakota showed that even after 50 years of abandonment, the species diversity in numerical prevalence was only half that of neighbouring unmined sites (Wali & Freeman 1973). However, Wali & Pemble (1982) found that relatively rapid changes in the habitats occurred in the first 17 years after mining.

Johnson *et al.* (1982) found higher calcium and nitrogen contents in the biomass in the undisturbed sites than the disturbed areas. Naylor (1974), Singh & Yadava (1974), Deshmukh (1986) and Messier *et al.* (1991) carried out studies on biomass and productivity of the coal mine affected areas. Lyngdoh (1995) and Das Gupta (1999) studied the biomass and productivity in coal mine spoils of Meghalaya.

STUDY AREA

In the western part of Meghalaya, an area of 820 sq. km covering all the three districts of Garo Hills viz., East Garo Hills, West Garo Hills and South Garo Hills has been designated as Nokrek Biosphere Reserve. The Biosphere Reserve is lying between 25°18'39" N and 25°36'7" N latitudes and 90°13'30" E and 91°37'17" E longitudes (Fig. 1.1).

The Nokrek Biosphere Reserve is one of the 13 Biosphere Reserves notified in India and amith 4 Biosphere Reserves from North-East India. The Nokrek Biosphere Reserve was notified on 1st September 1988 which is the third Biosphere Reserve in India after Nilgiri Biosphere Reserve (notified on 1.01.1986) and Nanda Devi

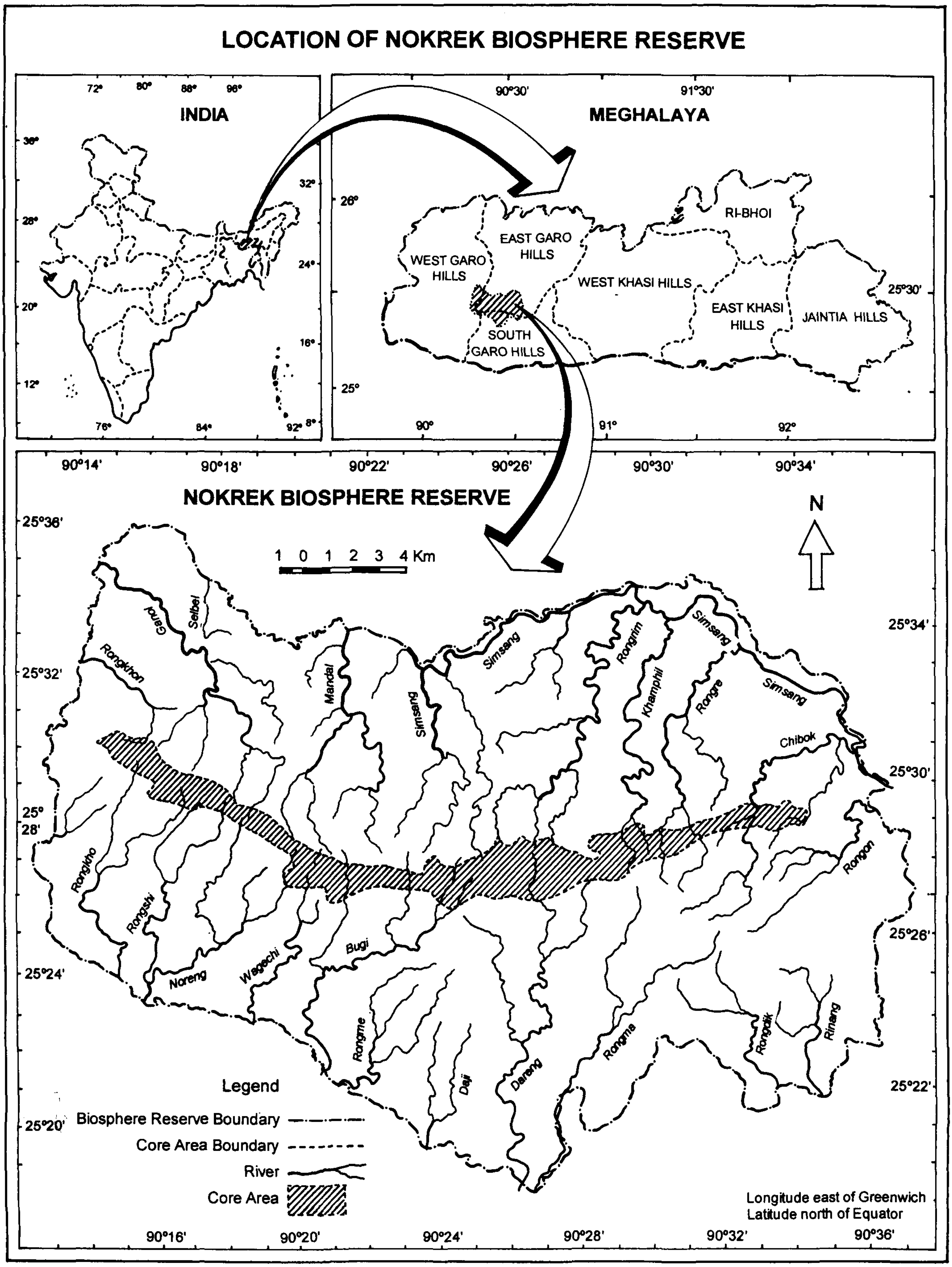

LOCATION OF NOKREK BIOSPHERE RESERVE
INDIA
MEGHALAYA
WEST GARO HILLS
EAST GARO HILLS
SOUTH GARO HILLS
WEST KHASI HILLS
RI-BHOI
EAST KHASI HILLS
JAINTIA HILLS
NOKREK BIOSPHERE RESERVE
1 0 1 2 3 4 Km
N
Legend
Biosphere Reserve Boundary
Core Area Boundary
River
Core Area
Longitude east of Greenwich
Latitude north of Equator

Fig. 1.1

Biosphere Reserve (notified on 18.01.1988). The creation of Biosphere Reserve around the world was initiated by UNESCO in 1972, through its Man & Biosphere Programme. Currently 125 nations are participating in the Biosphere Reserve programme and an international network of 337 Biosphere Reserves representing world's major eco-regions has been established in 85 countries (SBR, 2000). Though in India thirteen Biosphere Reserves have been declared by the Government of India, except Nilgiri Biosphere Reserve no other Biosphere Reserve has been registered with UNESCO (Kutty *et al.* 2001).

Biosphere Reserve is an area of terrestrial or coastal environment representing one of the world's natural or bio-geographical regions. It covers as many kinds of plants and animals as possible and includes a great variety of landscapes. In Biosphere Reserve concept, people are considered as an important part of the ecosystem and the concept is designed to be flexible enough to meet the local needs and conditions, and also to take account of the people's hope. The Man and Biosphere (MAB) programme of UNESCO, that represents a form of international co-operation, took the initiative to organise and establish a global network of protected areas based on sustainable principles and designated them as Biosphere Reserve. The network was started in 1976.

Each biosphere reserve is intended to fulfill three basic objectives:

(i) *In situ* conservation of biodiversity (that includes genetic, species and ecosystems) of natural and semi-natural ecosystems and landscapes.

(ii) Contribution to foster sustainable economic development of the human population living within and around the Biosphere Reserve.

(iii) Provide facilities for long-term ecological studies, environmental education and training and research and monitoring related to local, national and global issues of conservation and sustainable development.

In accordance with above objectives, the special feature of a Biosphere Reserve is that it combines four major groups of activities: (i) Conservation, (ii) Research, (iii) Education and (iv) Local involvement. All Biosphere Reserves operate on a zoning system that consists of a core area, a buffer area and a transition area. The zoning system has been specially developed to combine conservation with other activities.

Physiography

Nokrek Biosphere Reserve is located in the Tura Range, which is a part of Meghalaya Plateau, having an average altitude of 600 m. The highest point in this region is the Nokrek Peak (1412m) lying within the Biosphere Reserve. The core area of the Biosphere is Nokrek National Park, which is spread over an area of 47.48 sq. km.

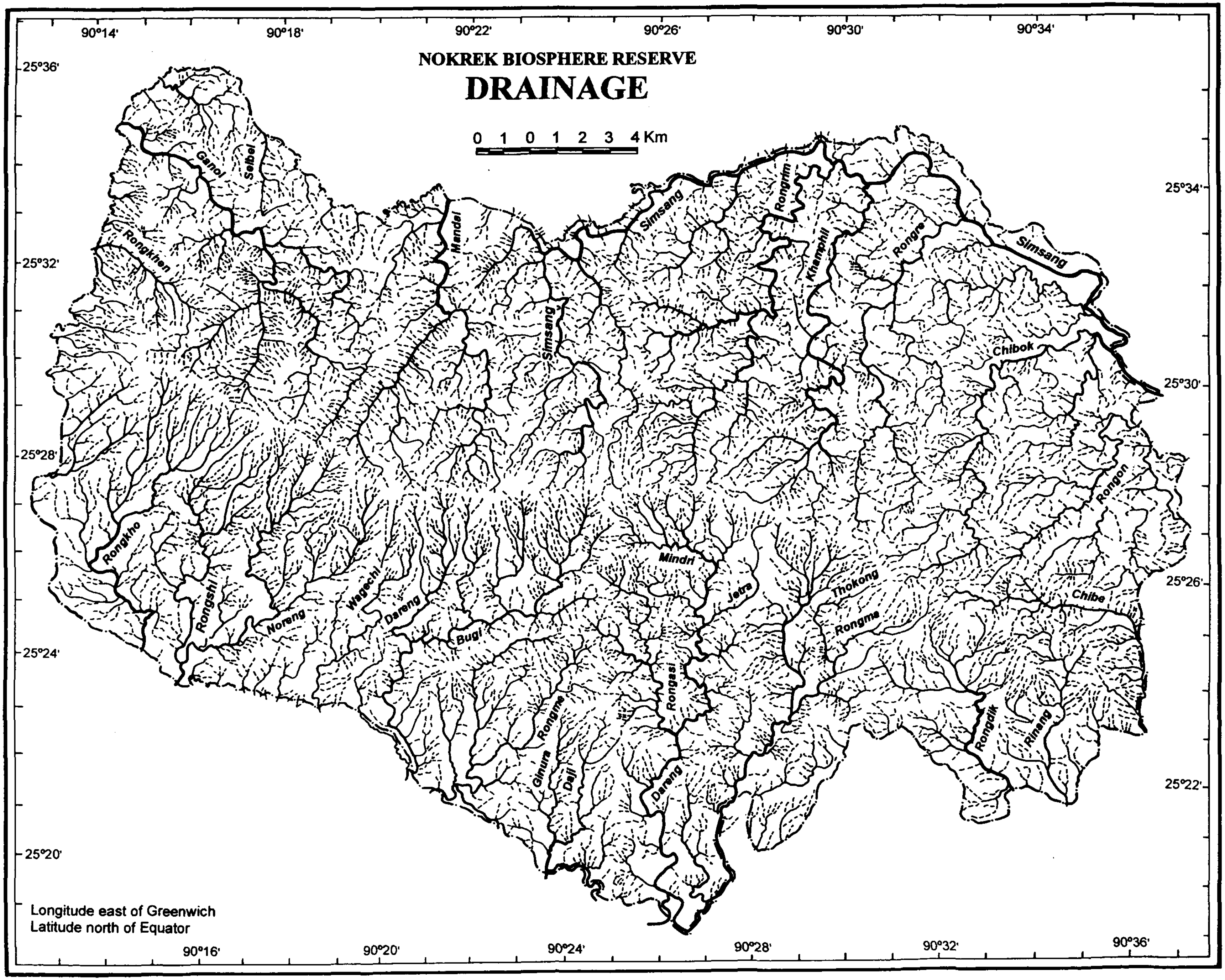
The sources of water for flora and fauna of Nokrek Biosphere Reserve are either by way of rainfall or springs and streams which comprise the perennial drainage system in the Biosphere Reserve. The Tura range is the source of these drainage systems comprising of both north and south flowing rivers. Simsang is the main drainage system of the Biosphere Reserve which originates near Nokrek peak. From the source it flows directly north and takes an eastward turn from where it forms the northern boundary of the biosphere. The main tributaries of Simsang river which drain the Biosphere Reserve are Rongrim, Khamphil, Rongre, Chibok, Rongon, and Chibe. The other north flowing main drainage systems are Mandal, Ganol, Selbel and Ronkhen. The main south flowing rivers which ultimately flow to Bangladesh are Ronkho, Rongshi, Noreng, Wagechi, Dareng, Bugi, Rongme, Ginura, Daji, Mindri, Jetra, Rongasi, Thokong, Rongma, Rongdik and Rinang (Fig. 1.2).

Soil

The soil of most part of the Biosphere Reserve is a red loam. The soil is poor in silica but rich in clay forming materials. The soil is generally loamy but often found clay to sandy loam. The surface horizon which is about 30 cm thick has colours ranging from reddish brown to dark reddish brown. The soils are rich in organic matter and nitrogen but deficient in phosphorous and potassium. The soil of the Biosphere Reserve is acidic in reaction.

Climate

The general climate of the study area is monsoonic and is directly influenced by the south-west monsoon. Based on the climatic conditions the year may be divided into


NOKREK BIOSPHERE RESERVE
DRAINAGE
0 1 0 1 2 3 4 Km
90°14'
90°18'
90°22'
90°26'
90°30'
90°34'
25°36'
25°34'
25°32'
25°30'
25°28'
25°26'
25°24'
25°22'
25°20'
90°16'
90°20'
90°24'
90°28'
90°32'
90°36'
Ganol
Seibel
Rongkhen
Mandal
Simsang
Rongrim
Khamphil
Rongre
Simsang
Simsang
Chibok
Rongkho
Rongshi
Noreng
Wagechi
Dareng
Bugi
Mindri
Jetra
Thokong
Rongma
Chibe
Rongon
Rongasi
Rongme
Ginura
Dalji
Dareng
Rongdik
Rinang
Longitude east of Greenwich
Latitude north of Equator
Fig. 1.2

summer, rainy, autumn and winter seasons. The summer season (April to mid May) is characterized by relatively high temperature, occasional thunderstorms and high velocity wind. In this season, the average maximum temperature goes up to 30.7° C. The rainy season commences with the setting up of south-west monsoon in mid May and lasts upto September. This is the wettest period of the year and about three fourth of the annual rainfall is received during this period. The air temperature is close to that of the summer season. The rainy season is followed by a brief autumn during October and November. The sharp decline in rainfall and lowering of temperature are the characteristic features of this season. It is a transitory period between rainy and winter seasons. The winter season extends from December to March. It is the coldest period of the year. Morning fog and dry weather are the characteristic features of this season. A few intermittent light showers are also received during this period. The mean temperature goes down to 7.5° C during mid winter i.e., December/January. The area receives the mean annual rainfall of 2400 mm.

Vegetation

The vegetation of Nokrek Biosphere Reserve can be broadly classified into tropical and subtropical types depending on the altitude. The tropical vegetation are found upto an elevation of about 1000m. It includes evergreen, semievergreen and moist deciduous forests, bamboo brakes, grasslands riverine forests and swamps. The forests could be distinguished into three distinct vertical layers viz., tree, shrub and herb. The trees in the upper storey include *Aesculus assamica, Aporusa wallichii, Bridelia* *retusa, Butea monosperma, Castonopsis armata, Cryptocarya andersonii, Dillenia indica, Dillenia pentagyna, Ficus* spp. *Gmelina arborea, Grewia* spp., *Gymnosporia salicifolia, Hovenia acerba, Largerstroemia parviflora, Leea macrophylla, Munronia pinnata, Pilioatigma malabaricum, Schima wallichii, Schleichera trijuga, Shorea robusta, Syzygium kurzii, Talauma hodgsonii, Terminalia belerica, Terminalia chebula, Toona ciliata,* and *Vitex pedunchrularis. Engelhardtia spicata, Ficus prostrata, Helicia robusta, Hibiscus macrocarpus, Miliusa velutina* and *Zizyphus rugosa* form the lower canopy in the forest. The main shrub species are: *Acacia concinna, Bauhinia acuminata, Capparis zeylanica, Eupatorium adinoforum, Garcinnia lancifolia, Mimosa himalayayana* and *Mussaendra roxburghii.* Several species of bamboo form thickets of secondary vegetation, which cover substantial area of the Biosphere Reserve. The ground flora in deciduous forests is generally poor. In evergreen forests, species of *Alpinia, Amomum, Colocasia,* and *Hedychium* dominate the ground flora. The epiphytic climbers such as *Rhaphidophora* spp., *Hoya* spp. and many stem parasites are seen in these forests. A few species of epiphytic orchids viz., *Aeridis, Bulbophyllum, Dendrobium, Eria, Liparis, Photidota, Thunia* and *Vanda* are seen in the evergreen forests. The herbaceous vegetation is less profuse and includes the members of Oxlidaceae, Balsaminanceae, Acanthaceae, Leeaceae, Fabaceae, Asteraceae and Poaceae. Besides, *Sida* spp. and *Leea* spp., *Coffea bengalensis, Impereta cylindrical* and *Chromolaena odorata* are also prominent.

The subtropical vegetation occurs at elevations beyond 1200 m above sea level. This type of forest is restricted to the Tura peak and Nokrek peak only. These are mainly evergreen forests but a few elements of deciduous forest are also seen, The top canopy is occupied by species like C*astanopsis hystrix, Betula culindristachvs, Kevia floribunda, tamula phellocarna, Dryntes lancifolia, Ficus* spp., *Vitex altissima, Adina cardifolia* and *Sterculia villosa.* Species such as *Machilus gamblei, Machilus villosa, Carnicia paniculata, Eriobotrya bengalensis, Quercus semiserrata* and *Litsea* spp. form the middle canopy of the forest. The lower canopy comprises of *Aglata roxburghii, Mitrephora tomentosa, Premna multifolia, Litsea* spp. and *Ficus* spp. The shrub layer is dominated by *Munronia pinnata, Eriobotrya angustissima, Antistriphe oxyantha, Strobilanthes glomeratus and Erianthus* spp.

OBJECTIVE

The objectives of the study are as follows:

I. To identify, map and determine the extent of the coal mining area in the Nokrek Biosphere Reserve.

II. To characterize land degradation and landforms due to coal mining.

III. To assess the impact of coal mining on: (i) vegetation, (ii) soil characteristics and (iii) water quality.

METHODOLOGY

Pre-field phase

- Selection of the problem and consultation of literature.
- Identification, mapping and determination of area under coal mining in the Nokrek Biosphere Reserve by using topographical sheets and satellite imageries, following manual interpretation method.
- Collection of general information on climate, soil, vegetation, geology etc.

Field-work phase

- Selection of three coal mining areas from the NBR- Budugiri, Budu Wathegiri and Faramgiri.
- Vegetation and soil studies were done in two stands of unmined and mined areas while water samples were collected from three stands i.e., upstream, downstream and mining stands. Composite soil samples were collected in three depths, i.e., 0-10 cm, 10-20 cm and 20-30 cm while for vegetation study tree, shrub and ground vegetation (herb) were considered. Study was carried out for two years considering three seasons viz., pre-monsoon, monsoon and post-monsoon.
- The method applied for vegetation study in the field carried out following the methods described in Mishra (1968).
- Field photographs have been taken.

Post-field work phase

- Geomorphology:

  -For different geomorphic analysis toposheet no. 78 K/2, 78 K/3, 78 K/6, 78 K/7, 78 K/10 and 78 K/11 have been used.

- Water:

  -pH, Conductivity, Sodium, Potassium, Nitrate, Sulphate, Phosphate, Hardness, Dissolved Oxygen

- Soil:

  -pH, Moisture, Texture, Nitrogen, Phosphorous, Soil Organic Matter, Soil Organic Carbon, C/N

- Vegetation:

  -Floristic composition,

  -Density,

  -Population Structure: Density Distribution Diameter, Basal Cover Distribution Pattern, Dominance, Species Diversity, Distribution Pattern (Regular, Random and Contagious), Impact on Regeneration

PLAN OF WORK

The present thesis on "Coal mining and its impact on environment of Nokrek Biosphere Reserve, Meghalaya" has been divided into following five chapters.

CHAPTER-I: INTRODUCTION

i. General Introduction

ii. Objectives

iii. Review of Literature

iv. Study Area

CHAPTE-II: GEOLOGY AND LOCATION OF COAL MINING SITES IN NOKREK BIOSPHERE RESERVE

i. Geological setting of the area

ii. Location of coal mines

CHAPTER-III: GEOMORPHOLOGY OF NOKREK BIOSPHERE RESERVE

i. Analysis of various geomorphic attributes viz., relief, slope and drainage analysis for the entire Biosphere Reserve

ii. Detailed drainage basin study for seven selected drainage basin

CHAPTER-IV: IMPACT OF COAL MINING ON VEGETATION, SOIL AND WATER OF NOKREK BIOSPHERE RESERVE

i. Impact of coal mining on vegetation

ii. Impact of coal mining on soil characteristics

iii. Impact of coal mining on water quality

CHAPTER-V: GENERAL DISCUSSION

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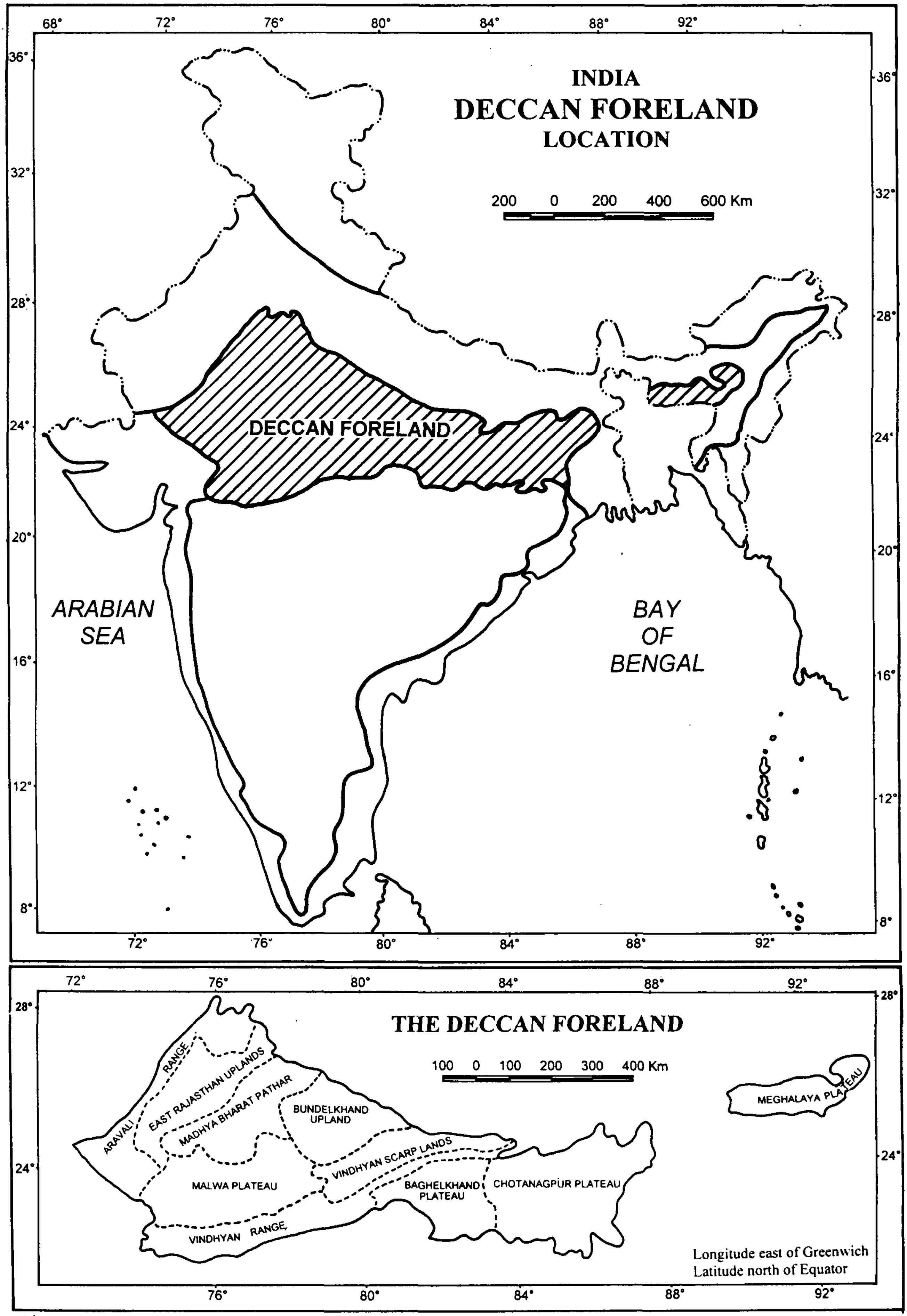
CHAPTER-II

GEOLOGY AND LOCATION OF COAL MINING SITES IN NOKREK BIOSPHERE RESERVE

In Lower Gondwana times, which are estimated to have lasted for thirty million years, approximately 200 million years ago, India was part of the great southern continent of Gondwanaland. Geologically the country represents a monumental assemblage of land pieces, varying in age from Pre-Cambrian to Recent. The peninsular massif is the core, around and upon which different acts of geological drama were staged and all have left their imprints in some form or the other. The northeastern part of India comprising seven states can be geologically grouped into three divisions, viz., the folded hills and mountains of Tertiary origin born out of the Tethyan Geosyncline, the narrow foreland or rift valley that represents the Brahmaputra plain and the rigid massif of the Meghalalya and Karbi Plateaus which are a part of the Peninsular Gondwana.

The Meghalaya-Karbi Plateaus are linked with Chotanagpur Plateau with an underground extension below the Raja Rajshahi-Rongpur Gap, which is known as the Malda Gap or Rajmahal-Garo Gap (Rai 1986) (Fig. 2.1). The massif is a geomorphological arch bounded on all sides by faults (Murthy *et al.* 1976a and Mazumdar 1986). The southern and northern boundaries are marked the Dauki fault and the Brahmaputra lineament respectively. To the west the massif is bordered by Rajmahal Garo lineament and the eastern boundary is a NE-SW lineament separating the massif from the sediments of Bengal-Assam shelf. Its underground tongue extends



After Rai, 1986

Fig. 2.1

to the north beyond the Brahmaputra and to the east up to the Kakodonga River in Jorhat district. The tongue of the rigid mass is so projected as to make the Tethyan geosynclinorium sweep round its end towards the south. The geanticlines contained in it, thus had their both ends curved and became concave to the Indian landmass at the head of the underground tongue and convex in other parts presenting a syntaxial structure.

The relatively mobile tongue of the Peninsular block moved towards the north-east with its frontal foreland part dipping towards the brim of the horse-shoe shaped geosynclinorium. Although the fringe of the foreland is buried under thick layers of the Pleistocene, Recent and Sub-Recent rock and alluvial deposits of what is today the Brahmaputra Valley.

Geological work in Meghalaya was initiated by Oldham (1858) after the inception of Geological Survey of India (G.S.I.) in 1851. Medlicott (1869) also did substantial work on Meghalaya geology. In the post independence period large areas of Meghalaya have been mapped by the G.S.I. The compiled geological framework of Meghalaya is given by Anon (1974), Murthy *et al.* (1976a, 1976b) and Majumdar (1986). The generalized stratigraphic succession of Meghalaya is given in Table 2.1, which was modified after Anon (1974) and Mazumdar (1976).

Table 2.1: Generalized Stratigraphic Succession of Meghalaya (Modified after Anon 1974 and Mazumdar 1976)

Recent	Newer Alluvium (Thickness not known)	Represented by sand, silt and clays	
	---Unconformity---		
Pleistocene	Older Alluvium (Thickness not known)	Represented by sand, clay, pebble, gravel and boulder deposits	
	---Unconformity---		
Mio-Pliocene	Dupitila Group (Approx. 1050 m)	Represented by unclassed mottled clays, feldspathic sandstone and diamictite	
	---Unconformity---		
Oligo-Miocene	Garo Group	Chengpara Formation: (Approx. 700 m)	Represented by sand, siltstone, clay and marl
		Baghmara Formation: (Approx. 530 m)	Represented by feldspathic sandstone, pebble, diamictite, clay, silty clay
		Simsang Formation: (1150m)	Represented by siltstone-sandstone alternations, sand
Eocene	Jaintia Group	Kopili Formation (500m):	Represented by shale, sandstone, marl
		Shella Formation (600m):	Represented by alternations of sandstone-limestone
		Langpar Formation (100m):	Represented by calcareous shale, sandstone, limestone

Table-continued...

Upper Cretaceous	Khasi Group	Mahadek Formation: (150m)	Represented by arkose (Glauconitic)
		Bottom Conglomerate (25m):	Represented by conglomerate, arkose
		Jadukata Formation: (140m)	Represented by sandstone-conglomerate alternations
	----------Unconformity----------		
Upper Cretaceous	Sung Valley Complex	Pyroxenite, serpentite, syenite, carbonatite etc	
	----------Unconformity----------		
Jurassic	Sylhet Trap (Approx. 600m)	Basalt, alkali basalt, rhyolite, acid tuff	
	----------Unconformity----------		
Permo-Carboniferous	Lower Gondwana Group (Approx. 200m)	Sandstone, shale, conglomerate, coal	
	----------Unconformity----------		
	Prophyritic Granitoid	These dot the Meghalaya Plateau. Those entirely within the Gneissic Complex and those intrusive into the Shillong Group, are of the same age. Because the South Khasi batholith transects both the older sequences.	
	----------Intrusive Contact----------		
Proterozoic	Khasi Greenstone	Basic sills and dykes mostly within the Shillong Group	
	----------Intrusive Contact----------		

Contd....

Table-continued...

Proterozoic	Shillong Group	Formerly termed the 'Shillong Series'. They are a Conglomerate – sandstone - siltstone – shale rhythm. Weakly metamorphosed in the northern parts. Metamorphosed in proximity with Porphyritic granitic plutons. Occurs as a cover on older rocks. Strike persistently NE with open folds alternating with zones of steep dips.
	---Unconformity---	
Archaean	Nonphorphyrite Migmatite Granitoids	They are a variety of textural and compositional types developed exclusively within the gneissic complex where grade of metamorphism reaches amphibolite facies.
	---Diffused Contact---	
	Gneissic Complex	Formerly described as "Older Gneissic" or "Gneissic Series" or "Archaeans". A telescope sequence of stratigraphic, deformational and metamorphic events which needs further elucidation, mostly show only one phase of recrystallisation, probably due to a late major regional metamorphism, are considered relicts of a still earlier orogeny.

THE GNEISSIC COMPLEX

The central and northern parts of the Meghalaya plateau is made essentially of highly metamorphosed crystalline rocks of Pre-Cambrian origin. This has often been referred to as "Archaean Gneissic Complex" (Anon 1974 and Murthy *et al.* 1976a). It comprises gneisses as well as schistose members of varying composition. Gneisses are by far the dominant constituents of the complex represented by biotite gneiss, biotite granulite, biotite-hornblende gneiss, quartz-sillimanite gneiss, locally containing cordierite, garnet, clinopyroxene and chondrodite. The schistose members are represented by amphibolite, mica schist, quartz-sillimanite schist, metabasite, locally with garnet, andalusite and sillimanite. Further, the base of the plateau is intruded by igneous rocks like granite and gneissic granite with a mixture of basalt rhyolite and tuff.

THE SHILLONG GROUP

The Shillong Group of rocks which are weakly metamorphosed overlies the Gneissic Complex with an unconformity and comprises friable quartzite with subordinate phyllites, sandstone, siltstone, quartz-sericite schist and minor diamictite. The rocks occur in an NE-SW elongated tract in Khasi Hills and extend upto the northwestern fringe of Karbi-Anglong district of Assam. The Shillong Group of rocks show a zone of subvertical dips with local reversal from west of Mawphlong to Barapani, away from this zone the dips show gentle rolling disposition. Such folding represents "Intermediate crestal type folding" (Beloussov 1962). In the late Paleozoic period volcanicity and marine transgression affected the southern and western parts of the

Shillong Plateau respectively giving rise to the Sylhet Trap in Khasi Hills and Gondwana deposits in Garo Hills. The Sylhet Traps are exposed in a narrow E-W patch between 25°12'N and 25°15' N latitudes and 91°15'E and 92°15'E longitudes along the southern border of the Shillong plateau (Medlicott 1869). The Traps overlie the eroded Pre-Cambrian basement and underlie non-conformity the Upper Cretaceous-Eocene sediment sequence. The Sylhet Traps comprises predominantly basalts and minor alkali basalt (nepheline tephrite), rhyolite and acid tuffs.

THE CRETACEOUS-TERTIARY SEDIMENTARY SEQUENCE

It is found that from the Cretaceous up to the Oligocene period the southern part of the plateau was again under the sea allowing Mesozoic and Tertiary Khasi, Jaintia and Garo groups of sediments of sandstone, carboniferous shale, coal, limestone and conglomerate to deposit.

The Khasi Group

The Khasi Group represents the Cretaceous section of the pile and is represented by Jadukata Formation, Bottom Conglomerate Formation and the Mahadek Formation. The Jadukata Formation overlies unconformably the Sylhet Traps and represents an arenaceous facies composed of conglomerate at the base overlain by pebbly sandstone, coarse grained sandstone with Carboniferous streaks. This Formation is limited to the north of the Raibah fault which formed the limit of the shoreline. The progressive migration of the shoreline towards north is marked by the presence of thick conglomerate bed, north of Raibah fault, known as Bottom Conglomerate Formation. These two formations are overlain by Mahadek Formation with continuous contact. It is well exposed in Mawsynram area. The Mahadek Formation represents an arenaceous sequence made up of the fine pebbly sandstone at the base grading upwards to coarse to medium grained sandstone which is mainly quartzwacke (Anon 1974).

The Jaintia Group

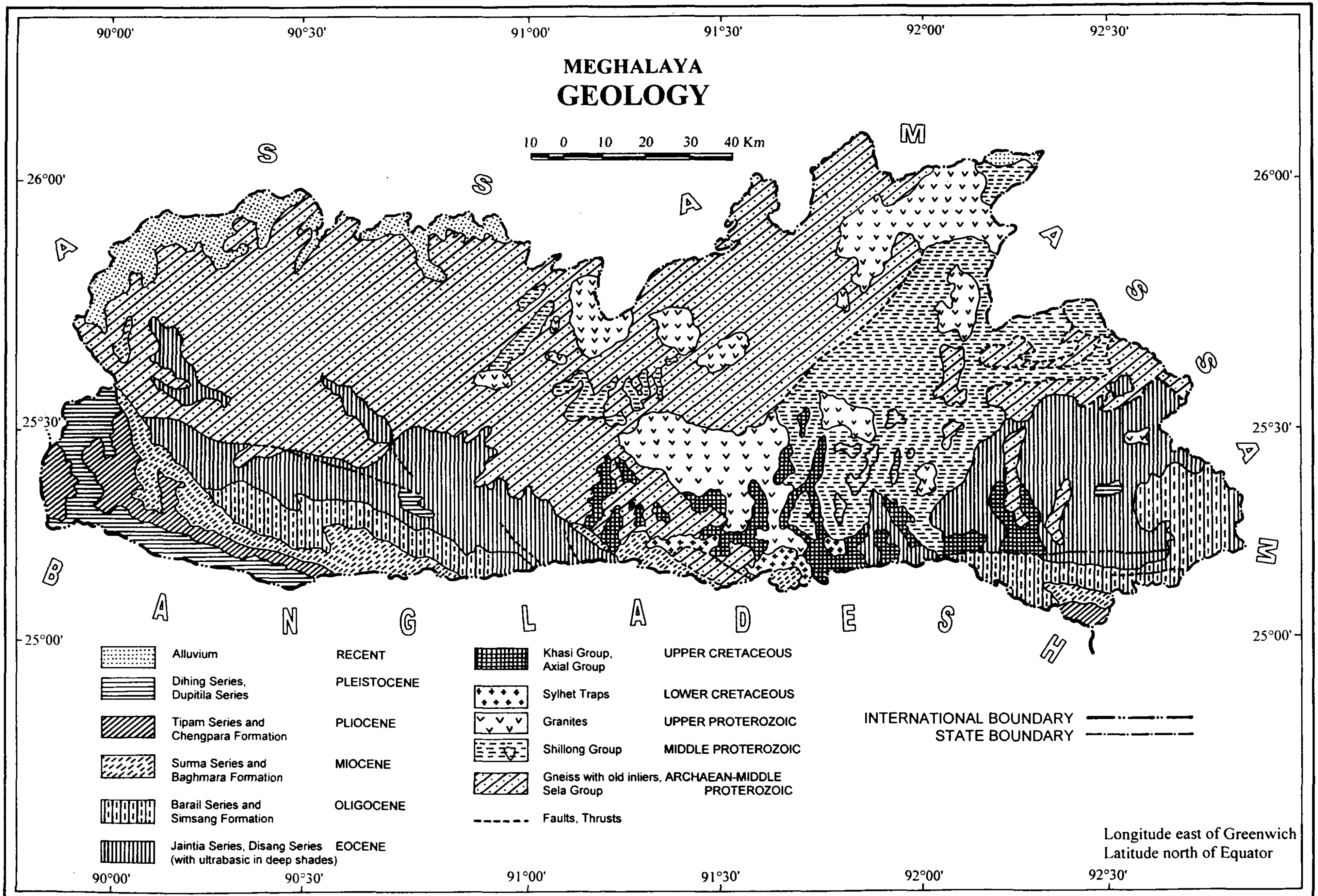
The Jaintia Group marks the onset of change in depositional environments. This group is divisible in three formations viz. Langpar Formation, Shella Formation and the Kopili Formation. The Langpar Formation represents the beginning of the Tertiary segment of the sedimentary pile of Meghalaya Plateau. It represents a sequence of Carboniferous siltstone, calcareous shale, sandy limestone and marks a distinct change in sedimentary facies. The succeeding Shella Formation comfortably overlies the Langpar Formation and comprises alternations of three sandstone and limestone members (Murthy *et al.* 1976b). These have been designated successively as the Lower (Therria sandstone / Lakadong limestone), Middle (Lakadong sandstone / Umlatdoh limestone) and Upper (Nurpur sandstone / Parang limestone / Siju limestone and Sylhet sandstone / limestone) member. The Shella Formation is succeeded by Kopili Formation with a gradational contact. The rocks represent alternations of thin sandstone and shale with minor thin bends of limestone. The base of the Kopili Formation represented by a shale horizon often contain phosphatic nodules.

The Garo Group

The Garo Group represents the Upper Tertiary sequence and is well exposed in Garo Hills. It is divisible into three formations viz. Simsang Formation, Baghmara Formation and Chengpara Formation. The oldest of the three i.e. the Simsang Formation overlies comfortably the Kopili Formation and represents a cycle of massive festoon cross bedded sandstone, siltstone members. The succeeding Baghmara Formation has gradational contact with the underlying Simsang Formation and is mainly confined in the eastern tracts of Garo Hills. It is represented by impersistent beds of felspathic sandstone with minor mudstone, pebbly sandstone-conglomerate, massive clay, silty clay-sand beds. The overlying Chengpara Formation also has gradational contact with the underlying Baghmara Formation. It comprises poorly cemented fine grained micaceous sand, blue to brown siltstone and clays with thin beds of marls at the base. A prominent angular unconformity marks the top of Chengpara Formation in the western parts of the Garo Hills. This angular unconformity is well exposed in the Tura-Dalu road section near Nokchi and north of Mahendraganj (Anon 1974). The Changpara Formation is overlain by the Dupitila Group with an angular unconformity. It consists of alternations of coarse felspathic sandstone with thin layers of pebbles of vein quartz and mottled sandy clays.

Isolated patches of Older Alluvium overlies unconformably the eroded top of the Tertiary rocks along the southern and western borders of Garo Hills and along the southern flanks of Khasi Hills. Recent Alluvium consisting of fine silty sand and light to dark gray clay with rare pockets of coarse sand and shingles occur in river valleys. The sands invariably contain abundant mica. These recent alluvium occur along the northern and southern flanks of Garo and Khasi Hills.

The Meghalaya Plateau is thus composed in the north of highly metamorphosed crystalline gneissic complex, granite, quartzite, conglomerate of Pre-Cambrian origin, and in the south of largely Mesozoic and Tertiary sedimentary outcrops. In the ultimate phase of Himalayan orogeny in the late Tertiary period, the southern part of the Shillong Plateau must have experienced tremendous tectonic impacts and its southern most part must have sank down giving rise to the steep scarp which today stands aloft facing the Sylhet plain of Bangladesh (Fig. 2.2).



Geological Survey of India Publication, 1976

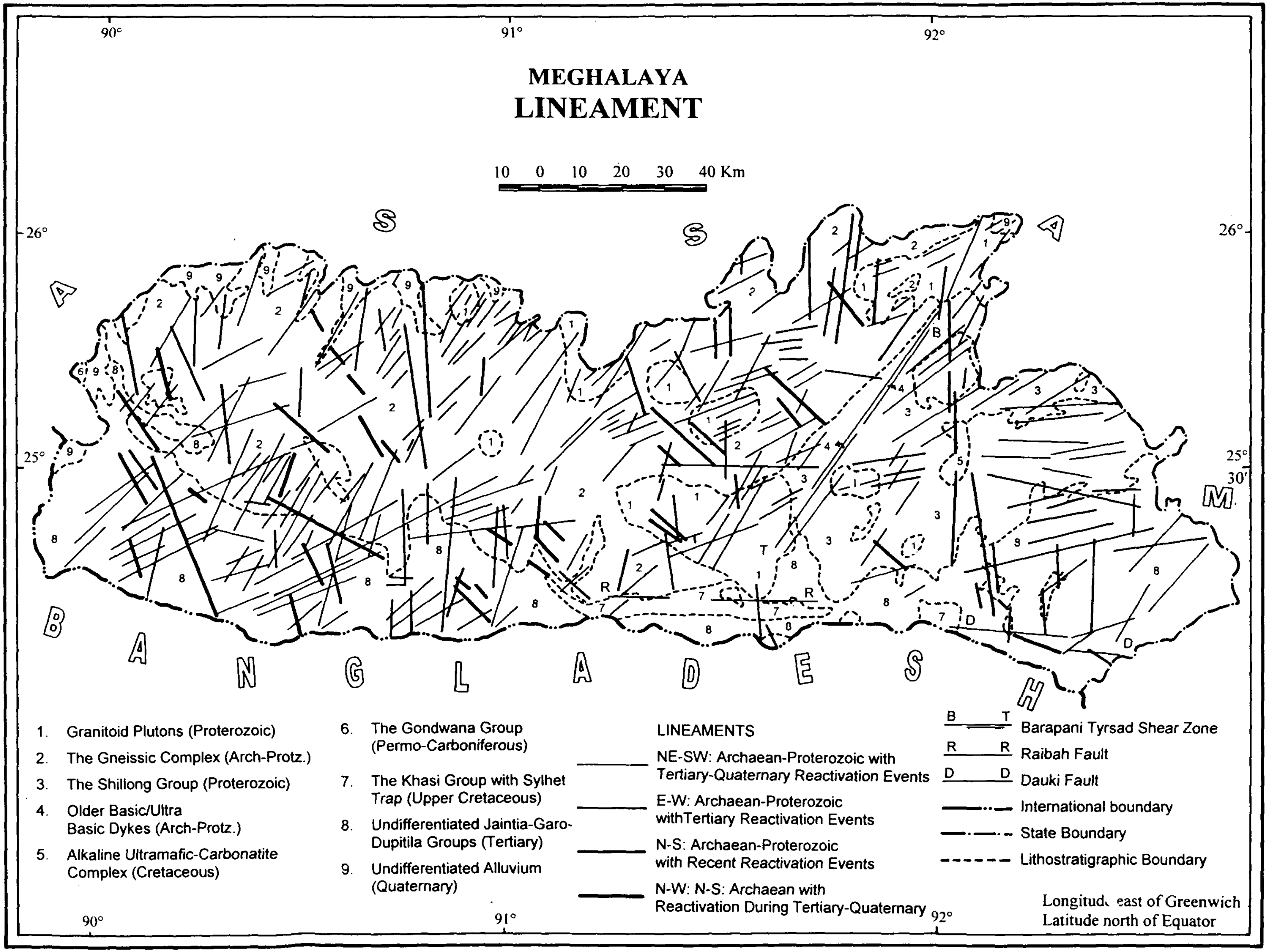
Fig. 2.2

TECTONIC EVOLUTION OF MEGHALAYA

Tectono-stratigraphically Meghalaya can be divided into three domains each having distinct evolution, viz., the Peninsular Shield Extension comprising the Gneissic Complex, Intracratonic Sedimentary Basin represented by the Shillong Group and the Mesozoic-Tertiary Sedimentary Sequence along with the Sylhet Trap occupying the southern fringe of the plateau.

Satellite imagery, aerial photographs and topographic maps of Meghalaya reveal long and persistent lineaments segmenting the plateau. According to Murthy *et al.* (1976b), these lineaments are manifestations of deep seated fracture systems having repeated reactivation. The various lineaments have been classified as per their activity and geological domain. The lineaments have been grouped into four classes with interval of 20° on either side of N-S, NE-SW, E-W and NW-SE alignments (Fig. 2.3).

The fundamental and earliest lineament trends are E-W. Later in the Pre-Cambrian this trend was superseded by NE-SW trend which



Based on Satellite Imageries

Fig. 2.3

probably persisted during the intrusion of the porphyritic granitoids. The Pre-Cambrian is thus marked successively by the dominance of E-W trend. The porphyritic granitoids appear to have been emplaced along the NE-SW trend. This lineament appears to be a deep suture along which major vertical tectonics have played vital role in shaping the evolution of the Meghalaya Plateau. The boundary between the Pre-Cambrian and the Jurassic Sylhet Traps is an Important E-W lineament. This E-W trending lineament is the famous Raibah Fault dipping towards south which was active till Cretaceous. Further south, the Dauki fault also a E-W lineament is known to have been active till tertiary and has been responsible for the upliftment of Meghalaya (*Murthy et al.* 1967).

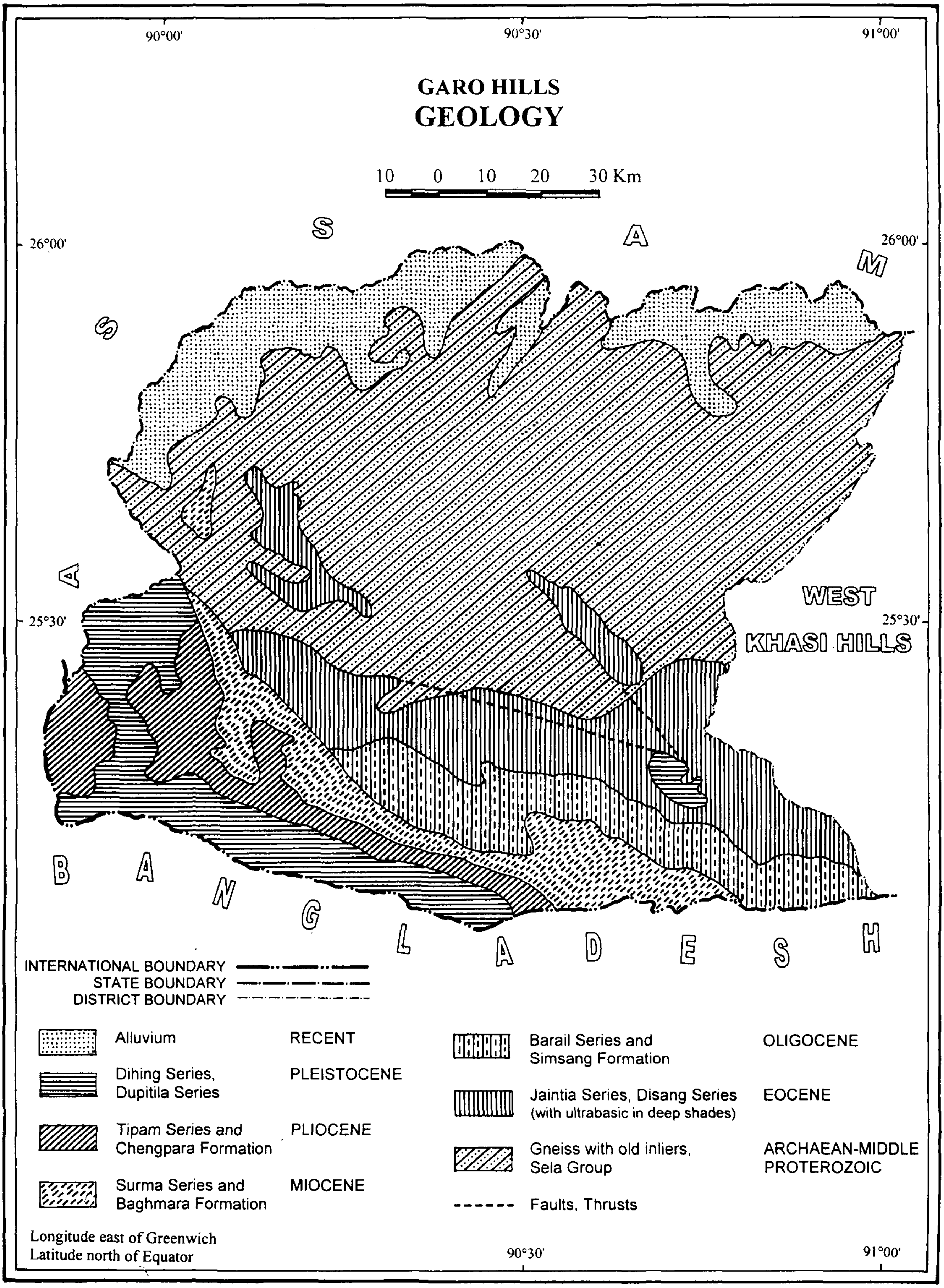
The Pre-Cambrian Gneissic Complex is the northeastern extension of the peninsular shield. This segment forms the core part of the plateau. It is the basement for the subsequent events. The central part of the complex covering Khasi and Jaintia Hills, developed a linear and narrow NE-SW trending basin during the late Proterozoic. This basin was the repository for the detritus, which later on formed the Shillong Group of rocks. These sedimentary rocks experienced low grade metamorphism and gentle warping.

The Pre-Cambrian terrain remained more or less a positive mass till the early Carboniferous period and was subjected to degradation. However, Permo-Carboniferous period saw development of a minor intra cratonic basin where the Gondwana were deposited as evident from the western tip of Garo Hills. The terrain remained more or less dormant till the beginning of the Jurassic when Sylhet Traps were erupted towards the southern margin of the plateau through E-W fissures i.e. Raibah fault system along which the southern block subsided and the northern block upheaved. The end of Jurassic saw deposition of thick sedimentary pile (Cretaceous-Tertiary) along the southern boundary. Sedimentation continued till Miocene along the southern and western fringe of Garo Hills and the southern part of the Khasi Hills. But, the Jaintia Hills got uplifted as a block and formed a positive area. However, the principal block upliftment of Meghalaya commenced at the end of Miocene. As a result all along the southern Khasi and Garo Hills, shallow lacustrine basins were formed. In these basins the Dupitila sediments (Pliocene) were deposited. Over these the subrecent and recent (Quaternary) deposits were laid along the various fluvio-lacustrine regimes.

Many of the lineaments are still active as evidenced by the high micro seismic activities in and around Meghalaya Plateau. Some of the lineaments when traced towards north into the Brahmaputra plains as well as towards south into the Surma plains show evidences of Neotectonic movements. Probably these activities are the manifestation of release of built up stress mainly through vertical movements coupled with little or no lateral displacement.

GEOLOGY OF GARO HILLS

The Garo Hills region of the Meghalaya Plateau is an extensively dissected tract formed of gneissic rock with old inlier, Sela group. Some patches in the northern and southern parts are formed of recent alluvium, Jaintia Series and Simsang Series (with ultra-basic in deep shades) rocks respectively (Fig. 2.4). The basement of Gneissic Complex covering an area about 60% of the Garo Hills of Pre-Cambrian age is the oldest litho unit exposed, in central and northern parts of Garo Hills and composed of gneissic, granulites, migmatites, amphibolites and Bonded Iron-Formation (BIF) intruded by basic and ultra basic bodies. Over the Pre-Cambrian crest localized patchy occurrences of sedimentary rock belonging to the Gondwana group comprising of pebble bed, sandstone and carboniferous shales with streak and lenses of coal and contain fossil plant imprints of *Vertebraria indica* that grew luxuriantly during Upper Carboniferous Permian. Occurrences of basaltic trap rock and rhyolitic crystals tuff as detached sheet lenses, is indicative of Cretaceous-Palaeocene volcanic activity in West



Source: Geological Survey of India

Fig. 2.4

Garo Hills district. Sediments of Tertiary age occur extensively around Siju, Adugre, Baghmara, Rongra and many other localities towards southern part of Garo Hills. The Shella formation is composed of sandstone, lithomargic clay, shale and coal seams. The important minerals found in the region are coal, limestone, pyrite, phosphorite gypsum, glass sand, clay and iron.

A strip of vast coal deposit occurs in the southern part of the Garo Hills districts. The coal occurring in the districts is of Lower Eocene geological horizon. The rocks concerned belong to the Jaintia Series. The stage of the Jaintia Series is the Tura sandstones which are underlaid by Cretaceous beds of Upper Senonian age, where they do not rest directly on crystalline rocks. The Cretaceous and Lower Tertiary rocks at one time spread widely over the gneisses of the range which stretches west wards from the Shillong Plateau and forms the culminating ridge of Garo Hills. As a result, however, of flexuring and subsequent block faulting in later Tertiary times, all that now remains of the Tura Sandstone Stage and its associated coal measures are a few detached outliers and small basins which may be grouped as, the Karaibari field, the Rongrengiri field, Siju field and the Darrangiri field. The Tura Sandstones cover large tracts to the north and north-west of the Tura, between the Ringgi and Kalu rivers, but the thin seams of dull and shally coal, seldom over 1 m thick of the Karaibari area. Siju field is located on the southern slope of the main ridge is flanked by the Lower Eocene strata and though often buried beneath thick over burden of later rocks, the

Coal Measures are visible at various places around Siju. The Main Seam between Dapsi Tholegiri and Siju Songmong is 1.5 m, and over an area of 67 sq. km. The Rongrengiri field covers an area of about 65 sq. km in the Simsang valley, north of the main range, and some 51 km east of Tura. The seams are of poor appearance, thin and inconsistent. A few km below the Rongrengiri lies the Darranggiri field which is divided into a western and eastern portion by the Simsang river. In the western part there is a Main Seam averaging 2 m thick of hard coal and, 61 m higher, an Upper Seam 0.45 to 0.60 m thick. The Main Seam has a low dip and contains 127 million tons of coal. In the eastern portion owing to differential movements of the gneissic floor, the Coal Measures have been disrupted into seven or eight separate units, six of which occupy nearly 23 sq. km. The Main Seam of them averages 1 m in thickness and contains 31 million tons of coal (Brown *et al.* 1975).

GEOLOGY OF NOKREK BIOSPHERE RESERVE

Being the part of Meghalaya Plateau most of the area of Nokrek Biosphere Reserve is formed of gneissic rock with old inlier, Sela group. The basement of gneissic complex covering the central and northern part of the Biosphere Reserve of Pre-Cambrian age is the oldest litho unit exposed, composed of gneissic, granulites, migmatites, amphibolites and Bonded Iron Formation (BIF) intruded by basic and ultra basic bodies. A strip along southern margin and two patches in the eastern and western parts of the Biosphere Reserve are formed of Jaintia and Simsang Series with ultra-basic in

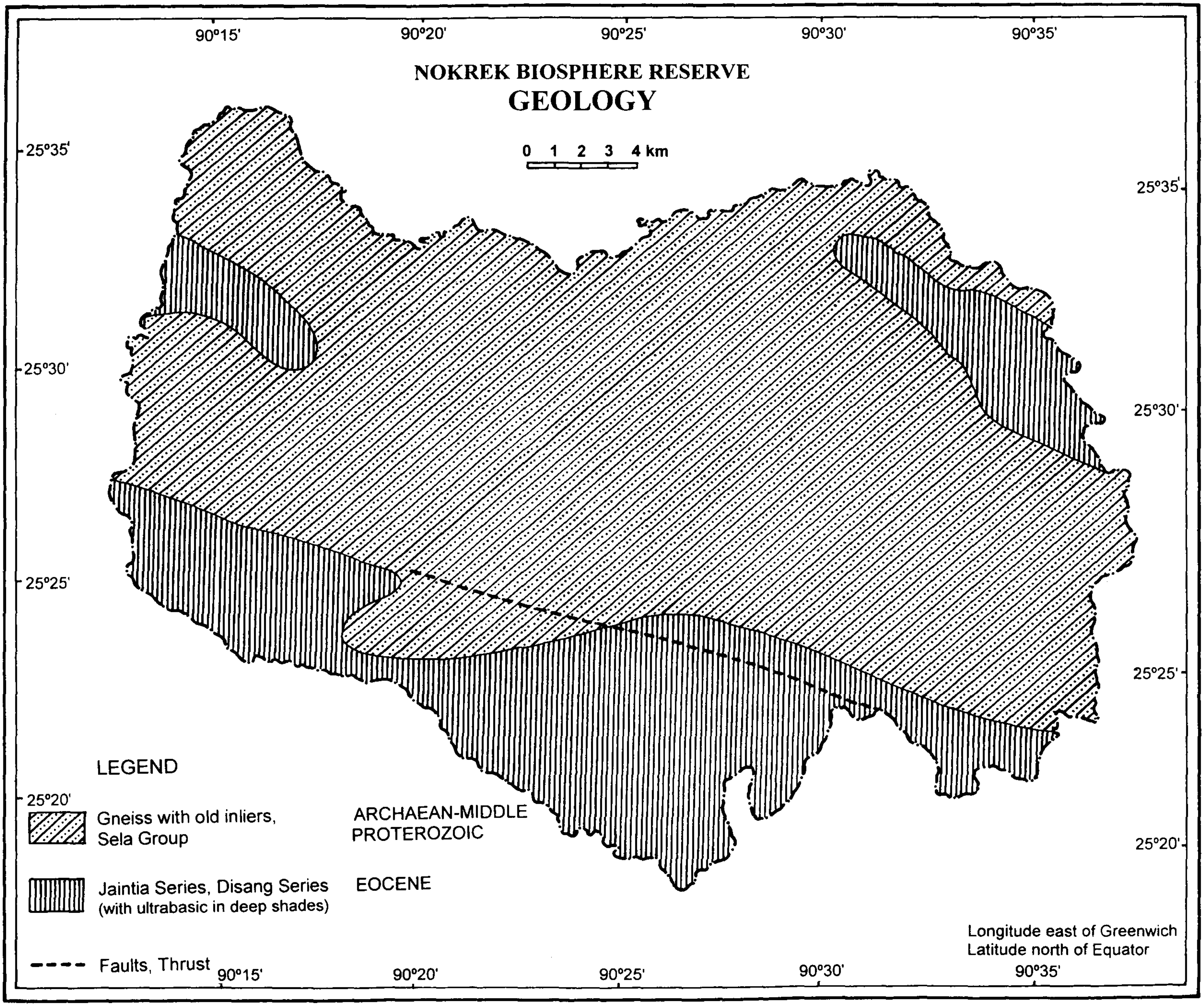

NOKREK BIOSPHERE RESERVE
GEOLOGY
0 1 2 3 4 km
90°15'
90°20'
90°25'
90°30'
90°35'
25°35'
25°30'
25°25'
25°20'
LEGEND
Gneiss with old inliers, Sela Group
ARCHAEAN-MIDDLE PROTEROZOIC
Jaintia Series, Disang Series (with ultrabasic in deep shades)
EOCENE
Faults, Thrust
Longitude east of Greenwich
Latitude north of Equator

Fig. 2.5

deep shades rocks. Coal beds are of Lower Eocene geological horizon which are mostly found along with Jaintia and Simsang Series. The stage of the Jaintia Series is the Tura sandstone which are underlined by Cretaceous beds of Upper Senonian age, where they do not rest directly on Crystalline rocks (Fig. 2.5).

In the entire Garo Hills, the total reserve of coal has been estimated to be 359 million tons and West Darrangiri area alone has more than 35 percent of it. A considerable portion of this deposit falls under the Nokrek Biosphere Reserve, which lies in the southern and eastern part of it. Because of the complex geological setting, peculiar land holding system and lack of infrastructure, unscientific extraction of coal in unorganized sector within the Biosphere Reserve is going on and the area of coal mining in this region is increasing day by day. Coal mining started within the Biosphere Reserve in the year 1985 at Darenggiri area. At present coal is being extracted from 18 coal mining sites (Fig. 2.6) viz., Darenggiri, Jatragiri, Rongragiri, Khamalgiri, Rongmagiri, Budu Wathegiri, Budugiri, Gopgiri, Khibalamagiri, Khakijagiri, Faramgiri, Anchenggiri, Rongphakgiri, Rongmigiri, Rongrugiri, Ruabangagiri, Bandarigiri and Rongdianchengiri. The thickness of the seam of coal ranges from 0.45 m to 2.00 m. The annual extraction of coal from these mining sites is 4,32,000 tonnes. All the coal extracted are exported to Bangladesh through Gasuapara, Barengapara and Mahendraganj.

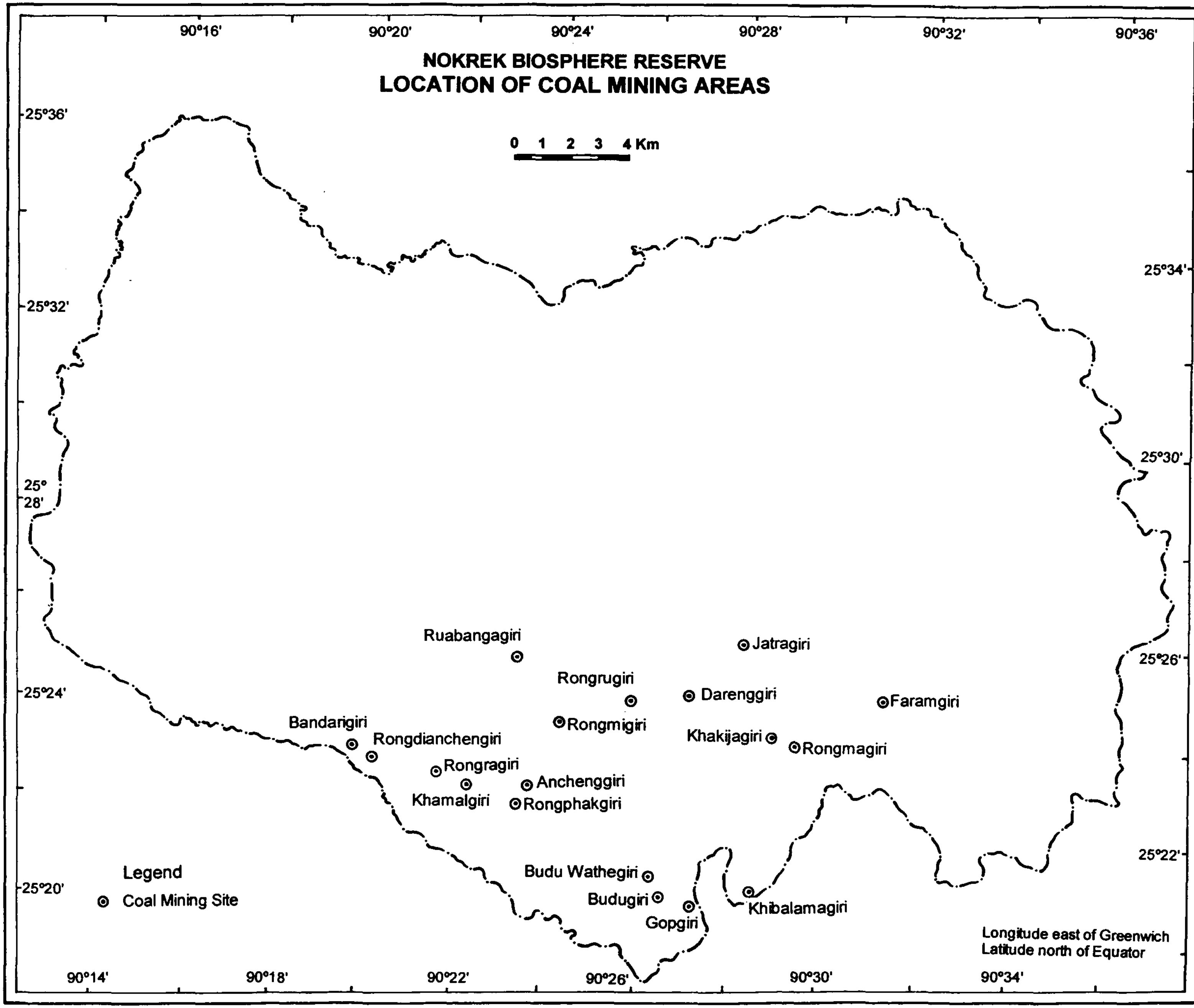

NOKREK BIOSPHERE RESERVE
LOCATION OF COAL MINING AREAS
0 1 2 3 4 Km
90°16'
90°20'
90°24'
90°28'
90°32'
90°36'
25°36'
25°32'
25° 28'
25°24'
25°20'
25°34'
25°30'
25°26'
25°22'
Ruabangagiri
Jatragiri
Rongrugiri
Darenggiri
Faramgiri
Rongmigiri
Khakijagiri
Rongmagiri
Bandarigiri
Rongdianchengiri
Rongragiri
Anchenggiri
Khamalgiri
Rongphakgiri
Budu Wathegiri
Budugiri
Gopgiri
Khibalamagiri
Legend
Coal Mining Site
Longitude east of Greenwich
Latitude north of Equator
90°14'
90°18'
90°22'
90°26'
90°30'
90°34'

Fig. 2.6

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CHAPTER-III

GEOMORPHOLOGY OF NOKREK BIOSPHERE RESERVE

INTRODUCTION

Geomorphology has been described as the 'earth-shape-science' (Brown, 1970). Study of geomorphology of an area reveals not only the description of landscape, but also provides physical basis for resource evaluation towards attaining a sustainable development. Many works have been done in the field of geomorphology in recent times. In fact, geomorphological literature has now become quite voluminous and newer and newer literature are being added.

There has been a phenomenal development in the field of geomorphological studies in the twentieth century. The earlier works in this field led to a variety of approaches, which led to the development of several schools of thought. King (1966) categorized these thoughts into three groups. The first arises out of the work of Walter Penck which is known as 'mobilistic view'. The second school of thought gives priority to the effects of climate in studying the characteristics of the landscape and the third is based on the idea of correlation with altitude, and therefore, has been termed as 'eustic view'.

The Modern trend in geomorphological study is adopting quantitative methods of study. Under the impetus of Horton (1932, 1945), the description of drainage basins and 'channel network' were transformed from a purely qualitative and descriptive study to a rigorous quantitative science. He was the first to suggest the quantitative techniques in the analysis of morphometric characteristics of drainage basin. After Horton, Strahler (1952, 1957) made outstanding contribution to the field of quantitative analysis of basin morphometry. The works of Schumm (1956), Chorley (1966), Gregory (1977), Knighton (1984), Petts & Foster (1985) and Schumm *et al.* (1987) are also worth mentioning in this regard. However, several other geomorphologists interested in the study of basin morphology through analytical descriptions of basin dynamics have contributed much towards understanding the complex geomorphic system in the basin context. In this regard, the works of Coates (1958), Gardiner (1975), Gregory (1976, 1977), Dunnne (1980), Abrahams (1984) and Morisawa (1985) may be mentioned.

In the field of fluvial mechanics, Gilbert (1877) attempted to combine the fluvial mechanics with those of the fluvial geomorphology for the first time. But, the study of rivers and river basins from hydrologic, hydraulic and fluvial geomorphic points of view gained due importance since the middle of the 20th century. Dury (1964, 1965), Brush (1961), Schumm (1960), Thornbury (1969), Chorley (1967), Leopold and Maddock (1953), Leopold and Wolman (1957), Gregory (1977), Gregory & Walling (1973) and Hart (1986) emphasized on the study of the form and process of river basin and channels. The works of Langbein and Leopold (1964), Dury (1969), Maddock (1970), Ferguson (1973), Morisawa (1968) and Richards (1973, 1982) relating to channel patterns and channel dynamics are noteworthy. The work of Leopold *et al.* (1964) has been outstanding and pioneer in putting the river basin study in the true perspective of fluvial geomorphology. These works have made outstanding contribution to the fluvial field of fluvial system, river hydrology, hydraulic geometry, channel morphology, spatio-temporal changes in channels and floodplain morphology. Some more elaborative and exhaustive analyses of these fluvio-geomorphic aspects of river systems are those of Bloom (1979), Knighton (1984), Petts & Foster (1985), Gupta (1988, 1997), Postel (1995) and Leopold (1994, 1997).

In India, many works have been recently done on river geomorphology. The works of Rai (1980), Mukhopadhyay (1980, 1982), Sharma (1980), Goswami (1982), Basu (1979), Singh & Upadhyaya (1982), Sharma & Padmaja (1982), Barman (1986) and Bora (1990) have been outstanding. Debnath & Seethapathi (2000) have given geomorphological morphometric analysis of drainage basins a new direction by applying GIS & remote sensing techniques in the study.

The present study area forms the part of Meghalaya plateau, which is a '3rd order' modulation of the earth's surface (Fairbrige, 1968). Land degradation appraisal studies involve geomorphic characterization of the terrain for which different geomorphic attributes have been studied. The attributes of slope, relief, drainage density and drainage frequency are studied for the whole biosphere reserve while seven drainage basins are selected from the study area for a detailed drainage basin study. The drainage basins have been selected in such a way that more than half of the drainage basins should form the part of potential coal mining areas.

SLOPE CHARACTERISTICS

To study the geomorphological features of any area, the first step is the analysis of its slope and relief. The study of slope and relief provides not only the variety of topographical features but also makes available the evidences needed for the interpretation of the complex form of landscape.

Slope is one of the most important aspects of geomorphological study. Slopes are fundamental elements of the landscape (King 1962). In its broadest sense, it is an element of the interface between lithosphere and either hydrosphere or atmosphere (Fairbridge, 1968). The slope elements of an area reflect the evolutionary history of the existing landscape. Thus, study of slopes of an area is of paramount interest.

The slopes, defined as an angular inclination of terrain between the hill tops and valley bottoms, makes with horizontal datum which is generally expressed in degrees. A slope profile may have a variety of forms. Geometrically, slope may consist segments which are concave upward, convex downward, straight or rectilinear and complex (Savigear 1956, Young 1964, and Fairbridge 1968). Young (1963) classified slopes into ten classes based on their inclination, as given below:

0°-2°	Level to very gentle
2°-5°	Gentle
5°-10°	Moderate
10°-18°	Moderately steep

18°-30°	Steep
30°-45°	Very steep
45°-70°	Precipicious
70-°90°	Over hanging

METHODS

There are different methods suggested by many geographers for the study of average slope. The method devised by Wentworth (1930) for 'general and random' determination of average slope over an area from contour map has been adopted for the slope analysis in the present study.

The formula devised by Wentworth is:

Average slope $\tan \theta = N \times CI / 3361$

Where, N = Average Mp x pf crossing in an area per mile

CI = Contour interval in feet

3361 = A constant figure

Zakrzewska (1967) modified Wentworth's above formula as follows:

Slope in degree = $\tan \theta = V \times N / 0.6366 K$

Where, V = Vertical contour interval in metre or in feet

N = Number of contour crossing per square kilometre or per square mile a

K = Constant, 1000 for metric units and 5280 for British units

Thus, to find out the nature of average slope and its characteristics, the area have been divided into one by one kilometre grids and the number of contours crossing per square kilometre are counted. With the above modified Wentworth's formula, average slope per grid is computed. Based on the results, a slope map has been prepared showing five categories of slope (Fig. 3.1).

RESULTS AND DISCUSSION

About 7.4% of the total area (61 sq. km) has an average slope of 2°-8°. The average slope ranging from 9° to 15° covers an area of 263 sq. km. which accounts for 32.1% of the total Biosphere Reserve area. An area of 367 sq. km falls within the slope category of 16° to 22°, which constitutes 44.8% of total area. About 14.2% i.e., 116 sq. km of area comes under 23° to 29° category. The slope range of above 29° category represents only a very small portion of the Biosphere Reserve, i.e., 13 sq. km accounting only 1.6% of the total area.

Table 3.1 Area (sq. km) and proportion (in percentage) of different slope category in the Nokrek Biosphere Reserve

Slope (in°)	Area (sq. km)	% of area to the total area
Above 29	13	1.58
23 – 29	116	14.15
16 – 22	367	44.76
9 – 15	263	32.07
2 –8	61	7.44
Total	**820**	**100**

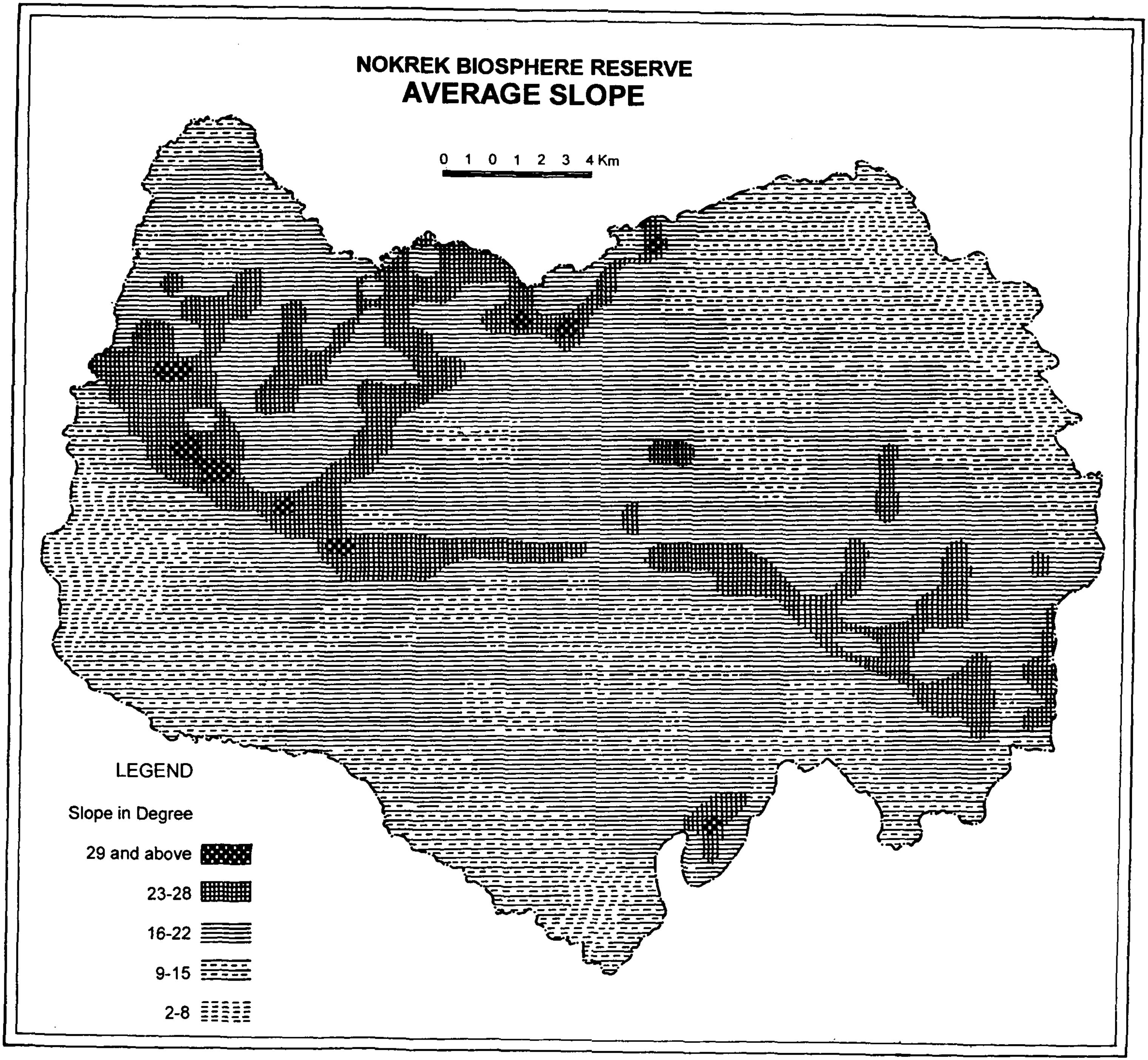

NOKREK BIOSPHERE RESERVE
AVERAGE SLOPE
0 1 0 1 2 3 4 Km
LEGEND
Slope in Degree
29 and above
23-28
16-22
9-15
2-8

Fig. 3.1

The average slope map reveals that the most of the central part and the central northern part of the Biosphere Reserve have the higher average slope (more than 16°). The highest slope i.e., above 29° is confined along the Tura range in the western part and three small pockets in the northern fringe. The area under 23°-28° slope range falls mainly along the central ridge and northwestern part. The slope range of 16°-22° occupies the central part of the Biosphere Reserve. The slope range between 9° and 15° confines to the northeastern, southern and southwestern corner. The average slope of 2°-8° falls in the southwestern and northeastern corner and a small area in the southern part (Table 3.1).

RELIEF CHARACTERISTICS

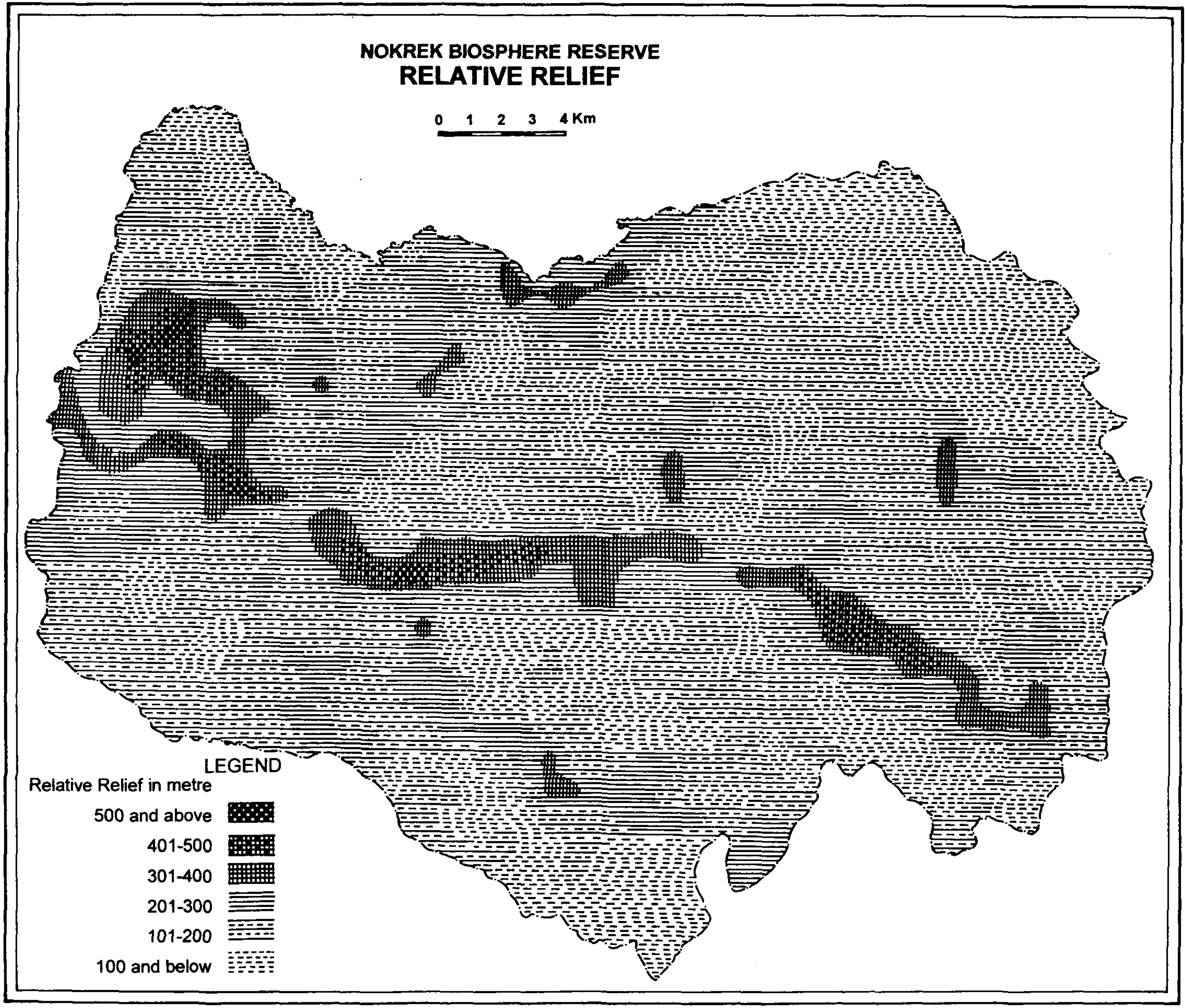
The relief is the relative vertical inequality of differences in elevation of any part of the earth surface. The process of evolution of the relief of an area depends upon geological structure, lithotypes, climatic conditions and the nature of the original topographic surfaces of the area. In this chapter an attempt has been made to analyse the relative relief of Nokrek Biosphere Reserve. The term relative relief denotes the actual variation of height in a unit area with respect to its base level. Relative relief is also known as relative altitude, topographic relief, amplitude of available relief, drainage relief and local relief . Importance of relative relief study in understanding landform has been highlighted by Johnson (1933) and Smith (1935). Relative relief is one of the methods, which may overcome the difficulty of presenting the three dimensional relief characteristics with the help of two dimensional maps. It visualizes the sharpness of relief, which may not be expressed by profiles, altitudinal zones and area-height relation curve.

METHODS

For the purpose of relative relief analysis, the whole area of the biosphere reserve is divided into one by one kilometre grids. The height difference between the highest and lowest elevation within each grid is computed. The value thus obtained gives directly the relative relief per square kilometre. The relative relief has been classified into six categories ranging from below 100m to more than 500 m. The spatial distribution of relative relief for Nokrek Biosphere Reserve is shown in the Fig. 3.2.

RESULTS AND DISCUSSION

It is found that an area of 244.72 sq. km, i.e., 29.8% of the total Biosphere Reserve area has the relative relief of less than 100 m. The relative relief ranges from 101-200 m covers an area of 329.94 sq. km, which accounts for 40.2% of the total area. An area of 159.21 sq. km that account for 19.4% of the total area falls under the relative relief category of 201-300 m. The relative relief range of 301-400 m covers an area of 60.22 sq. km comprising 7.3% of the total area. 22.94 sq. km area i.e., 2.8% of the Biosphere Reserve lies under the relative relief category of 401-500 m. The relative relief range above 500 m characterizes only a small portion of the biosphere reserve i.e., 2.97 sq. km accounting for only 0.4% of the total area (Table 3.2).



NOKREK BIOSPHERE RESERVE
RELATIVE RELIEF
0 1 2 3 4 Km
LEGEND
Relative Relief in metre
500 and above
401-500
301-400
201-300
101-200
100 and below

Fig. 3.2

Table 3.2 Area (sq. km) and proportion (in percentage) of different relative relief category

Relative relief (in metre)	Area (sq. km)	% of area to the total area
Above 500	2.97	0.37
401-500	22.94	2.79
301-400	60.22	7.34
201-300	159.21	19.42
101-200	329.94	40.24
Below 100	244.72	29.84
Total	**820**	**100**

High relative relief is found along the central ridge in western and central part of the Biosphere Reserve. The northeastern and southern part experience low relative relief.

DRAINAGE DENSITY

Drainage density is defined as the ratio of the sum of the channel lengths and basin area (Horton 1945). Thus, it gives a number with the dimension of inverse of length. It is a multifunctional interplay of underlying lithology, topography, climate and tectonics operating in the area. Gray (1960) defined that drainage density is a visual expression of denudation, which is directly related to the amount of vegetation cover. Chorley (1957) said that the drainage density has a significant influence on human activities and landform evolution of a region. The study of the drainage density and its functional relationship with causative factor seem to be inevitable in understanding the existing nature of land configuration and the intensity of processes operating in the area. Theoretically, the value should always come more than 1.

METHODS

The unit area has been used as a simple device developed by Horton (1945) to measure the drainage density. It can be expressed in mathematical formula as stated below:

Du = (EL) u / Au

Where,	Du	=	Drainage density in km per square kilometre
	(EL)	=	Sum of the total length of streams of all orders in km
	Au	=	Total area of drainage basin in square kilometre

To know the variation, drainage density has been computed per square kilometre for the entire Biosphere Reserve. The area has been divided into one by one km grids and drainage density per grid has been computed. The Nokrek Biosphere Reserve presents a drainage density of below 5 km per square kilometre to above 9 km per square kilometre (Fig. 3.3).

RESULTS AND DISCUSSION

The zones with dissected hilly terrain of high altitude, high negative relief and high average slope usually show high drainage density. As Nokrek Biosphere Reserve itself is a dissected hilly terrain with high average slope, the drainage density shown in the area is quite high.

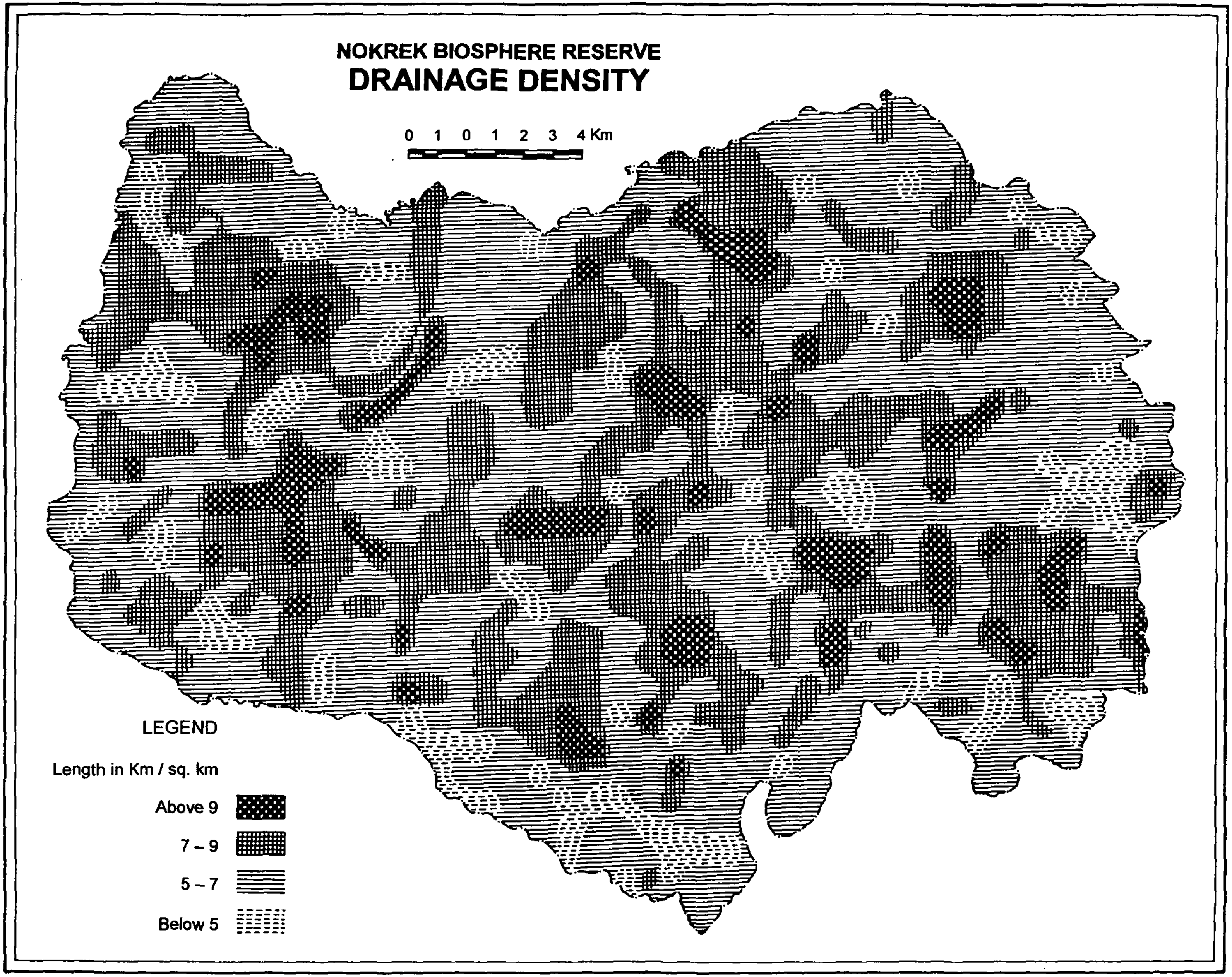

NOKREK BIOSPHERE RESERVE
DRAINAGE DENSITY
0 1 0 1 2 3 4 Km
LEGEND
Length in Km / sq. km
Above 9
7 – 9
5 – 7
Below 5

Fig. 3.3

Table 3.3 Area (sq. km) and proportion (%) of different drainage density category in Nokrek Biosphere Reserve

Drainage Density (km/sq. km)	Area (sq. km)	% of area
Above 9	91	11.09
7 - 9	274	33.42
5 - 7	368	44.88
Below 5	87	10.61
Total	**820**	**100**

Maximum area found in the Biosphere Reserve falls under 5-7 km/sq. km category which covers 44.9% (368 sq. km) of the total area. The 7-9 km/sq. km category covers an area of 274 sq. km (33.4%) and the drainage density above 9 km/sq. km category covers 91 sq. km (11.1%). An area of 87 sq. km (10.6%) comes under below 5 km/sq. km category (Table 3.3).

DRAINAGE FREQUENCY

Drainage frequency is defined as the number of streams per square kilometre. It determines relative closeness of streams in the basin.

METHODS

Drainage frequency is defined by the following relation:

Fu = (EL)u / Au

Where, Fu = Drainage frequency in number per square kilometre

EL = Sum of the total number of streams of all orders

Au = Total area of drainage basin in square kilometre

The expression Fu gives the average frequency of streams in the area. But, to know the variation of drainage frequency, the frequencies have been computed per square kilometre. The whole area of the biosphere reserve is divided into one by one kilometre grid and the number of channel segments in each grid is recorded. The value obtained gives directly the frequency per square kilometre.

RESULTS AND DISCUSSION

From the drainage frequency map (Fig. 3.4) it can be seen that drainage frequency is high in the entire Biosphere Reserve, which ranges from below 5 to above 13 streams per sq. km. Like drainage density, drainage frequency also depends on the lithology of the area.

Table 3.4 Area and proportion of different drainage frequency category

Drainage Frequency (No. of stream/sq. km)	Area (sq. Km)	% of area
Above 13	58	7.07
11-13	227	27.68
8-10	335	40.86
5 - 7	188	22.93
Below 5	12	1.46
Total	**820**	**100**

Maximum area of 335 sq. km (40.9%) falls under the category of 8-10 stream segments per sq. km, followed by 11-13 stream segments per sq. km category (227 sq. km). 188 sq. km (22.9%), 58 sq. km (7.1%) and 12 sq. km (1.5%) fall under the

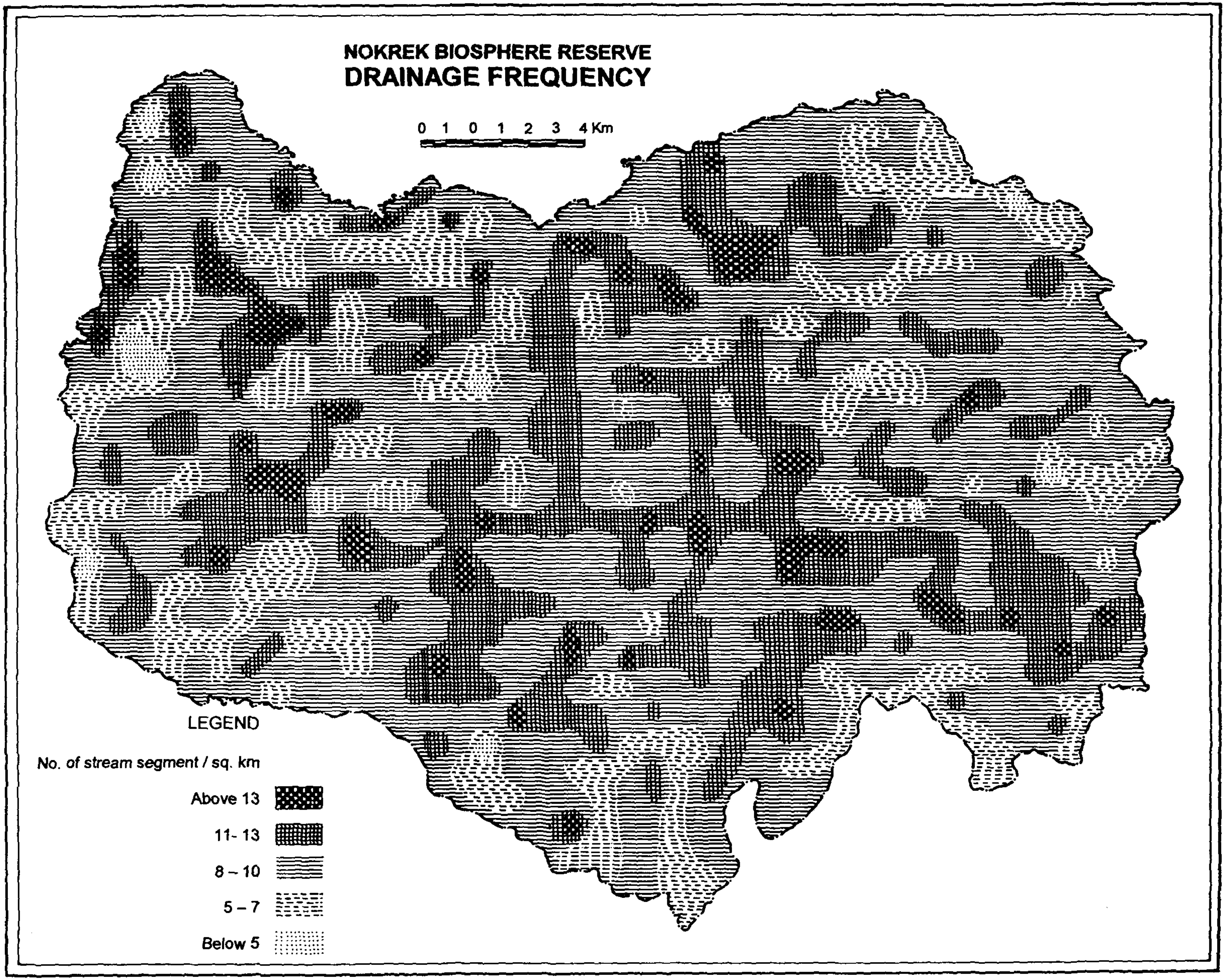

NOKREK BIOSPHERE RESERVE
DRAINAGE FREQUENCY
0 1 0 1 2 3 4 Km
LEGEND
No. of stream segment / sq. km
Above 13
11- 13
8 – 10
5 – 7
Below 5

Fig. 3.4

categories of 5-7, above 13 and below 5 stream segments per sq. km respectively (Table 3.4).

QUANTITAVE ANALYSIS OF SEVEN SELECTED DRAINAGE BASINS OF NOKREK BIOSPHERE RESERVE

With the pioneer work of Horton (1945), the description of drainage basins and channel network was transformed from a purely qualitative and deductive study to rigorous quantitative science capable of providing hydrologists with numerical data of practical value. Horton's work was further elaborated by Strahler (1950, 1952, 1956 and 1958), Melton (1958), Morisawa (1958), and Schumm (1956). In the present study seven drainage basins viz., Dareng, Rongrim, Rongon, Rongma, Rongme, Noreng and Mandal within the Nokrek Biosphere Reserve were selected for detailed drainage basin study (Fig 3.5).

ORDER OF BASINS

Different stream segments have definite positions in the domain of a drainage basin. They have their distinct morphometric characteristics, which necessitate the determination of their relative positions on hierarchical scale of stream segments. This has required the assignment of a level of relative order of magnitude to each segment in a stream segment-hierarchy, determined by sequential arrangement of tributaries with respect to the main trunk (Gregory 1977). Thus, stream order is defined as a

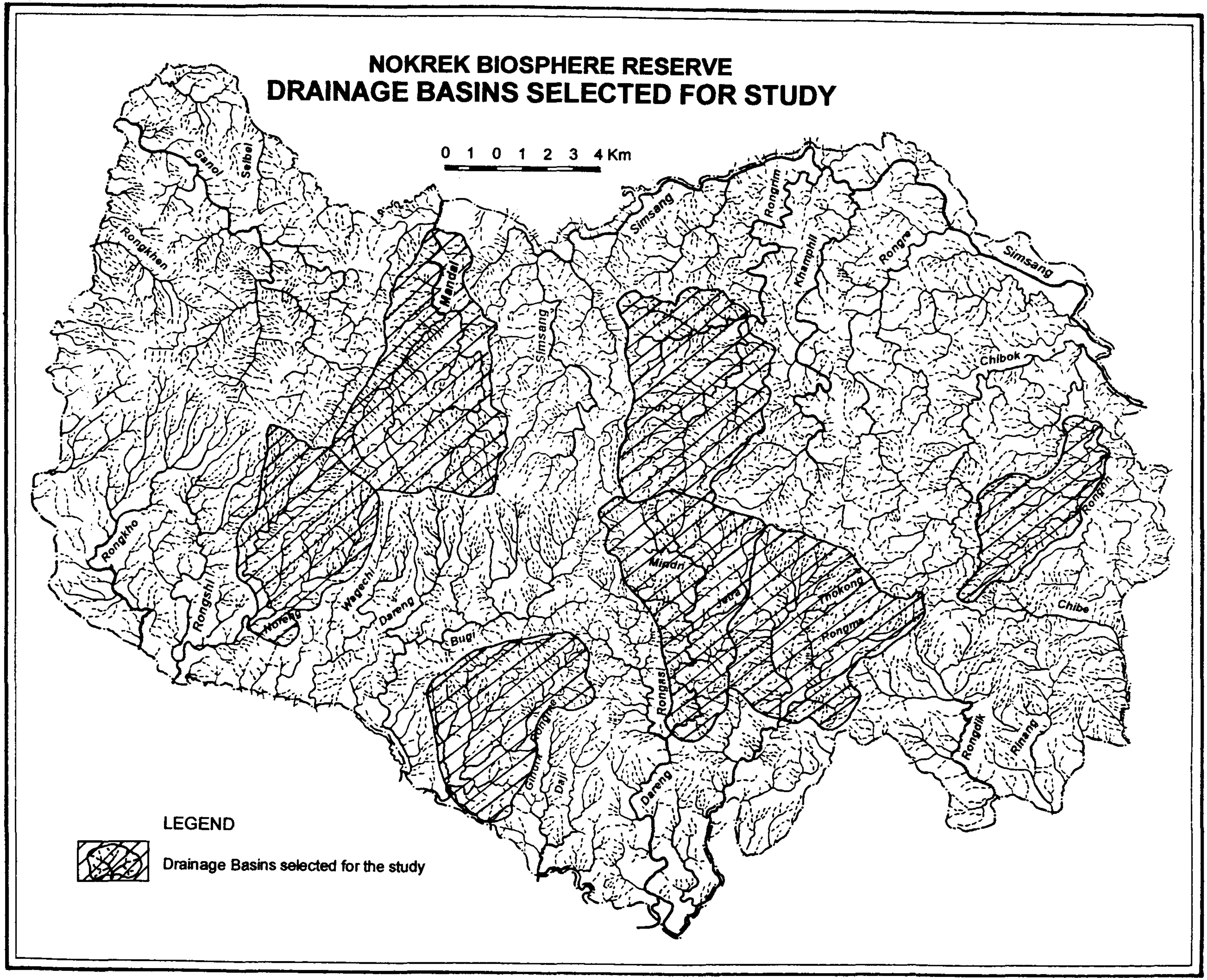

NOKREK BIOSPHERE RESERVE
DRAINAGE BASINS SELECTED FOR STUDY
0 1 0 1 2 3 4 Km
Ganol
Seibel
Rongkhen
Mandal
Simsang
Simsang
Rongrim
Khamphil
Rongre
Simsang
Chibok
Rongkho
Rongshi
Noreng
Wagechi
Dareng
Bugi
Mindri
Jetra
Thokong
Rongma
Chibe
Rongdal
Rongasi
Rongdik
Rinang
Dareng
Daji
Rongme
LEGEND
Drainage Basins selected for the study

Fig. 3.5

measure of the position of a stream in the hierarchy of tributaries (Leopold *et al.* 1964).

Playfair was the first geomorphologist who recognised the unitary features of the geometry and process presented by the erosional drainage basin. Later on Davis (1899) described the drainage basin as a leaf and the streams as the veins of that leaf. Horton described the stream ordering as measures of the position of a stream in the hierarchy of tributaries. Shreve (1966, 1967) presented his scheme of 'stream link magnitude' based on the 'interval scale' of stream ordering wherein each exterior link or 1st order segment is given magnitude of 1, and each successive link a magnitude equal to the sum of all the 1st order segments, which ultimately feed it. Scheidegger (1965) proposed his scheme of consistent law of stream ordering based on ratio-scale measures and presented for postulates defining an algebra of combination of stream segments which is cumulative as well as associative.

METHODS

Strahler modified the Horton's ordering scheme and proposed a simple scheme out of it. According to Strahler each finger-tip channel is designated as a segment of the first order. At the junction of any two first order segments, a channel of second order is produced and extends down to the point whereupon a segment of third order results and so fourth. In the present study Strahler's method of drainage ordering is followed. All the selected seven drainage basins have been ordered according to Strahler's scheme of ordinal scale of stream ordering and stream segments of different orders are represented in Fig. 3.6a, Fig. 3.6b, Fig. 3.6c, Fig. 3.6d, Fig. 3.6e, Fig. 3.6f and Fig. 3.6g. To find out the relationship between the orders and number of stream segments the equation for negative exponential function model is applied as suggested by Strahler. The regression co-efficient (b) for each drainage basin have been calculated by using the following formula:

$Y = ae^{-bx}$

$Y = \log_e a - bX$

where, Y = number of stream segments

X = Stream order (u)

a = Constant

b = regression co-efficient

Stream orders have been plotted against the number of streams on a semi-logarithmic graph paper to get the relationship.

RESULTS AND DISCUSSION

Out of the seven drainage basins Dareng, Rongrim, Rongma, Rongme, Noreng and Mandal are 5th order basins while Rongon is 4th order basin. Mandal basin tops the list having the largest number of stream segments (297), whereas, the bottom position is occupied by Rongon basin with only 95 stream segments (Table 3.5).

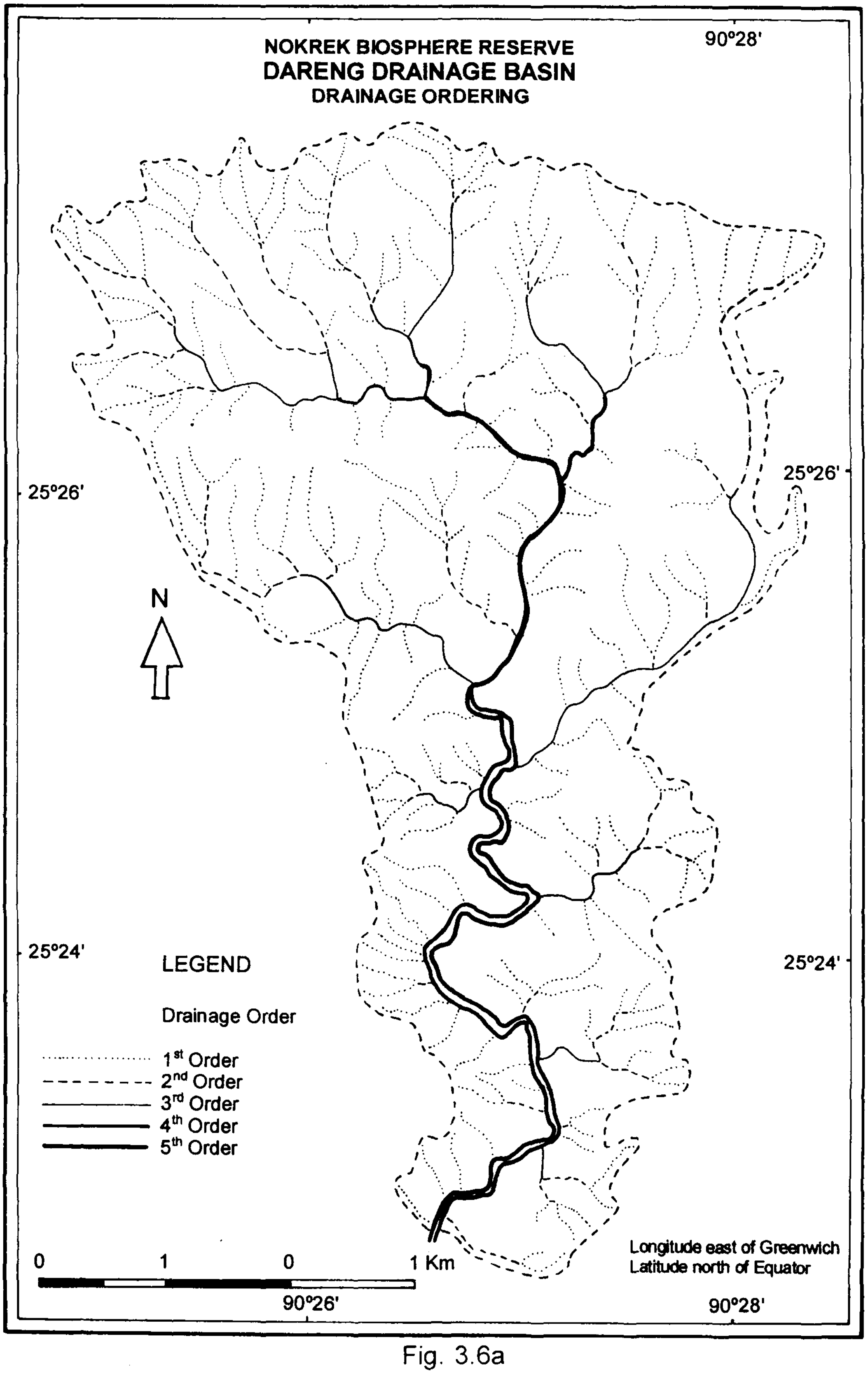
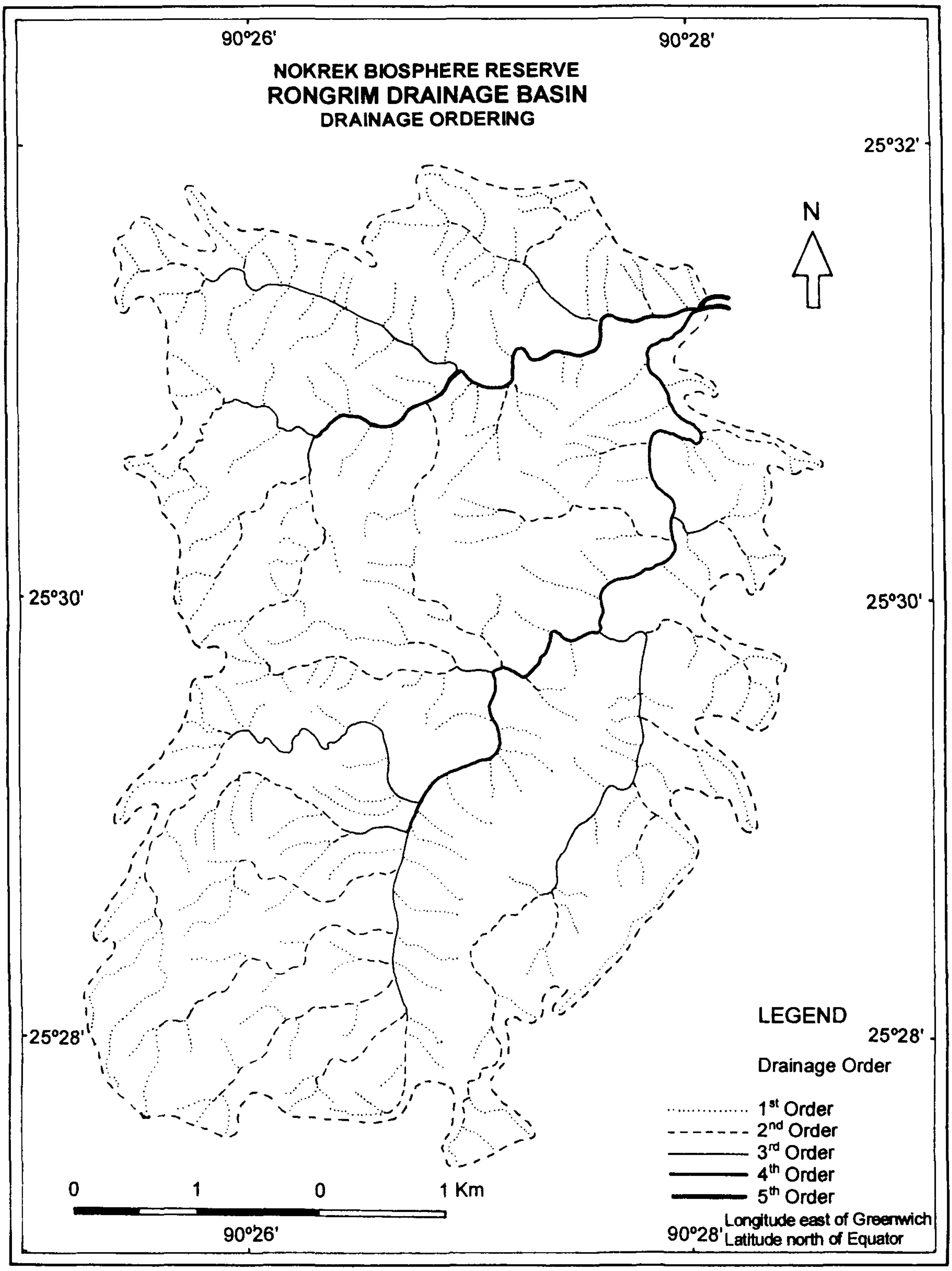
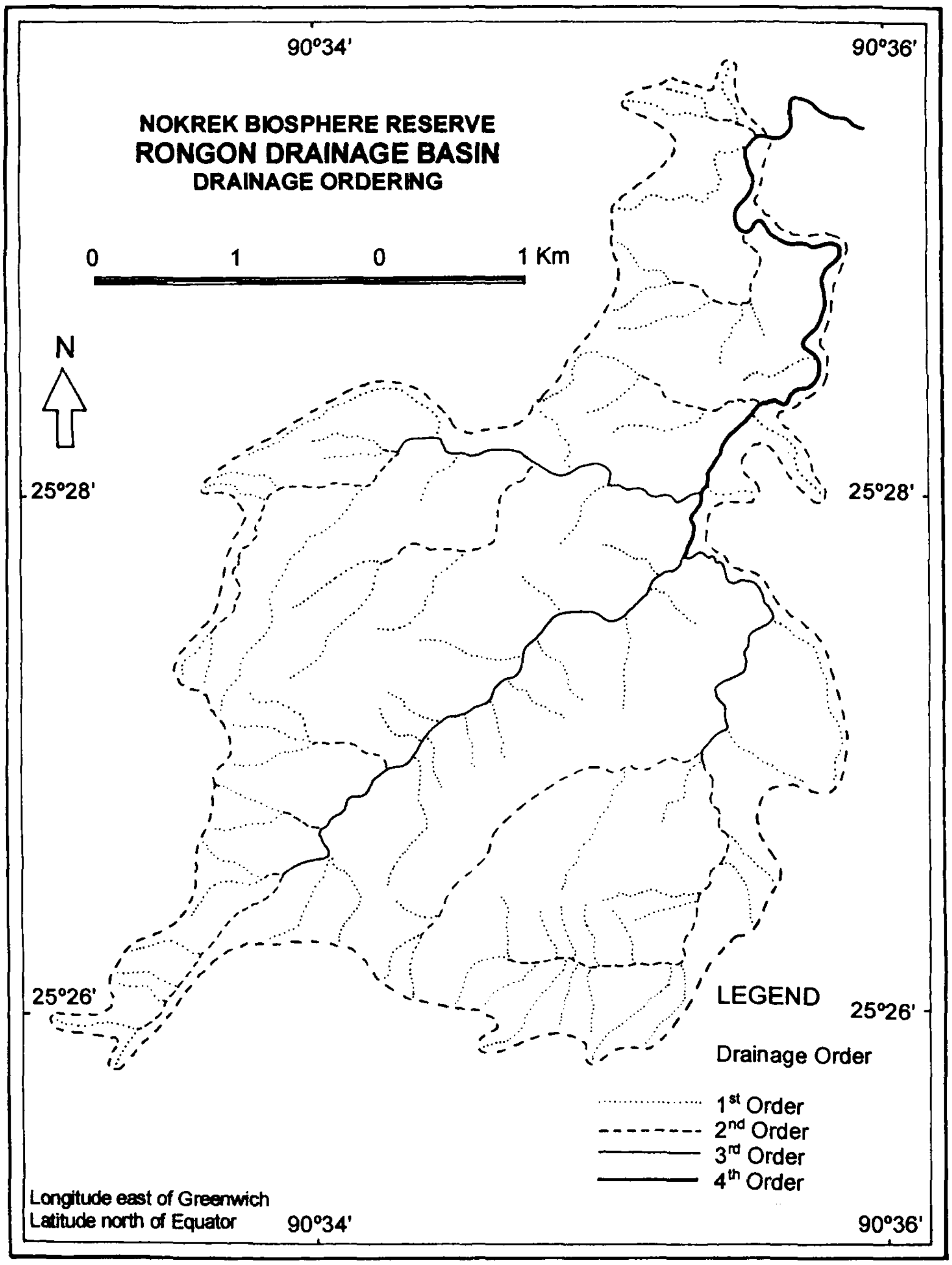

NOKREK BIOSPHERE RESERVE
DARENG DRAINAGE BASIN
DRAINAGE ORDERING
90°28'
25°26'
25°26'
N
25°24'
25°24'
LEGEND
Drainage Order
1st Order
2nd Order
3rd Order
4th Order
5th Order
0
1
0
1 Km
Longitude east of Greenwich
Latitude north of Equator
90°26'
90°28'

Fig. 3.6a



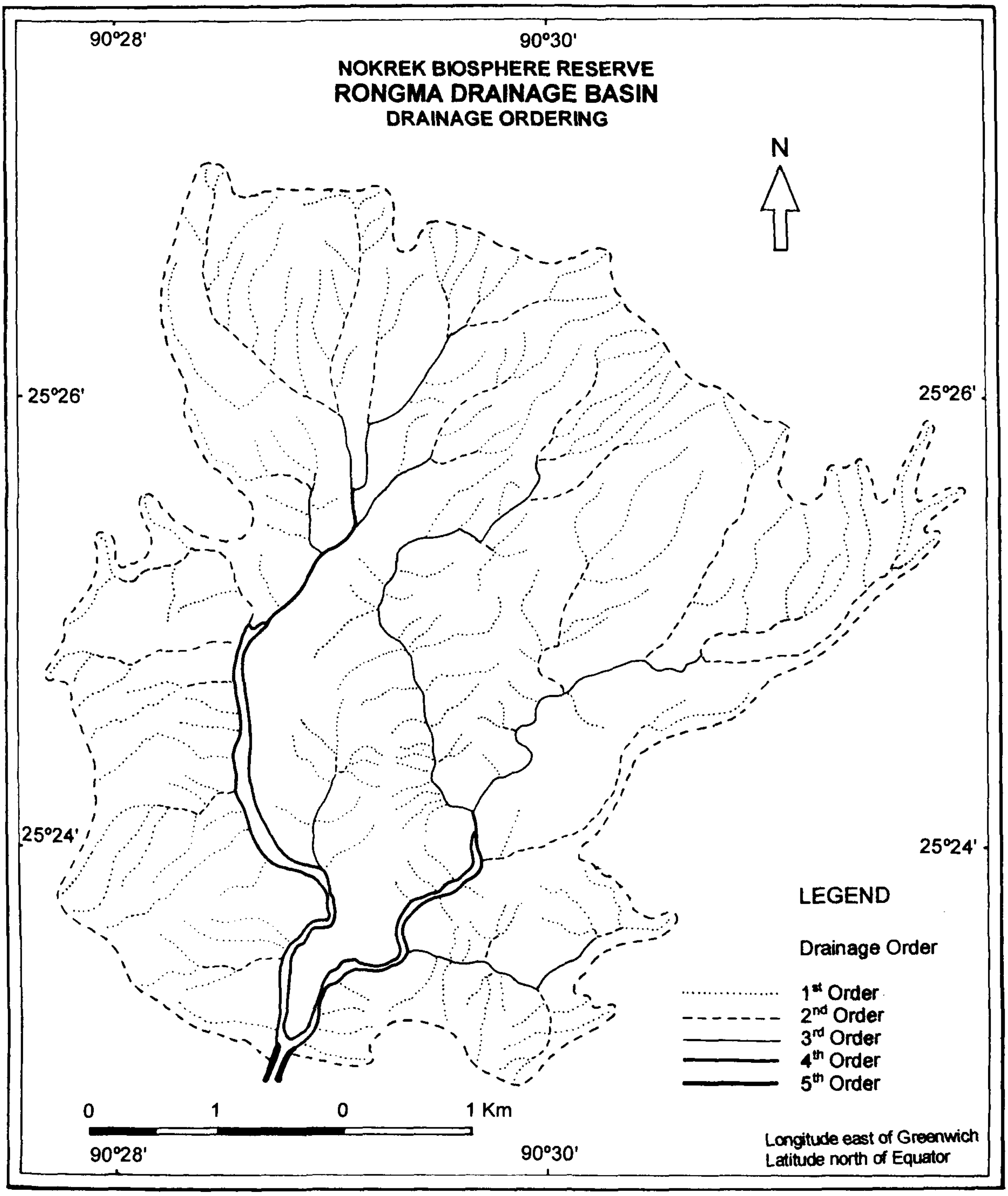
90°26'
90°28'
NOKREK BIOSPHERE RESERVE
RONGRIM DRAINAGE BASIN
DRAINAGE ORDERING
25°32'
N
25°30'
25°30'
LEGEND
25°28'
25°28'
Drainage Order
1st Order
2nd Order
3rd Order
4th Order
5th Order
0
1
0
1 Km
90°26'
90°28'
Longitude east of Greenwich
Latitude north of Equator

Fig. 3.6b



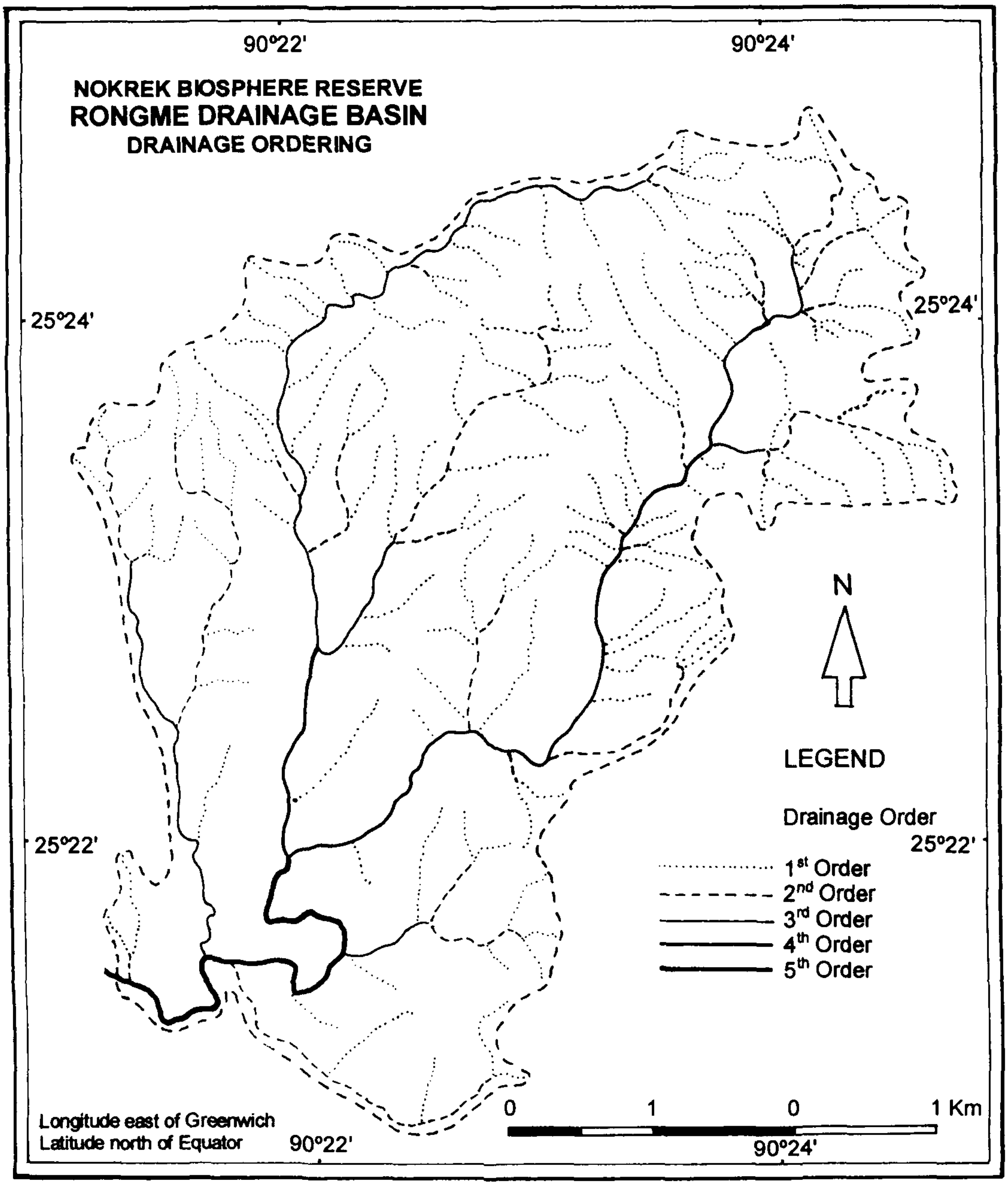
90°34'
90°36'
NOKREK BIOSPHERE RESERVE
RONGON DRAINAGE BASIN
DRAINAGE ORDERING
0
1
0
1 Km
N
25°28'
25°28'
25°26'
25°26'
LEGEND
Drainage Order
1st Order
2nd Order
3rd Order
4th Order
Longitude east of Greenwich
Latitude north of Equator
90°34'
90°36'

Fig. 3.6c



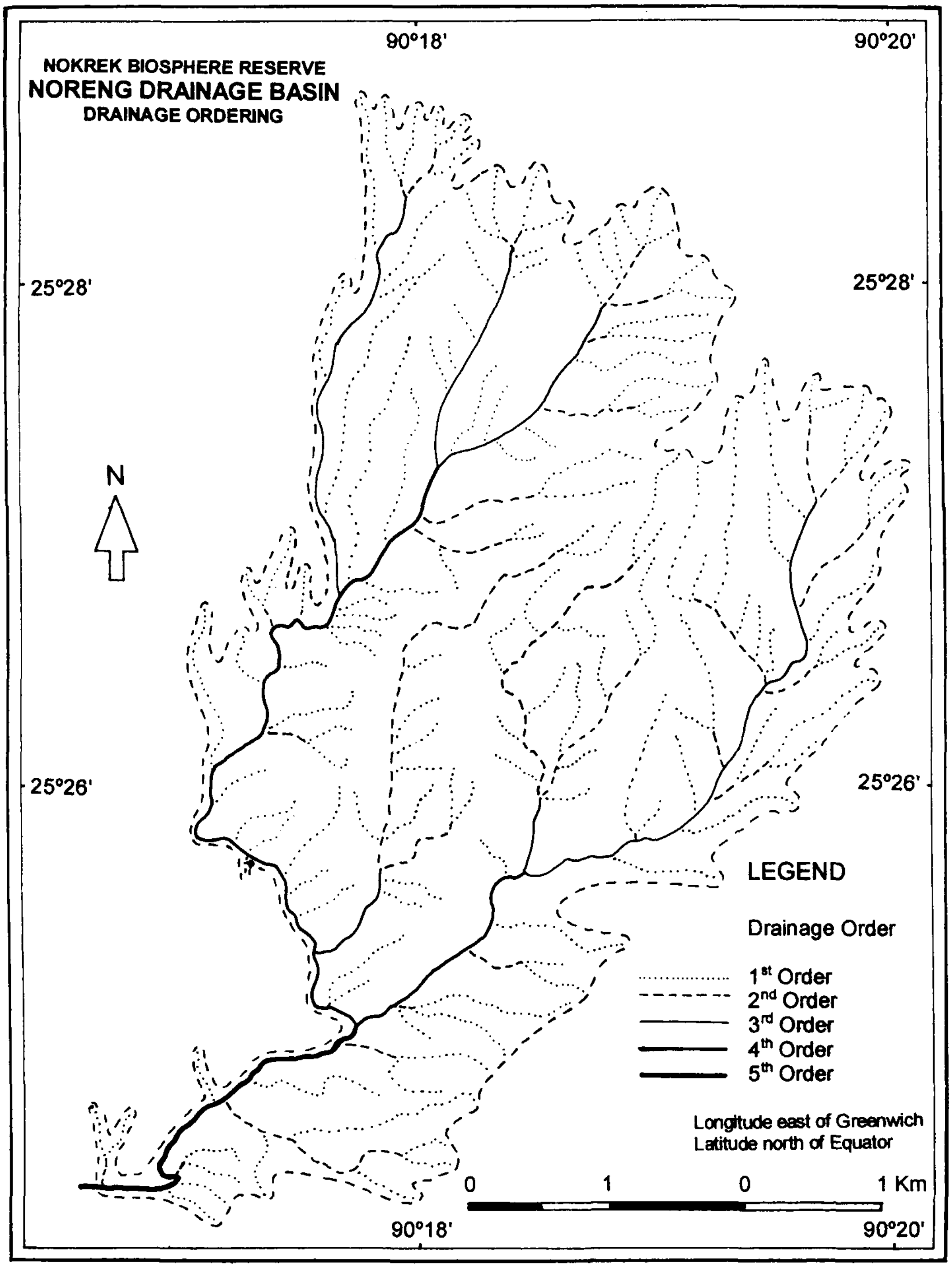
90°28'
90°30'
NOKREK BIOSPHERE RESERVE
RONGMA DRAINAGE BASIN
DRAINAGE ORDERING
N
25°26'
25°26'
25°24'
25°24'
LEGEND
Drainage Order
1st Order
2nd Order
3rd Order
4th Order
5th Order
0
1
0
1 Km
90°28'
90°30'
Longitude east of Greenwich
Latitude north of Equator

Fig. 3.6d



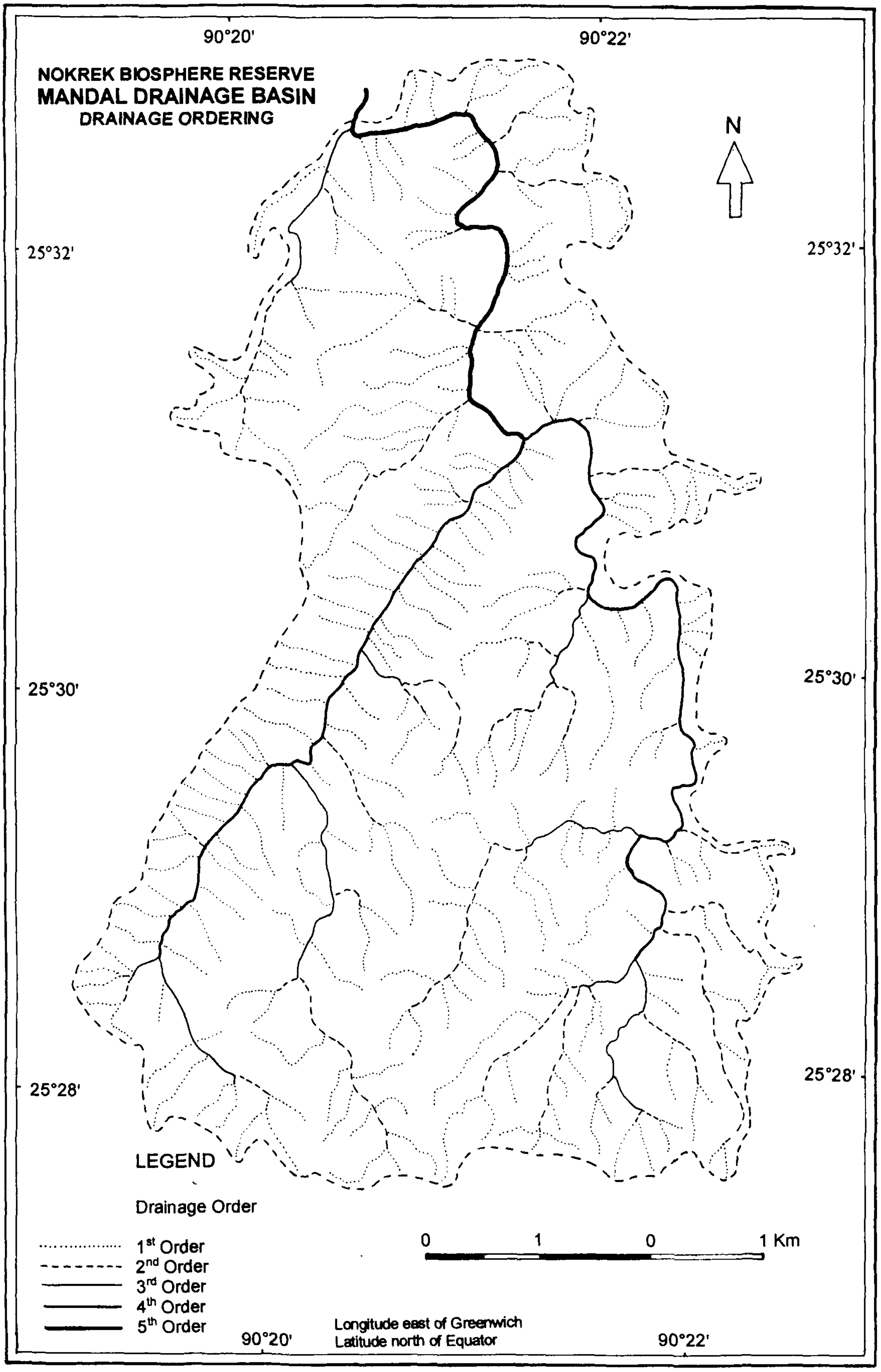
90°22'
90°24'
NOKREK BIOSPHERE RESERVE
RONGME DRAINAGE BASIN
DRAINAGE ORDERING
25°24'
25°24'
N
LEGEND
Drainage Order
25°22'
25°22'
1st Order
2nd Order
3rd Order
4th Order
5th Order
0
1
0
1 Km
Longitude east of Greenwich
Latitude north of Equator
90°22'
90°24'

Fig. 3.6e



NOKREK BIOSPHERE RESERVE
NORENG DRAINAGE BASIN
DRAINAGE ORDERING
90°18'
90°20'
25°28'
25°28'
25°26'
25°26'
N
LEGEND
Drainage Order
1st Order
2nd Order
3rd Order
4th Order
5th Order
Longitude east of Greenwich
Latitude north of Equator
0
1
0
1 Km
90°18'
90°20'

Fig. 3.6f



90°20'
90°22'
NOKREK BIOSPHERE RESERVE
MANDAL DRAINAGE BASIN
DRAINAGE ORDERING
N
25°32'
25°32'
25°30'
25°30'
25°28'
25°28'
LEGEND
Drainage Order
1st Order
2nd Order
3rd Order
4th Order
5th Order
0
1
0
1 Km
90°20'
Longitude east of Greenwich
Latitude north of Equator
90°22'

Fig. 3.6g

Table 3.5 Number of stream segments in different drainage basins

Sl. No.	Basin	Area (in sq. km)	Order (u)					Total number of stream segment
			Nu_1	Nu_2	Nu_3	Nu_4	Nu_5	
1.	Dareng	30.55	198	38	12	3	1	252
2.	Rongrim	34.44	218	36	10	2	1	267
3.	Rongon	19.89	79	12	3	1	-	95
4.	Rongma	30.43	170	33	8	2	1	214
5.	Rongme	28.05	133	29	6	2	1	171
6.	Noreng	28.73	142	29	6	2	1	180
7.	Mandal	42.75	241	44	9	2	1	297

It is apparent that there is a direct relationship between the area of the basin and number of stream segments in all the seven drainage basins.

Some definite relationship exits between the orders of the basins and the number of stream segments. Horton and Strahler have propounded an inverse geometric series of the number of stream segments and orders and have staked that the number of stream segments of successively lower orders in a given basin tends to form a geometric series beginning with the simple segment of the highest order and increasing according to constant bifurcation ratio. In the present study, the relationship between stream orders and numbers have been calculated using the equation of negative exponential function model as suggested by Strahler. The regression co-efficient for each drainage basin have been represented in Fig. 3.7. From the figure it is apparent that a negative relationship exists between stream order and number of streams for all the drainage basins. Thus the relationship follows the law of stream order (Horton 1945) i.e., as stream order increases the number of stream decreases.

STREAM ORDER AND NUMBER RELATIONSHIP

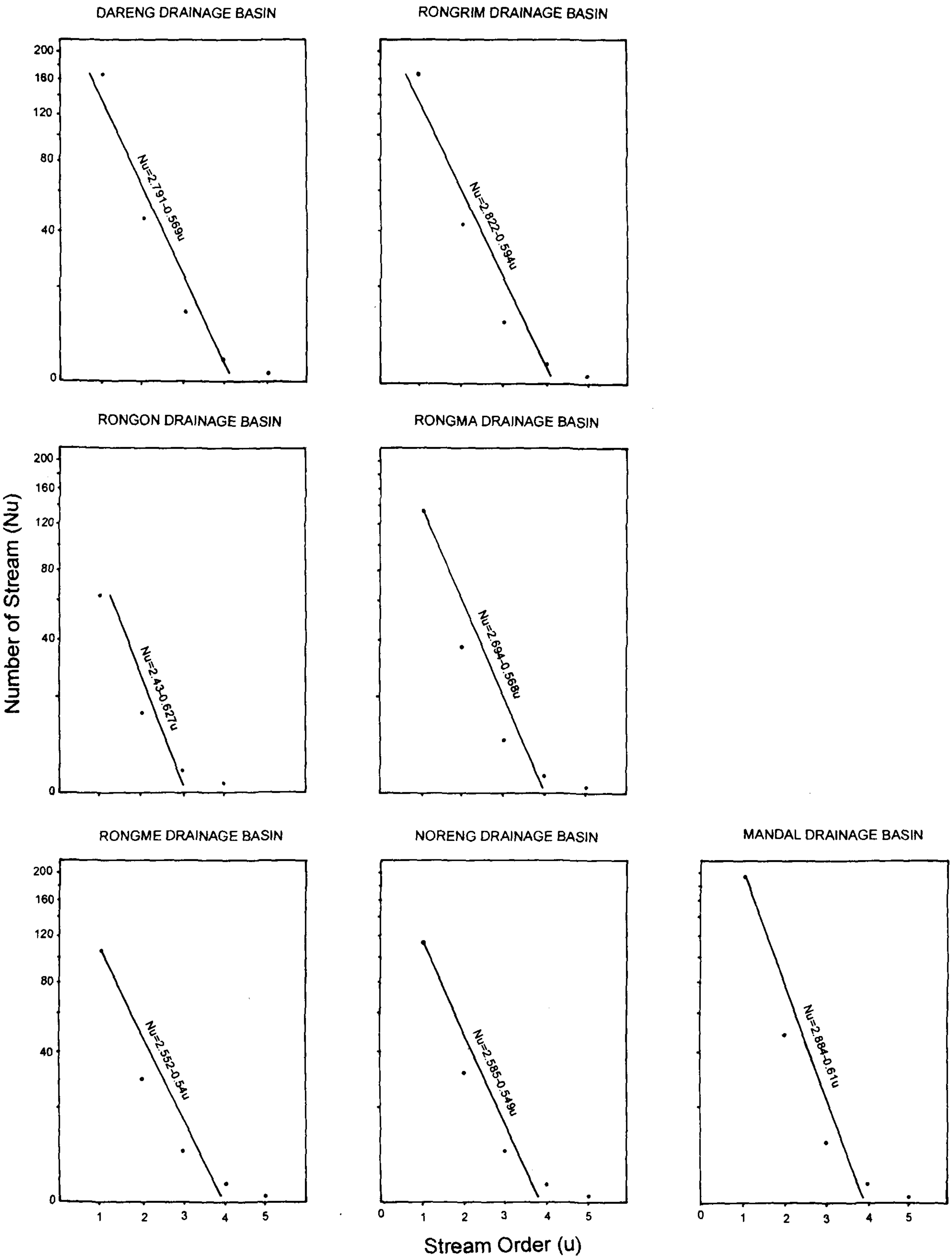


Fig. 3.7

STREAM LENGTH

The stream length is a significant morphometric parameter of the drainage basin as it helps in the calculation of drainage density.

METHODS

The stream lengths of different orders of all the selected seven drainage basins have been measured in kilometre and presented in Table 3.6. The mean lengths (Lu) of each order have been calculated and arranged in Table 3.7. To find out the relationship between cumulative mean lengths (Table 3.8) and stream orders for all the seven drainage basins the regression lines have been drawn on the basis of the following regression equation:

$$Y = ae^{bx}$$

$$\log_e Y = \log a + bX$$

where, 'Y' stands for cumulative mean length

'X' denotes order (u)

'b' is the co-efficient of regression and,

'a' is the constant

RESULTS AND DISCUSSION

Generally, 1st order stream segments have shortest mean length but the mean length increases with the increase in order. All the segments follow this postulation except some departures in certain orders of a few streams viz., Dareng, Rongrim, Rongma and Mandal river basins exhibit departure in certain orders. Dareng river basin shows mean length of 4th order less than the 3rd order, while for other three river basins represent less mean lengths of 5th order segments.

Table 3.6 Stream length (Lu) of stream segments for different drainage basins

Sl. No.	Basin	Stream Length (in km)				
		L_1	L_2	L_3	L_4	L_5
1.	Dareng	165.45	53.84	27.03	5.4	10.07
2.	Rongrim	147.15	43.20	16.00	10.85	0.25
3.	Rongon	93.64	25.00	9.09	5.35	-
4.	Rongma	176.37	60.04	17.99	7.84	0.27
5.	Rongme	126.22	42.23	15.69	7.57	3.84
6.	Noreng	148.70	48.26	20.14	11.04	5.60
7.	Mandal	168.6	57.2	15.75	12.95	5.25

Table 3.7 Mean stream length (Lu) of stream segments for different drainage basins

Sl. No.	Basin	Stream Length (in km)				
		L_1	L_2	L_3	L_4	L_5
1.	Dareng	0.84	1.42	2.25	1.8	10.07
2.	Rongrim	0.67	1.2	1.6	5.43	0.25
3.	Rongon	1.18	2.08	3.03	5.35	-
4.	Rongma	1.07	1.82	2.25	3.92	0.27
5.	Rongme	0.95	1.46	2.62	3.78	3.84
6.	Noreng	1.05	1.66	3.36	5.52	5.60
7.	Mandal	0.70	1.3	1.75	6.47	5.25

Table 3.8 Cumulative mean lengths (Lu) of stream segments for different drainage basins

Sl. No.	Basin	Stream Length (in km)				
		L_1	L_2	L_3	L_4	L_5
1.	Dareng	0.84	2.26	4.51	6.31	16.38
2.	Rongrim	0.67	1.87	3.47	8.9	9.15
3.	Rongon	1.18	3.26	6.29	11.64	-
4.	Rongma	1.07	2.89	5.14	9.06	9.33
5.	Rongme	0.95	2.41	5.03	8.81	12.65
6.	Noreng	1.05	2.17	6.07	11.59	17.19
7.	Mandal	0.70	2.00	3.75	10.22	15.47

Horton (1945) has postulated a law of positive geometric progression between cumulative mean lengths and stream orders wherein the cumulative mean lengths of stream segments increase geometrically with successive increase in stream orders with constant length ratio. The model of law of stream length is called positive exponential function model. Fig. 3.8 shows that there is a strong positive relationship between cumulative mean length of stream segment and stream order for all the seven basins.

BIFURCATION RATIO

Bifurcation ratio is related to the branching pattern of the drainage network. It is defined as the ratio of the number of streams of a given order and the next higher order.

Horton (1945) recognised bifurcation ratio as one of the most important characteristics of the drainage basin. The bifurcation ratio will not be precisely the same from one order to the next but will tend to be a constant throughout the series. This observation is the basis of Horton's 'Law of stream numbers' which states that the number of stream segments of each order form an inverse geometric sequence with other number.

Bifurcation ratio has been studied by a number of eminent geomophologists (Schumm 1956, Chorley 1957, Strahler 1957, Strahler 1964, Milton 1965, Horton 1945) in different regions having varied geomorphological formations and relief characteristics. These studies clearly indicated marked regional variation in bifurcation ratios due to differences in climatic conditions, geological and structural characteristics of rocks,

STREAM ORDER AND AVERAGE STREAM LENGTH RELATIONSHIP

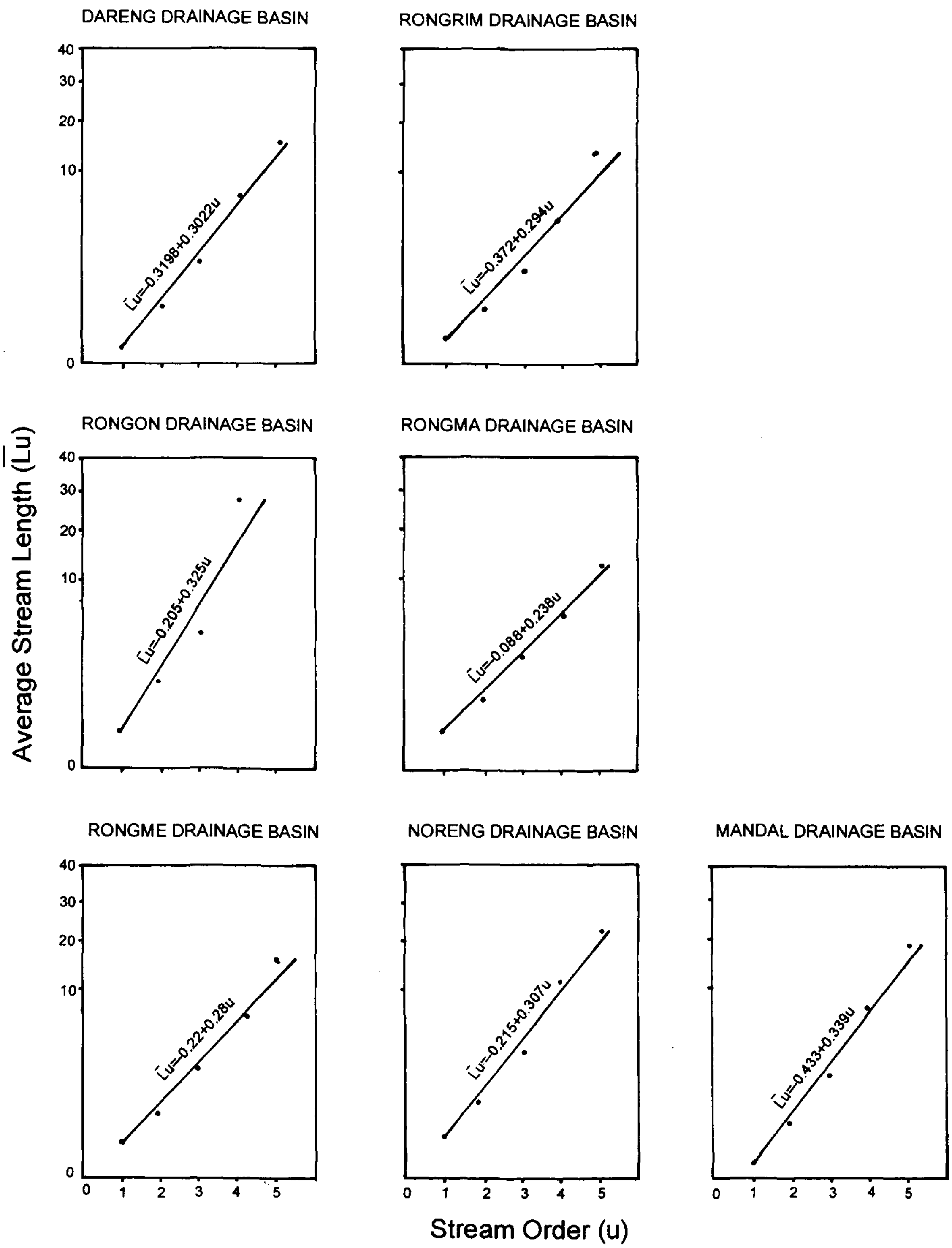


Fig. 3.8

relief features, and stage of basin development. Horton (1945) has postulated that bifurcation ratio varies from 2.00 in the flat or rolling basins to 3.00 to 4.00 in the mountainous highly dissected basins.

METHODS

Bifurcation ratio is expressed in terms of the following equation:

$R_b = Nu / Nu + 1$

Where, R_b = Bifurcation ratio

Nu = Number of streams of a given order

Nu + 1 = Number of streams of the next higher order

RESULT AND DISCUSSION

The bifurcation ratios of all the seven basins range between 3.00 and 5.00 (Table 3.9). The average bifurcation ratios (R_b) of all the basins confirm the observation of Horton.

Table 3.9 Bifurcation Ratios for different drainage basins

Sl. No.	Basin	N_{u1}/N_{u2}	N_{u2}/N_{u3}	N_{u3}/N_{u4}	N_{u4}/N_{u5}	R_b
1.	Dareng	5.21	3.17	4.00	3.00	3.85
2.	Rongrim	6.06	3.60	5.00	2.00	4.16
3.	Rongon	6.58	4.00	3.00	-	4.53
4.	Rongma	5.15	4.13	4.00	2.00	3.82
5.	Rongme	4.58	4.83	3.00	2.00	3.60
6.	Noreng	4.89	4.83	3.00	2.00	3.68
7.	Mandal	5.48	4.89	4.5	2.00	4.22

SINUOSITY INDEX

The sinuosity indices of streams have been widely used in understanding the geomorphological characters of a region. The usual approach is to derive the index as a ratio between the channel length (CL) of a reach and its valley length (VL). This restricts the analysis to speaking of hydraulic action as the sole performer of sinuosity limited to mature and old streams. As a result, the young streams whose valleys and channels are coincident, give the sinuosity index as unity thereby suggesting complete topographic control of the streams, which is as obvious flow in interpreting topography in relation to the character of drainage, because some amount of hydraulic action, also exists in most of the youthful streams owing to structural controls, rejuvenation and greater amount of precipitation in the catchment area. Another important drawback in this type of index is that this suggests all the streams with value of unity are not sinuous, (i.e., straight) which is not true because all streams have some amount of departure from a straight line course in what-so-ever stage and reach they are (Davis 1913).

Smart and Surken (1967) measured the unsystematic deviations from straight line paths and curves of considerable symmetry, whose dimensions were proportional to the size of the channel and they recognised two types of shapes of a drainage line viz., (i) Wandering and (ii) Meandering. The wandering path may be calculated by relating the length of the observed path (OL) to the length of the expected path (EL). Schumm (1956) after measuring the deviations from a straight line path presented five categories of channel sinuosity viz., (i) Straight (OL/EL=1.00), (ii) Transitional, (iii) regular, (iv) Irregular, and (v) Tortous (OL/EL>2.00).

Muller (1968) modified the difficulties found in Schumm's method and presented his model of sinuosity index. This model explains the effect of hydraulic and topographic controls on the courses of the streams. According to him the river courses are classified into three categories on the basis of the standard sinuosity index viz., (i) Straight course (SSI=1.00), (ii) Sinuous course (SSI=1.00-1.50) and (iii) Meandering course (SSI=>1.50).

METHODS

In the present study Muller's model of sinuosity indices have been followed for calculating sinuosity indices for all the selected seven drainage basins of the Nokrek Biosphere Reserve. Muller measured the length of the channel (CL), the length of the valley between the base of the valley walls (VL) and the shortest distance between the source and mouth of the river (Air L) and presented his model in the form of the following equations:

(i) CI = CL/Air L

where, CI = Channel Index

(ii) VI = VL/Air L

where, VI = Valley Index

(iii) HSI = % equivalent of CI-VI/CI-1

where, HSI = Hydraulic Sinuosity Index

(iv) TSI = % equivalent of VI-1/CI-1

where, TSI = Topographic Sinuosity Index

(v) SSI = CL/VL

where, SSI = Standard Sinuosity Index

RESULT AND DISCUSSION

The hydraulic and topographic sinuosity indices (HSI and TSI) are the valuable morphometric tools, which help in determining the controlling factors of sinuosity.

Table 3.10 Sinuosity indices for different drainage basins

Sl. No.	Basin	CI	VI	HSI	TSI	SSI
1.	Dareng	1.77	1.08	0.89	0.10	1.63
2.	Rongrim	1.54	1.04	0.93	0.07	1.48
3.	Rongon	1.41	1.03	0.93	0.07	1.37
4.	Rongma	1.30	1.13	0.57	0.43	1.15
5.	Rongme	1.95	1.08	0.92	0.08	1.79
6.	Noreng	1.59	1.01	0.98	0.02	1.58
7.	Mandal	1.51	1.06	0.88	0.12	1.42

All the basins studied show low percentage of TSI and high percentage of HSI, which indicate all the basins are in their mature stage of basin development. Dareng, Rongme and Noreng drainage basins indicate meandering course while the remaining four basins fall under sinuous course (Table 3.10).

DRAINAGE DENSITY

Drainage density is one of the linear properties of drainage basin. It is defined as the ratio of the sum of the channel lengths and basin area (Horton 1945). It gives a number with the dimension of inverse of length. Strahler (1960) postulated that a region underlained by massive, hard sandstone beds under heavy forest cover shows the drainage density averaging 1.8 to 2.5 km/sq. km. Low drainage density may also be described as having coarse texture, since the individual elements of the topography are very large, or gross. The region with medium drainage density averaging 7.5 to 10 km/sq. km is underlained by thin bedded sandstones and thick shales, relatively easily eroded, but developed under a heavy deciduous forest cover. This area may be described as medium texture. The region with drainage density ranging from 18.5 to 25 km/sq. km experiences fine texture, developed in easily eroded, weak sedimentary strata where vegetation is sparse. Much higher value of drainage density, ranging from 125 to more than 300 km/sq. km would be described as ultrafine texture. Drainage density is controlled by lithology, relief development, relative ease of infiltration of precipitation into the ground surface and downward to the water table, and presence or absence of vegetation cover. Chorley (1957) compared three lithologically similar areas from Britain and confined a close relationship between drainage density and rainfall. Doornkamp and King (1971) analyzed more than one hundred third order basins from Uganda and found drainage densities ranged from 0.62 to 6.25 km/sq. km.

METHOD

For the present study, the drainage density for the selected seven drainage basins have been calculated by using the formula as suggested by Horton (1945):

$Du = (EL)\ u / Au$

Where, Du = Drainage density in km per square kilometre

(EL) = Sum of the total lengths of streams of all orders in kilometre

Au = Total area of drainage basin in square kilometre

However, to know the variation of drainage density in different drainage basins, drainage density has been computed in all the seven drainage basins and thematic maps have been prepared (Fig. 3.9a and Fig. 3.9b). The area of all the basins has been divided into one by one kilometre grids and drainage density per grid has been computed. The drainage density has been classed from below 5 to above 9 km/sq. km.

RESULTS AND DISCUSSION

The drainage density of the seven drainage basins ranges between 6.07 and 8.63 km/sq. km (Table 3.11). The result of drainage densities for all the drainage basins indicates that the area may be considered as medium texture. The area is underlined by thin bedded sandstones and thick shales, relatively easily eroded, but developed under a heavy deciduous forest cover. Dareng drainage basin shows the maximum value of drainage density while Mandal drainage basin shows the minimum drainage density among the selected seven drainage basins of the Biosphere Reserve. The higher values

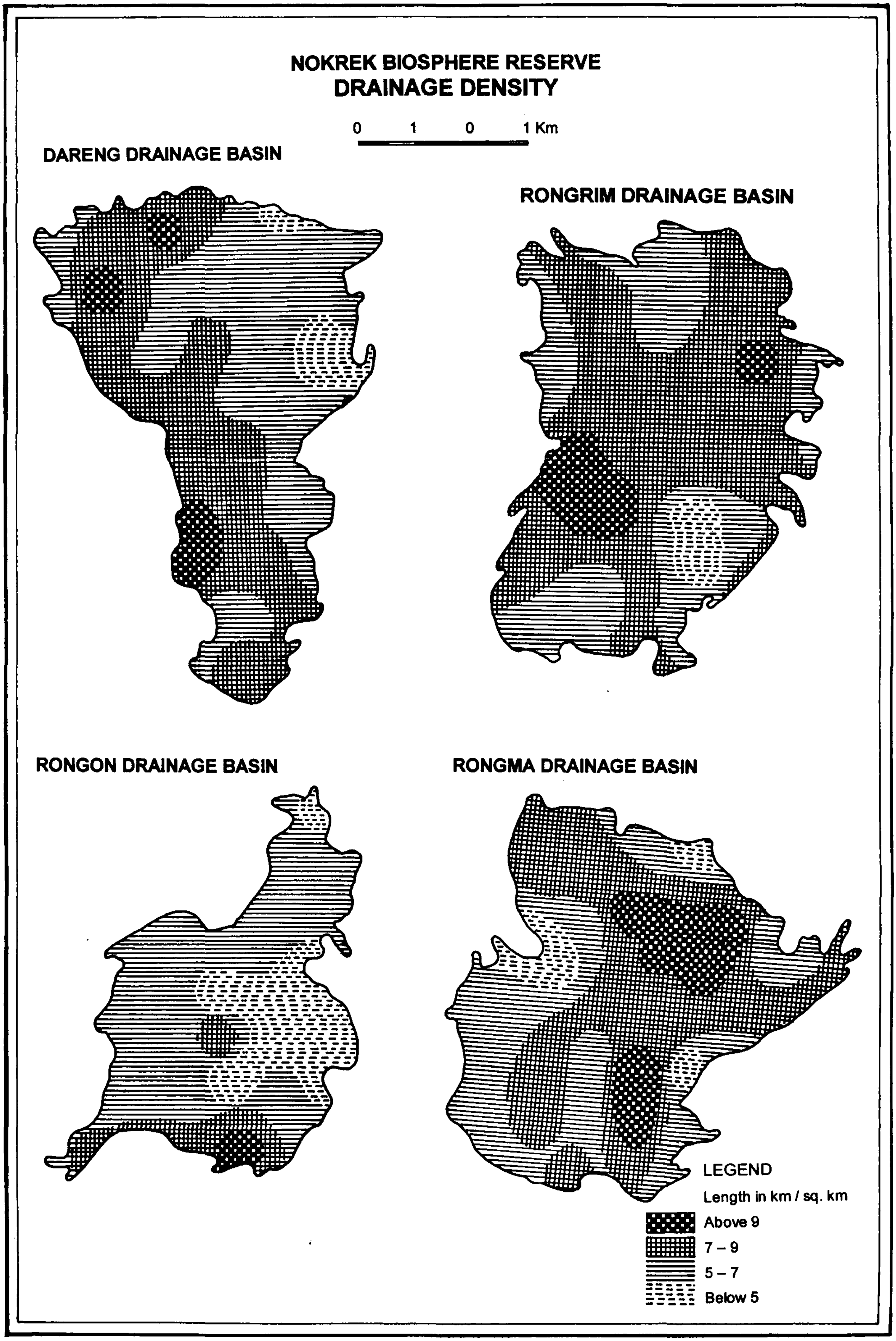
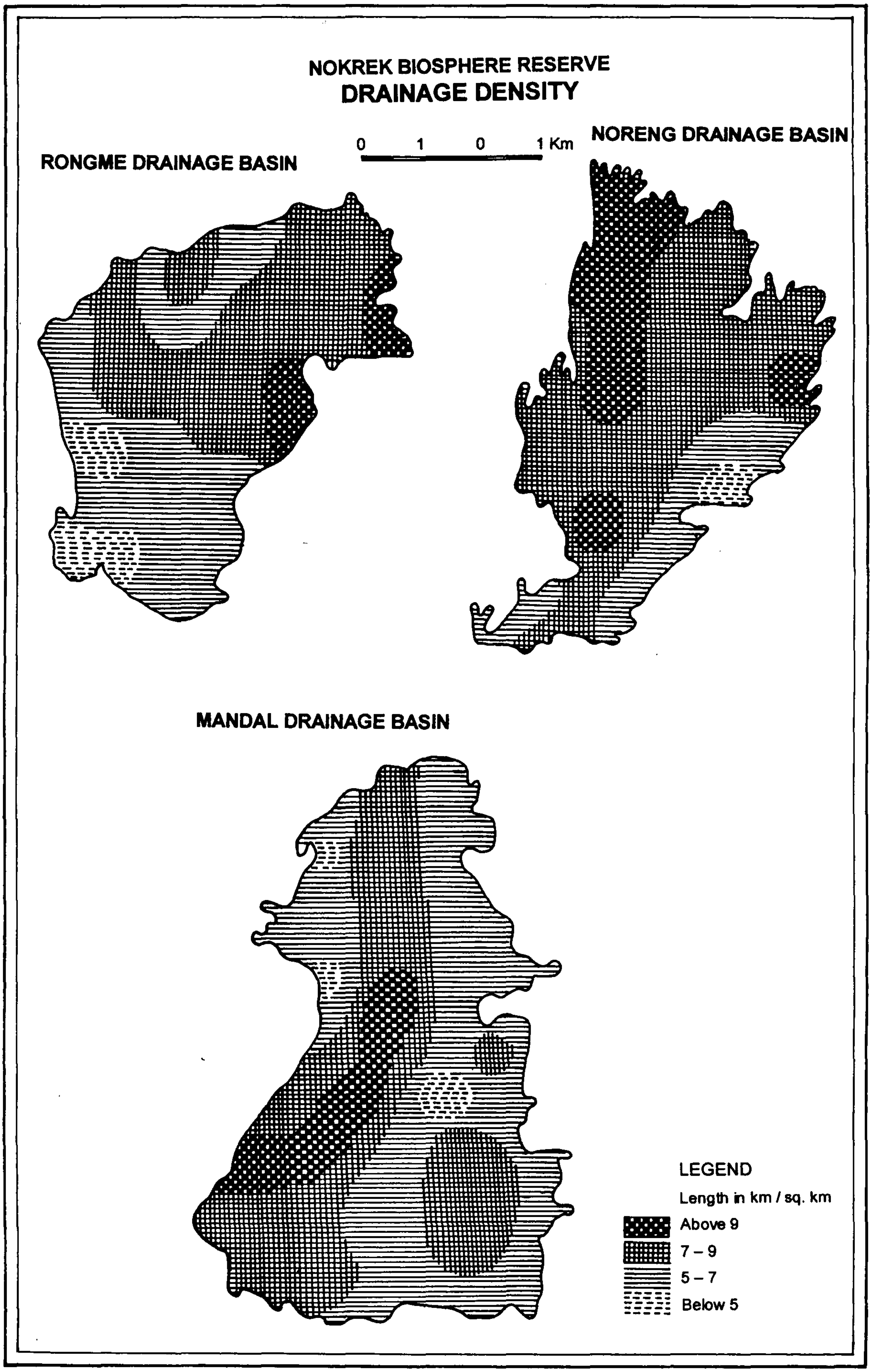

NOKREK BIOSPHERE RESERVE
DRAINAGE DENSITY
0 1 0 1 Km
DARENG DRAINAGE BASIN
RONGRIM DRAINAGE BASIN
RONGON DRAINAGE BASIN
RONGMA DRAINAGE BASIN
LEGEND
Length in km / sq. km
Above 9
7 – 9
5 – 7
Below 5

Fig. 3.9a



NOKREK BIOSPHERE RESERVE
DRAINAGE DENSITY
0 1 0 1 Km
RONGME DRAINAGE BASIN
NORENG DRAINAGE BASIN
MANDAL DRAINAGE BASIN
LEGEND
Length in km / sq. km
Above 9
7 – 9
5 – 7
Below 5

Fig. 3.9b

of drainage density indicate the impermeable surface materials, sparse vegetation and mountain relief.

Table 3.11 Drainage density for the seven selected drainage basins in Nokrek Biosphere Reserve

Sl. No.	Basin	Drainage Density (km/sq. km)
1.	Dareng	8.57
2.	Rongrim	6.31
3.	Rongon	6.69
4.	Rongma	8.63
5.	Rongme	6.97
6.	Noreng	8.14
7.	Mandal	6.07

Most of areas under all the seven drainage basins fall under the drainage density category of 7-9 km/sq. km, which accounts for 43.06% of the total areas of the basins (Table 3.12).

Table 3.12 Area (in sq. km) and proportion (in parenthesis) of drainage density (km/sq. km) category for different drainage basins

Sl. No.	Basin	>9 (km/sq. km)	7-9 (km/sq. km)	5-7 (km/sq. km)	<5 (km/sq. km)
1.	Dareng	3.40 (11.13%)	13.70 (44.85%)	11.70 (38.29%)	1.75 (5.73%)
2.	Rongrim	3.15 (9.15%)	21.54 (62.54%)	8.00 (23.23%)	1.75 (5.08%)
3.	Rongon	0.50 (2.52%)	2.10 (10.56%)	12.09 (60.78%)	5.20 (26.14%)
4.	Rongma	6.10 (20.05%)	12.88 (42.33%)	10.25 (33.68%)	1.20 (3.94%)
5.	Rongme	2.30 (8.2%)	12.25 (43.67%)	10.30 (36.72%)	3.20 (11.41%)
6.	Noreng	7.75 (26.97%)	16.53 (57.55%)	4.25 (14.79%)	0.20 (0.69%)
7.	Mandal	2.75 (6.43%)	13.5 (31.58%)	24.6 (57.54%)	1.90 (4.45%)

An area of 37.79% falls under the drainage density category of 5-7 km/sq. km. About 12.08% of area falls under the drainage density categories of above 9 km/sq. km and 7.07% area falls under below 5 km/sq. km categories. In Dareng drainage basin, 44.85% of the total basin area has the drainage density of 7-9 km/sq. km followed by the drainage density category of 5-7 km/sq. km which accounts for 38.29%. The remaining two categories i.e., above 9 and below 5 km/sq. km cover 11.13% and 5.73% of the total area respectively. Maximum area i.e., 62.54% of Rongrim drainage basin falls under the drainage density of 7-9 km/sq. km. 5-7 km/sq. km drainage density category covers an area of 23.23% of the drainage basin which is followed by above 9 and below 5 km/sq. km drainage density with proportion of areas of 9.15% and 5.08%. 60.78% of the total basin area of Rongon drainage basin falls under the drainage density of 5-7 km/sq. km category. Below 5 km/sq. km drainage category has 26.14% of area while 7-9 and above 9 km/sq. km categories have 10.56% and 2.52% areas respectively. In Rongma drainage basin 42.33%, 33.68%, 20.05% and 3.94% of area fall under the drainage density categories of 7-9, 5-7, above 9 and below 5 km/sq. km respectively. 43.67% of the total area of Rongme drainage basin comes under the drainage density category of 7-9 km/sq. km. This is followed by 5-7 km/sq. km category which occupies 36.72% of the basin area. The other two i.e., below 5 and above 9 km/sq. km categories constitute 11.41% and 8.20% respectively. In Noreng drainage basin 57.55% of the total area falls under 7-9 km/sq. km drainage density category. Above 9 km/sq. km category covers 26.97% area while 5-7 and below 5 km/sq. km categories occupy 14.79% and 0.69% respectively. The Mandal drainage basin has the maximum area i.e., 57.54%under the drainage density category of 5-7 km/sq. km. A percentage of 31.58 falls under the drainage density category of 7-km/sq. km. The drainage density categories of above 9 and below 5 km/sq. km occupy 6.43% and 4.45% respectively.

DRAINAGE FREQUENCY

The drainage frequency is the ratio of the total number of channels of all orders in a basin to the area of the whole basin. Horton (1945) introduced drainage frequency (or channel frequency) as the number of stream segments per unit area. It determines relative closeness of streams in the basin. The important factors, which affect drainage frequency, are climate, structural characteristics of rocks, relief, infiltration capacity and vegetation. The area receives high rainfall resulting high and very high drainage frequency per square kilometre. It is also noticed that the region has the relief of dissected hills with favourable lithology enjoys high drainage frequency. According to Horton (1945) infiltration capacity of the mantle rock and bed rock is probably the single most important factor influencing the drainage frequency. The drainage basins, which underlain by relatively less permeability rock surface and this results the moderately high frequency of streams. Climate indirectly affects drainage frequency by its control upon the amount and type of vegetation through their influence upon the amount and rate of surface runoff. Climate affects the capacity of the soil to absorb rainwater by determining whether the soil is frozen or whether it is nearly saturated with moisture. It is probably true that with similar conditions of lithology and geologic structure in semi-arid regions have their drainage texture than humid regions, although major streams may be more widely spaced in semi-arid than humid regions. The reason for this could be less extensive vegetal cover in dry regions and the larger percentage of runoff (Thornbury 1969).

METHODS

Numerically, drainage frequency is defined by the relation as given below:

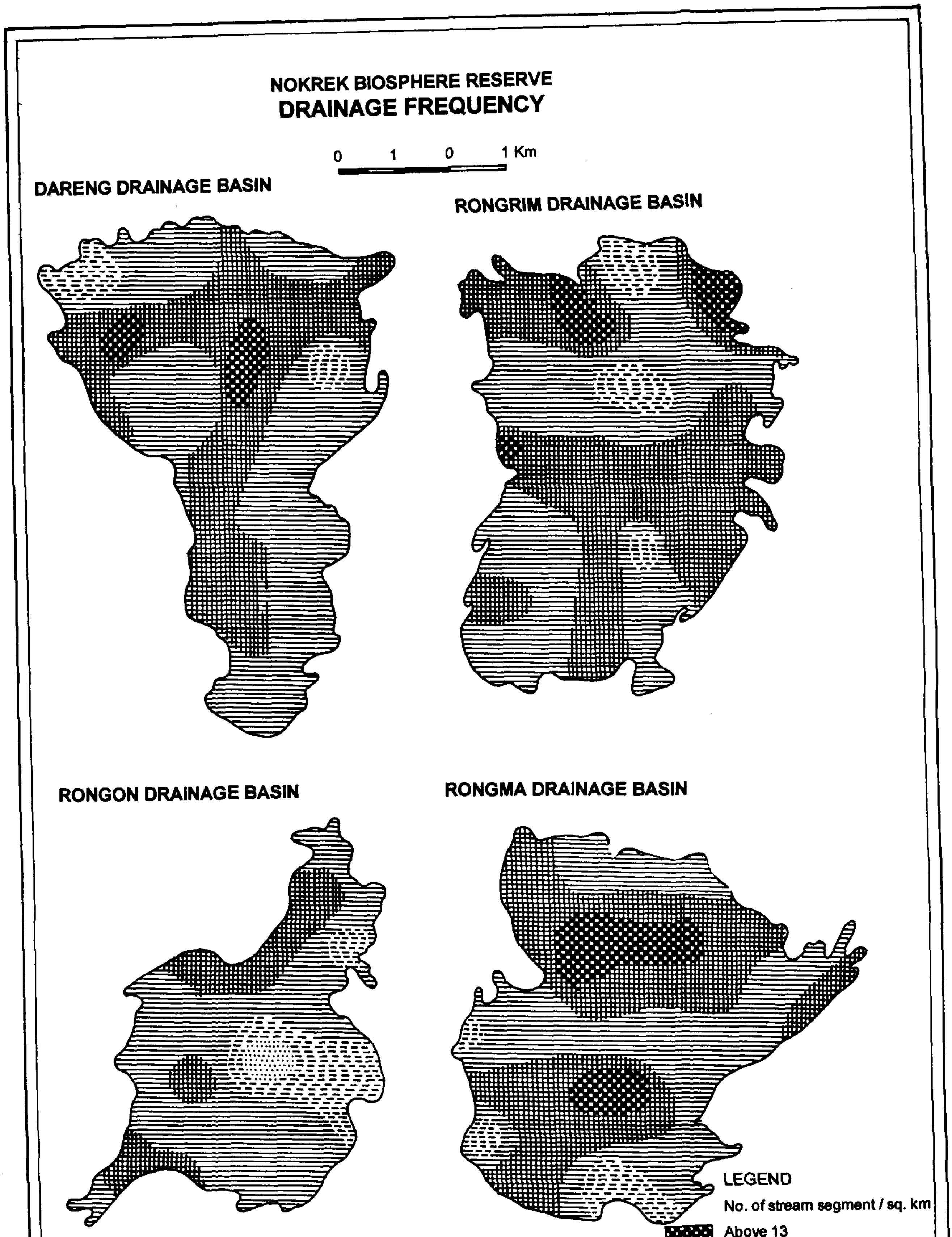
$Fu = (EL)u / Au$

where, Fu = Drainage frequency in number per square kilometre

EL = Sum of the total number of streams of all orders

Au = Total area of drainage basin in square kilometre.

The expression of Fu gives the average frequency of streams in the area. To know the variation in drainage frequency in the individual basin, the frequencies have been computed per square kilometre. The area in all the basins is divided into one by one kilometre grid and the numbers of channel segments in each grid were recorded. The values obtained were the frequency per square kilometre. Thematic maps have been prepared for all the seven drainage basins and are shown in Fig. 3.10a and 3.10b.



NOKREK BIOSPHERE RESERVE
DRAINAGE FREQUENCY
0 1 0 1 Km
DARENG DRAINAGE BASIN
RONGRIM DRAINAGE BASIN
RONGON DRAINAGE BASIN
RONGMA DRAINAGE BASIN
LEGEND
No. of stream segment / sq. km
Above 13
11- 13
8 – 10
5 – 7
Below 5

Fig. 3.10a

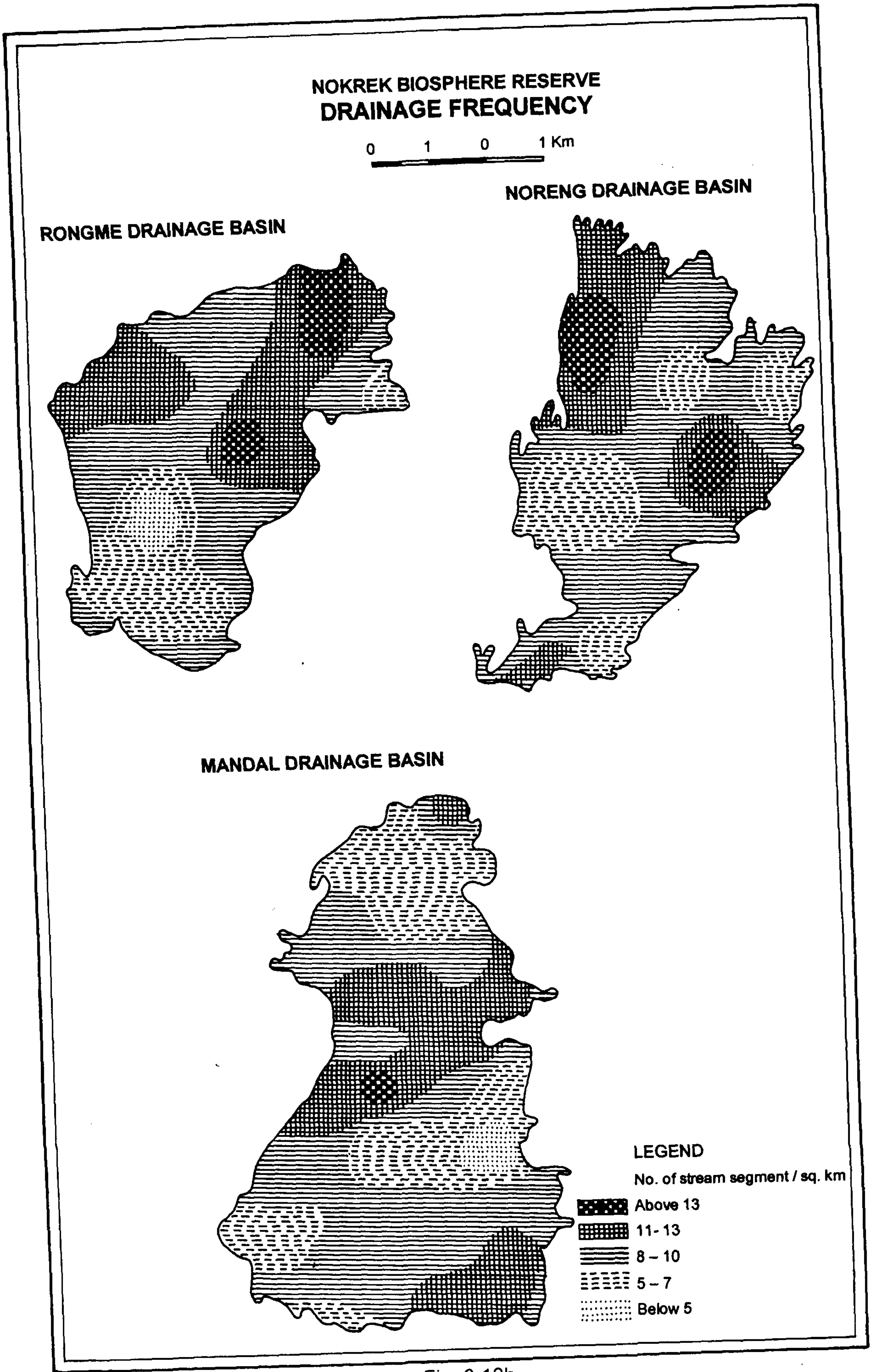

NOKREK BIOSPHERE RESERVE
DRAINAGE FREQUENCY
0 1 0 1 Km
NORENG DRAINAGE BASIN
RONGME DRAINAGE BASIN
MANDAL DRAINAGE BASIN
LEGEND
No. of stream segment / sq. km
Above 13
11- 13
8 – 10
5 – 7
Below 5

Fig. 3.10b

RESULTS AND DISCUSSION

The drainage frequencies for the seven drainage basins of Nokrek Biosphere Reserve range from 4.77 to 8.25 streams per square kilometre. Dareng river basin shows the maximum while Rongon drainage basin has the minimum drainage frequencies (Table 3.13).

Table 3.13 Drainage frequency (number of stream segments per square kilometre) for different drainage basins

Sl. No.	Basin	Drainage Frequency (no. stream segments / sq. km)
1.	Dareng	8.25
2.	Rongrim	7.75
3.	Rongon	4.77
4.	Rongma	7.03
5.	Rongme	6.09
6.	Noreng	6.26
7.	Mandal	6.95

From the drainage frequency maps it is seen that drainage frequency is high in all the drainage basins, which ranges from below 5 to above 13 streams per sq. km (Table 3.14).

Table 3.14 Area (in sq. km) and proportion (in parenthesis) of drainage frequency (no. of stream segments per sq. km) category for different drainage basins

Sl. No.	Basin	>13	11-13	8-10	5-7	<5
1.	Dareng	1.30 (4.26%)	12.65 (41.41%)	15.85 (51.88%)	0.75 (2.45%)	-
2.	Rongrim	1.65 (4.79%)	11.98 (34.78%)	19.11 (55.49%)	1.7 (4.94%)	-
3.	Rongon	-	3.10 (15.59%)	12.84 (64.56%)	3.50 (17.59%)	0.45 (2.26%)
4.	Rongma	3.1 (10.19%)	13.48 (44.29%)	12.25 (40.26%)	1.6 (5.26%)	-
5.	Rongme	2.20 (7.85%)	7.20 (25.67%)	14.35 (51.16%)	3.60 (12.83%)	0.70 (2.49%)
6.	Noreng	3.25 (11.32%)	6.66 (23.18 %)	11.97 (41.66%)	6.85 (23.84%)	-
7.	Mandal	0.40 (0.94%)	8.67 (20.28%)	23.06 (53.94%)	10.02 (23.44%)	0.60 (1.40%)

From the table it is apparent that 50.94% of the total area of the all seven drainage basins falls under the drainage frequency category of 8-10 stream segments per sq. km. This is followed by the categories of 11-13, 5-7, above 13 and below 5 number of stream segments per sq. km which occupy 29.67%, 13.04%, 5.54% and 0.81% respectively. In Dareng drainage basin most of the area is shared by the drainage frequency categories of 8-10 and 11-13 stream segments per sq. km which occupy 51.88% and 41.41% respectively. The remaining areas i.e., 4.26% and 2.45% are covered by above 13 and 5-7 stream segments per sq. km categories. In Rongrim drainage basin it is found that 55.49% of the total area has the drainage frequency of 8-10 stream segments per sq. km. The drainage frequency ranging from 11 to 13 stream segments per sq. km covers 34.78% of the total area. About 4.94% and 4.79% area of the basin fall under the drainage frequency categories of 5-7 and above 13 stream segments per sq. km. About 64.56% of Rongon drainage basin falls under the drainage frequency category of 8-10 stream segments per sq. km. 17.59% and 15.59% of the basin area come under the category of 5-7 and 11-13 stream segments per square kilometre. Only 2.26% falls under below 5 stream segments per sq. km drainage frequency category, Rongma drainage basin accounts for 44.29% and 40.26% which are under the drainage frequency categories of 11-13 and 8-10 stream segments per sq. km. The frequency more than 13 stream segments per sq. km occupies 10.19% while 5.26% of the total basin area comes under 5-7 stream segments per sq. km. The drainage frequency category of 8-10 stream segments per sq. km covers an area of

51.16% of Rongme drainage basin which is followed by 11-13, 5-7, above 13 and below 5 stream segments per sq. km drainage frequency categories with proportions of areas of 25.67%, 12.83%, 7.85% and 2.49%. Noreng drainage basin is shared by the drainage frequency categories of 8-10, 5-7, 11-13 and above 13 stream segments per sq. km, which accounts for 41.66%, 23.84% 23.18% and 11.32% respectively. Mandal drainage basin also exhibits the maximum area i.e., 53.94% of the total basin area under the drainage frequency category of 8-10 stream segments per sq. km. The frequency category of 5-7 stream segments per sq. km an area of 23.44% which is followed by 11-13, below 5 and above 13 stream segments per sq. km with proportion of areas of 20.28%, 1.40% and 0.94% respectively.

SLOPE

Slope is one of the most important aspects of geomorphological study. Slopes are fundamental elements of the landscape (King 1962). In its broadest sense, it is an element of the interface between lithosphere and either hydrosphere or atmosphere (Fairbridge 1968). The slope elements of an area reflect the evolutionary history of the existing landscape. Thus, study of slopes of an area is of paramount interest.

The slopes, defined as an angular inclination of terrain between the hill tops and valley bottoms, makes with horizontal datum which is generally expressed in degrees. A slope profile may have a variety of forms. Geometrically, slope may consist segments which are concave upward, convex downward, straight or rectilinear and complex (Savigear 1956, Young 1964 and Fairbridge 1968).

METHODS

There are different methods suggested by many geographers for the study of average slope. The method devised by Wentworth (1930) for 'general and random' determination of average slope over an area from contour map has been adopted for the slope analysis in the area.

The formula devised by Wentworth is given below:

Average slope $\tan\theta = N \times CI / 3361$

Where, N	=	Average Mp x pf crossing in an area per mile
CI	=	Contour interval in feet
3361	=	A constant figure

Zakrzewska (1967) modified Wentworth's above formula as given below:

Slope in degree = $\tan\theta = V \times N / 0.6366\ K$

Where, V = Vertical contour interval in metre or in feet

N = Number of contour crossing per square kilometre or per square mile

K = Constant, 1000 for metric units and 5280 for British units

Thus, to find out the nature of average slope and its characteristics, each drainage basin has been divided into one by one kilometre grids and the number of contours crossing per square kilometre are counted. With the above modified Wentworth's formula, average slope per grid is computed. Based on the results, slope maps have been prepared showing five categories of slope for all the seven drainage basins (Fig. 3.11a and 3.11b).

RESULTS AND DISCUSSION

The average slope for all the drainage basins has been classed from 2° to above 29° in five slope ranges. Under these slope ranges for all the seven drainage basins the maximum area falls under the slope range of 16°-22°, which occupies 59.58% of the total areas of all the drainage basins. This is followed by 9°-15° slope range which constitutes 20.93%. 23°-29° slope range occupies 18.77%. Two small areas of 0.63% and 0.09% of the total area of the basins have been found under above 29° and 2°-8° slope ranges.

Table 3.15 Area (in sq. km) and proportion (in parentheses) of slope (in °) for different drainage basins

Sl. No.	Basin	>29°	23°-29°	16°-22°	9°-15°	2°-8°
1.	Dareng	-	3.45 (11.29%)	13.77 (45.07%)	13.33 (43.64%)	-
2.	Rongrim	-	7.21 (20.93%)	26.78 (77.76%)	0.45 (1.31%)	-
3.	Rongon	-	2.45 (12.32%)	14.49 (72.85%)	2.75 (13.82%)	0.20 (1.01%)
4.	Rongma	-	7.05 (23.17%)	18.30 (60.14%)	5.08 (16.69%)	-
5.	Rongme	-	-	14.10 (50.27%)	13.95 (49.73%)	-
6.	Noreng	1.35 (4.70%)	5.17 (17.99%)	14.48 (50.40%)	7.73 (26.91%)	-
7.	Mandal	-	15.00 (35.08%)	26.08 (61.01%)	1.67 (3.91%)	-

Dareng drainage basin has 45.07% and 43.64% areas under 16°-20° and 9°-15° slope ranges and 11.29% under 23°-29° slope range. Maximum area i.e., 77.76% of Rongrim

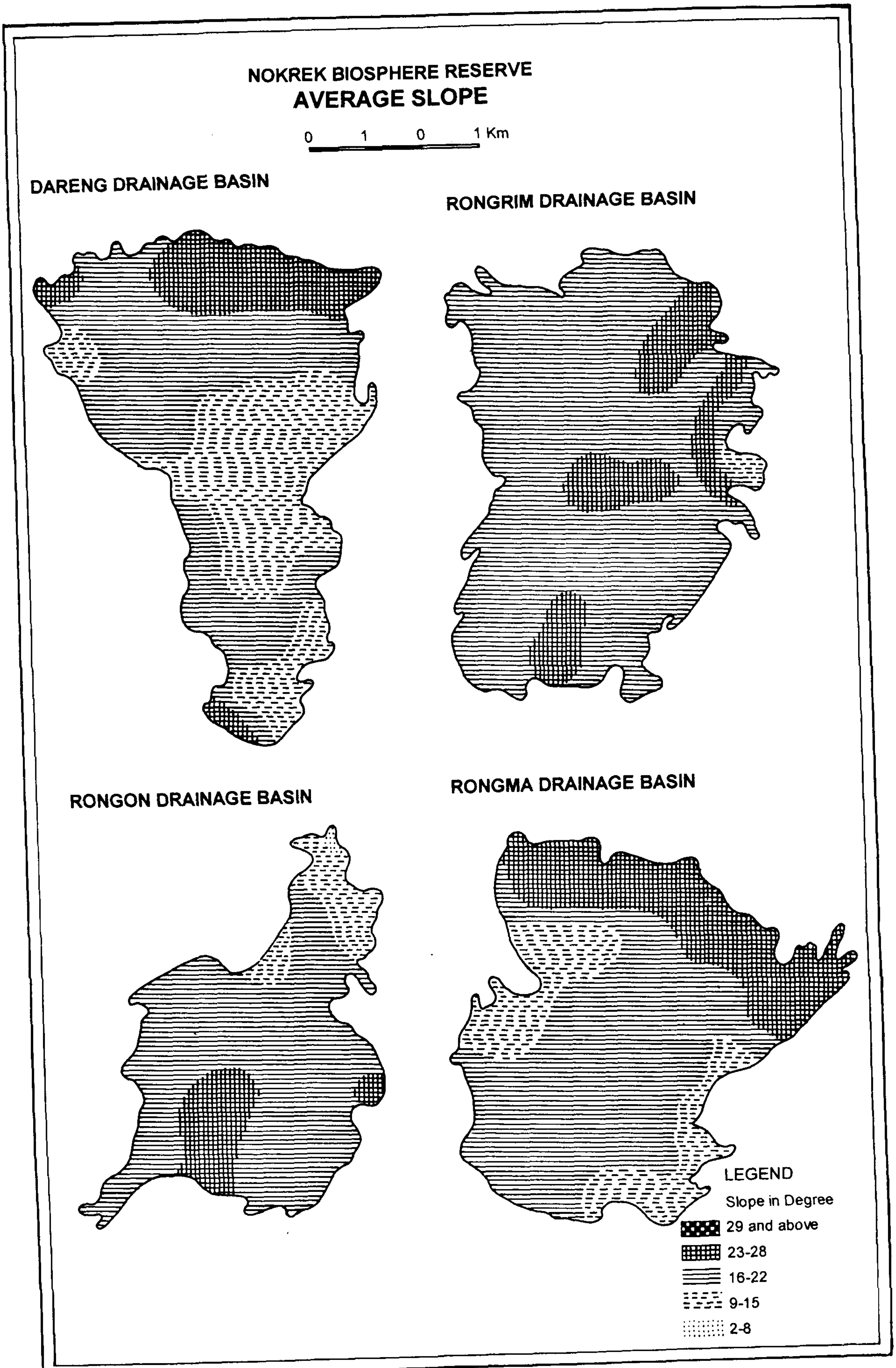
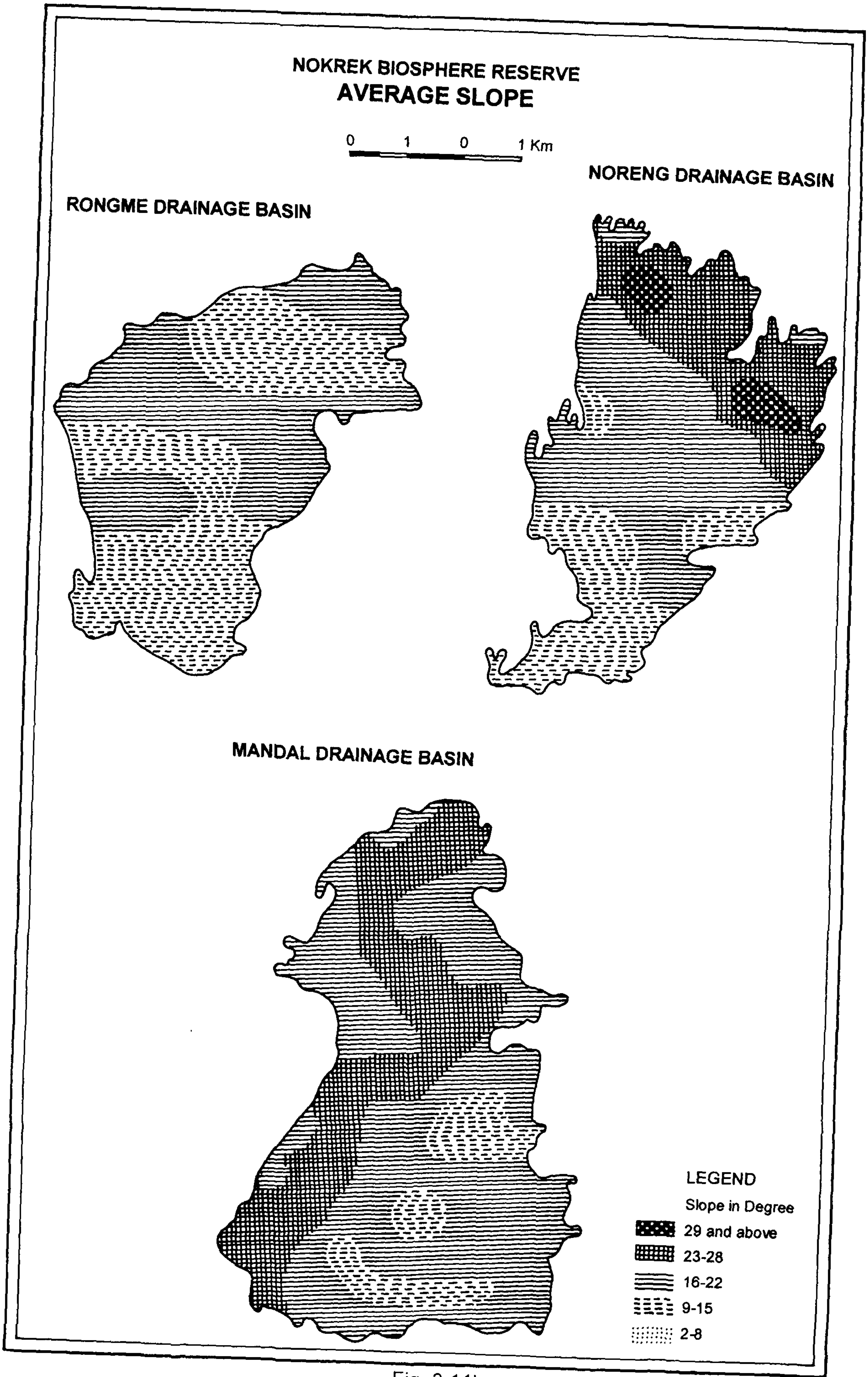

NOKREK BIOSPHERE RESERVE
AVERAGE SLOPE
0 1 0 1 Km
DARENG DRAINAGE BASIN
RONGRIM DRAINAGE BASIN
RONGON DRAINAGE BASIN
RONGMA DRAINAGE BASIN
LEGEND
Slope in Degree
29 and above
23-28
16-22
9-15
2-8

Fig. 3.11a



NOKREK BIOSPHERE RESERVE
AVERAGE SLOPE
0 1 0 1 Km
RONGME DRAINAGE BASIN
NORENG DRAINAGE BASIN
MANDAL DRAINAGE BASIN
LEGEND
Slope in Degree
29 and above
23-28
16-22
9-15
2-8

Fig. 3.11b

drainage basin falls under the slope range of 16°-22° followed by 20.93% under 23°-29° slope range. The area under 9°-15° slope range covers 1.31%. In Rongon drainage basin 72.85% of the total area falls under 16°-22° slope range. 13.82% and 12.32% of the total basin area fall under the slope range of 9°-15° and 23°-29° respectively. Only 1.01% area occupies under the slope range of 2°-8°. Maximum areas i.e., 60.14% in Rongma drainage basin falls under the slope range of 16°-22° followed by 23.17% and 16.69% under 23°-29° and 9°-15° slope ranges. There are only two slope ranges found in Rongme drainage basin i.e., 16°-22° and 9°-15°, which consider 50.27% and 49.73% respectively. In Noreng drainage basin 50.40% area falls under 16°-22° slope range followed by 26.91%, 17.99% and 4.70% under 9°-15°, 23°-29° and above 29° slope ranges. Mandal drainage basin enjoys 61.01% of area under 16°-22° slope range and 35.08% under 23°-29° slope range. A considerable portion of 3.91% is occupied by 9°-15° slope range (Table 3.15).

RELIEF

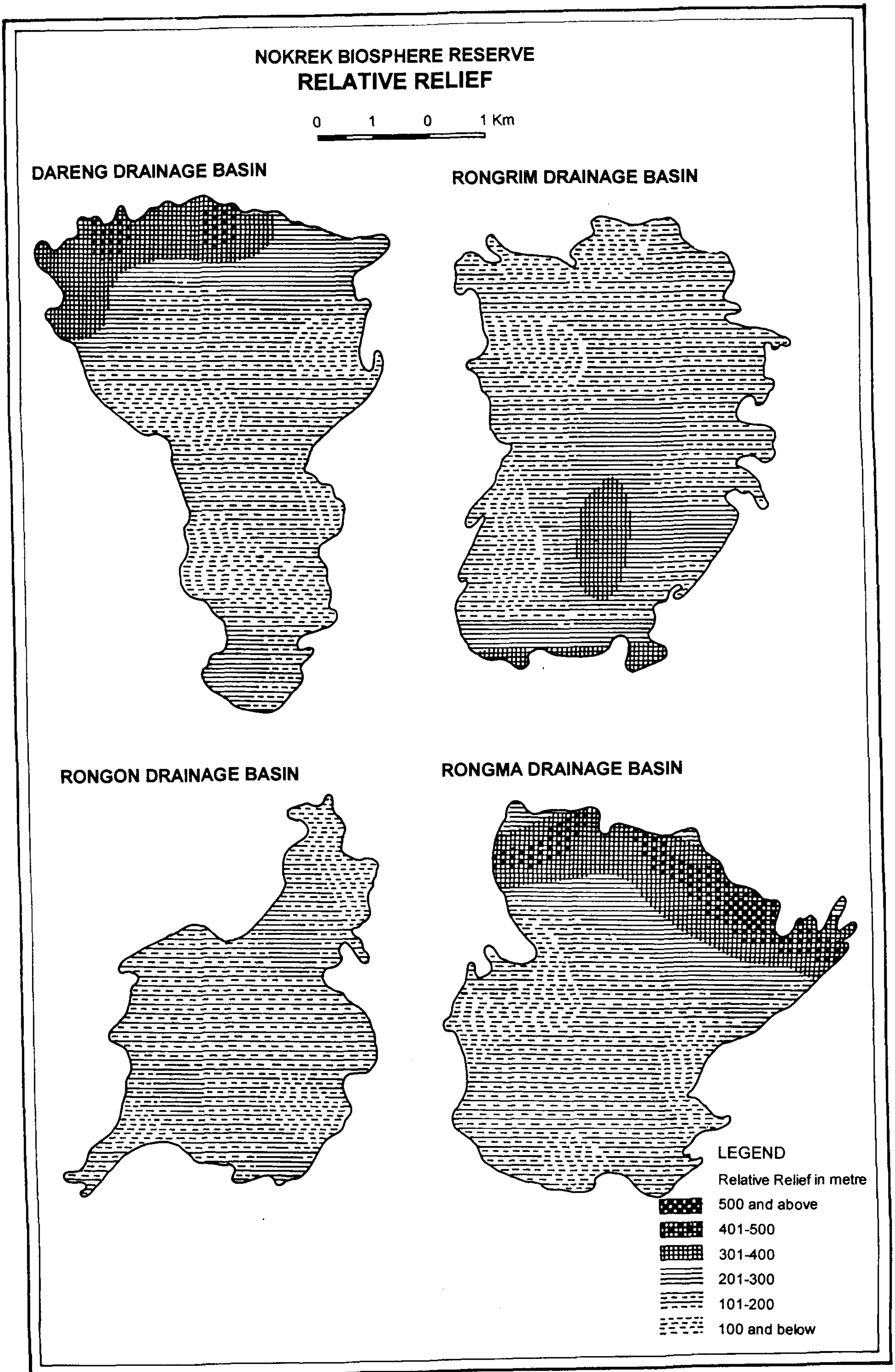
Relief is the relative vertical inequality of differences in elevation of any part of the earth surface. The study of relief provides not only the variety of topographical features but also makes available the evidences needed for the interpretation of the complex form of landscape. The process of evolution of the relief of an area depends upon geological structure, lithotypes, climatological conditions and nature of the original topographic surfaces of the area. In the present study an attempt has been made to analyse the relative relief of the selected seven drainage basins. The term relative relief denotes the actual variation of height in a unit area with respect to its local base level. Importance of relative relief study in understanding landforms has been highlighted by Johnson (1933) and Smith (1935). Relative relief is one of the methods which may overcome the difficulty of presenting the three dimensional relief characteristics with the help of two dimensional maps. It visualizes the sharpness of relief which may not be expressed by profiles, altitudinal zones and area-height relation curve.

METHODS

For the purpose of relative relief analysis, the area of each basin has been divided into one by one kilometre grids. The height difference between the highest and lowest elevation within each grid is computed. The value thus obtained gives directly the relative relief per square kilometre. To know the spatial variation relative relief has been computed in all the seven drainage basins and thematic maps have been prepared (Fig. 3.12a and Fig. 3.12b).

RESULTS AND DISCUSSION

The relative relief for all the seven drainage basins has been classified into six categories ranging from below 100m to above 500m (Table 3.16). From the table it is apparent that under these relative relief categories for all the drainage basins the maximum area falls under 101m-200m, which constitutes 48.21% of the total area of the basins. The second position is occupied by 201m-300m category which enjoys



NOKREK BIOSPHERE RESERVE
RELATIVE RELIEF
0 1 0 1 Km
DARENG DRAINAGE BASIN
RONGRIM DRAINAGE BASIN
RONGON DRAINAGE BASIN
RONGMA DRAINAGE BASIN
LEGEND
Relative Relief in metre
500 and above
401-500
301-400
201-300
101-200
100 and below

Fig. 3.12a

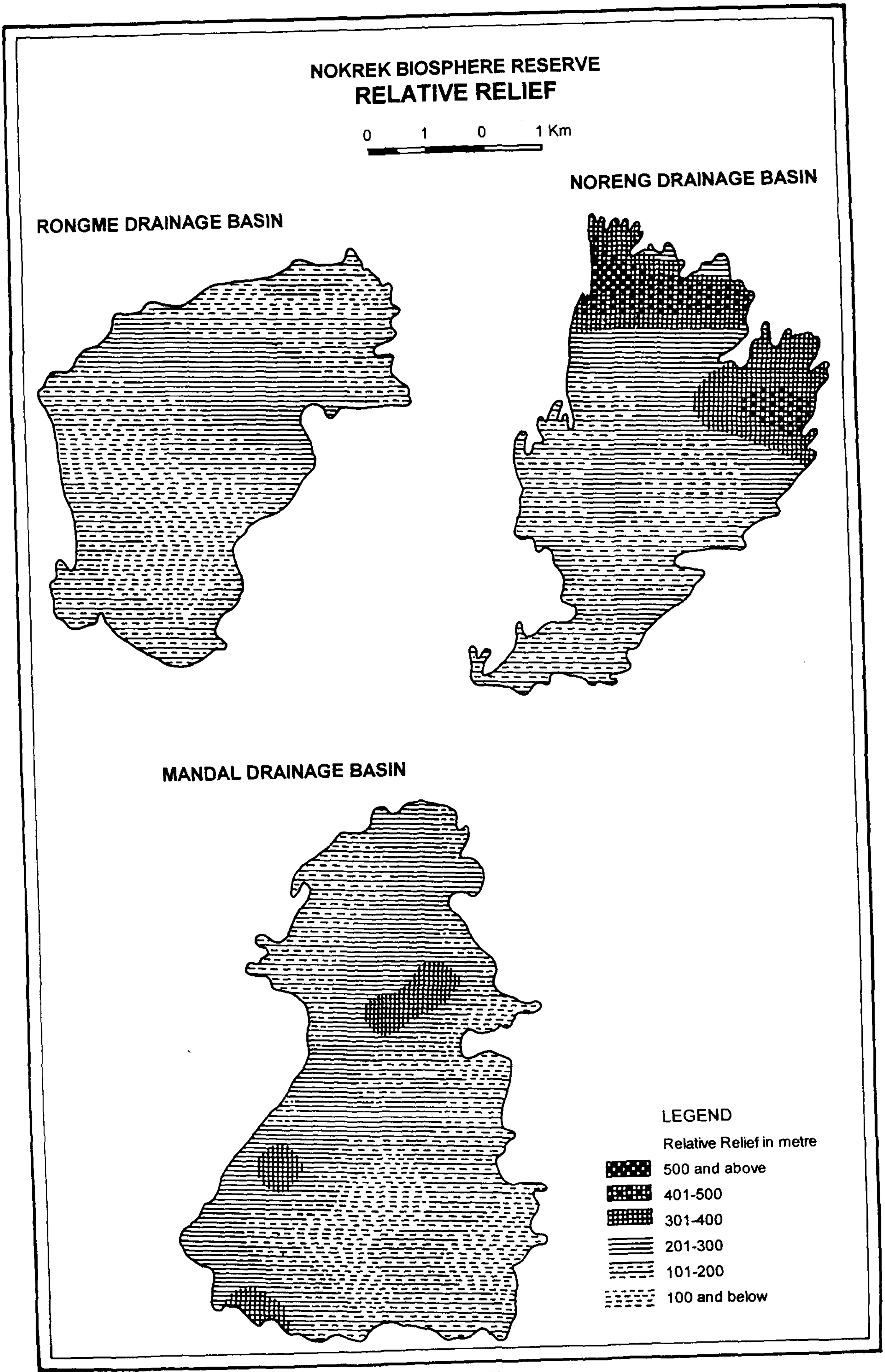

NOKREK BIOSPHERE RESERVE
RELATIVE RELIEF
0 1 0 1 Km
NORENG DRAINAGE BASIN
RONGME DRAINAGE BASIN
MANDAL DRAINAGE BASIN
LEGEND
Relative Relief in metre
500 and above
401-500
301-400
201-300
101-200
100 and below

Fig. 3.12b

22.32% area followed by below 100m category which occupies 18.56% of the total area of all the basins. 7.52%, 3.02% and 0.37% area fall under 301m-400m, 401m-500m and above 500m categories respectively.

Table 3.16 Area (in sq. km) and proportion (in parenthesis) of relative (in metre) for different drainage basins

Sl. No.	Basin	>500	401-500	301-400	201-300	101-200	<100
1.	Dareng	-	1.45 (4.74%)	4.03 (13.19%)	4.63 (15.16%)	14.24 (46.62%)	6.20 (20.29%)
2.	Rongrim	-	-	2.12 (6.16%)	6.57 (19.07%)	21.26 (61.73%)	4.49 (13.04%)
3.	Rongon	-	-	-	2.17 (10.91%)	13.84 (69.58%)	3.88 (19.57%)
4.	Rongma	0.45 (1.48%)	3.08 (10.12%)	3.35 (11.01%)	3.90 (12.82%)	13.75 (45.18%)	5.90 (19.39%)
5.	Rongme	-	-	-	5.26 (18.75%)	11.53 (41.11%)	11.26 (40.14%)
6.	Noreng	0.35 (1.22%)	1.95 (6.79%)	4.55 (15.84%)	8.35 (29.06%)	13.53 (47.09%)	-
7.	Mandal	-	-	2.10 (4.92%)	17.07 (39.93%)	15.43 (36.09%)	8.15 (19.06%)

Dareng drainage basin has the five categories of relative relief of which 101m-200m category occupies the maximum area (46.62%) followed by below 100m category which constitutes 20.29%. 201m-300m, 301m-400m and 401m-500m categories occupy the areas of 15.16%, 13.19% and 4.74% respectively. In Rongrim drainage basin most of the area falls under 101m-200m category which occupies 61.73%. The categories of 201m-300m, below 100m and 301m-400m constitute the area of 19.07%, 13.04% and 6.16% respectively. 69.58%, 19.57% and 10.91% of the total area of Rongon drainage basin fall under the relative relief category of 101m-200m, below 100m and 201m-300m respectively. In Rongma drainage basin the area is distributed in all the six relative relief categories. The maximum area i.e., 45.185% falls under the category of 101m-200m followed by below 100m, 201m-300m, 301m-400m, 401m-500m and above 500m categories which occupy 19.39%, 12.82%, 11.01%, 10.12%

and 1.48% respectively. The Rongme drainage basin enjoys 41.11% and 40.14% of the total area, which fall under 101m-200m and below 100m categories. The remaining 18.75% area falls under the relative relief category of 201m-300m. 47.09% area of Noreng drainage basin falls under the relative relief category of 101m-200m. This is followed by 201m-300m, 301m-400m, 401m-500m and above 500m categories which occupy the area of 29.06%, 15.84%, 6.79% and 1.22% of the total basin area. Mandal drainage basin constitute 39.93% and 36.09% under 201m-300m and 101m-200m relative relief categories which are followed by 19.06% under below 100m category and 4.92% under 301m-400m category.

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CHAPTER-IV

COAL MINING AND ITS IMPACT ON VEGETATION, SOIL AND WATER OF NOKREK BIOSPHERE RESERVE

Coal contains significant amount of irondisulphide in the form of pyrites (FeS_2). The exposure of pyrite to atmospheric oxygen through the mining operation brings about an oxidation process in which pyrite is converted into Ferric Sulphate and Sulphuric Acid in the presence of bacteria. The acid thus formed lowers the pH of the terrestrial and aquatic environment. Chemicals released from the mines, mine overburden and trailings also contain high concentrations of metals such as Cu, Cd, Fe, Hg, and Zn that also affect the environment adversely.

Because of the above reasons, the coal mining brings about significant physical, chemical and biological changes in the environment. These include, serious water pollution and damage to aquatic plants and fishes, air pollution, reduction in vegetal cover and biodiversity, reduction in discharge of streams, alteration in landscape structure due to land disturbance, alteration of soil physico-chemical properties, accelerated soil erosion, particularly loss of nutrient-rich top soil and production of silt and habitat fragmentation.

In this chapter an attempt has been made to analyse the impact of coal mining on vegetation, soil and water quality of the Nokrek Biosphere Reserve.

IMPACT OF COAL MINING ON VEGETATION

Introduction

Surface mining of coal causes massive damage to landscape and biological communities (Down & Stock 1977). Plant communities occurring naturally got disturbed due to mining activity and following the mining, the habitats become impoverished presenting a very rigorous condition for plant growth. The study of plant communities of the coal mining affected areas has been of great interest to the ecologists. The studies related to the floristic composition of the coal 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 & Jha 1987, Jha & Singh 1990). Prasad & Pandey (1985) have studied natural plant succession in the rehabilitated bauxite and coal mine overburden of Madhya Pradesh. Jha & Singh (1990) have analysed the vegetation developing naturally on dry subtropical mine spoils.

Meghalaya is bestowed with rich natural vegetation as well as large reserve of mineral resources. The depletion of natural vegetation and transformation of forest land into grasslands have been brought about by the age-old practice of slash and burn agriculture. During the last few decades, there have been phenomenal increase in mining of coal, limestone and sillimanite causing large scale destructions and deterioration of the natural vegetation of the state. Excessive coal mining operation in many parts of Meghalaya has been responsible for the conversion of original lush green landscape of the area into mine spoils. The primitive and unscientific 'rat-hole' method of mining adopted by private operators in several parts of Meghalaya had caused severe ecosystem destruction. However, no comprehensive studies have been carried out as yet to assess the impact of coal mining on vegetation and biodiversity in the state. Only a few studies (Lyngdoh *et al.* 1992, Lyngdoh 1995, Pandey *et al.* 1993 and Das Gupta 1999) have been conducted on the natural succession of plant communities of coal mine affected areas in Jaintia Hills of Meghalaya.

The vegetation of Nokrek Biosphere Reserve (NBR) has many distinct and unique features. The NBR is a unique area with a number of endemic, rare and endangered species of plants. The NBR is one of the richest sites for citrus genetic diversity, and it is believed to be the site of citrus origin. The vegetation of the Biosphere Reserve comprises tropical and subtropical evergreen and semievergreen forest, tropical moist deciduous forest, bamboo brakes, grasslands and riverine forest. All these forests are rich in bamboo, grass, orchid and medicinal plant species diversity. The whole buffer area of the Biosphere Reserve is degraded and disturbed due to large-scale coal mining, shifting cultivation and other human activities. Mining operation has been carried out indiscriminately within the Biosphere Reserve even on steep and fragile slopes without any concern for ecological and environmental consequences. Uncontrolled and unscientific mining operation within the Biosphere Reserve has been detrimental to the fragile ecosystem. This has resulted in large-scale degradation of the landscape, soil, water and forest ecosystems of the Biosphere Reserve.

A detailed understanding of the impact of coal mining on vegetation and plant diversity is a pre-requisite for developing an effective management plan to minimize the adverse impact of coal mining on the plant community of the Biosphere Reserve. Keeping this objective in view, the plant communities of the Biosphere Reserve have been studied in detail and the impact of coal mining on them has been assessed by comparing certain community attributes of the mined areas with those in the unmined areas.

METHODS:

The community characteristics of the Biosphere Reserve vegetation were studied during three seasons viz., monsoon (May-September), pre-monsoon (March-April) and post-monsoon or winter (October-February) over a period of two years from 2000 to 2002. Three coal mining sites were selected for the study viz., Budugiri, Budu Wathegiri and Faramgiri. At each site, the vegetation characteristics of the mined areas were compared with that of an unmined plot adjacent to the mined areas. For tree components, 10 quadrats of 10m x 10m size each were laid randomly in the unmined and mined areas at each site. For shrub species, 10 quadrats of 5m x 5m size each in mined and unmined areas were laid. The herb species were studied by laying 40 quadrats each of 1m x 1m size in mined and unmined areas. The species found in qadrats were identified with the help of the herberia of Botany Department, North-Eastern Hill University and Botanical Survey of India, North-Eastern Circle, Shillong.

Quantitative community characteristics such as frequency, density, basal area and importance value index (IVI) of each component were determined by following the methods as outlined by Mishra (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 for herbs and shrubs based on the measurement of stem diameter at basal level and for trees CBH at 1.37m height.

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

The distribution pattern of the species in the forests were studied by 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's index of General Diversity was calculated by using the formula

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

Where, $\bar{H}$ = Shannon's index of general diversity

n_i = importance value index of a species

N = total importance values of all species

RESULTS AND DISCUSSION

FLORISTIC COMPOSITION

The total number of plant species found in the mined areas was significantly less than the unmined areas (Fig. 4.1). The number of tree species was higher in the unmined areas (31-44) than the mined areas (25-26). With the exception of herb species at Budugiri site, the tree and shrub species showed a drastic reduction in their number due to mining. The number of shrub species was much less in comparison to tree and herbs at all the three sites (Table 4.1). Fifteen tree species, 4 shrub and 28 herb species were exclusively found in mined sites, while 27 tree species, 4 shrub species and 16 herb species were exclusively found in the unmined sites (Table 4.3).

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 & Singh (1990). Lyngdoh *et al.* (1992), while studying the vegetation dynamics on coal mine spoils of Jaintia Hills reported that relatively young spoils (2-5 year old) had lesser number of species than the unmined site and 10 year old spoil. Cornwell (1971) related the species richness on coal waste areas to spoil acidity and age of the spoil. Iverson & Wali (1982) observed an increase in species richness with age in reclaimed coal mine spoils of North-Western Dakota. Russel & La Roi (1986) reported higher species richness on fine textured spoil than on the coarse textured coal mine spoils in Alberta, Canada. Kimmerer (1984) while working on lead mine wastes observed the

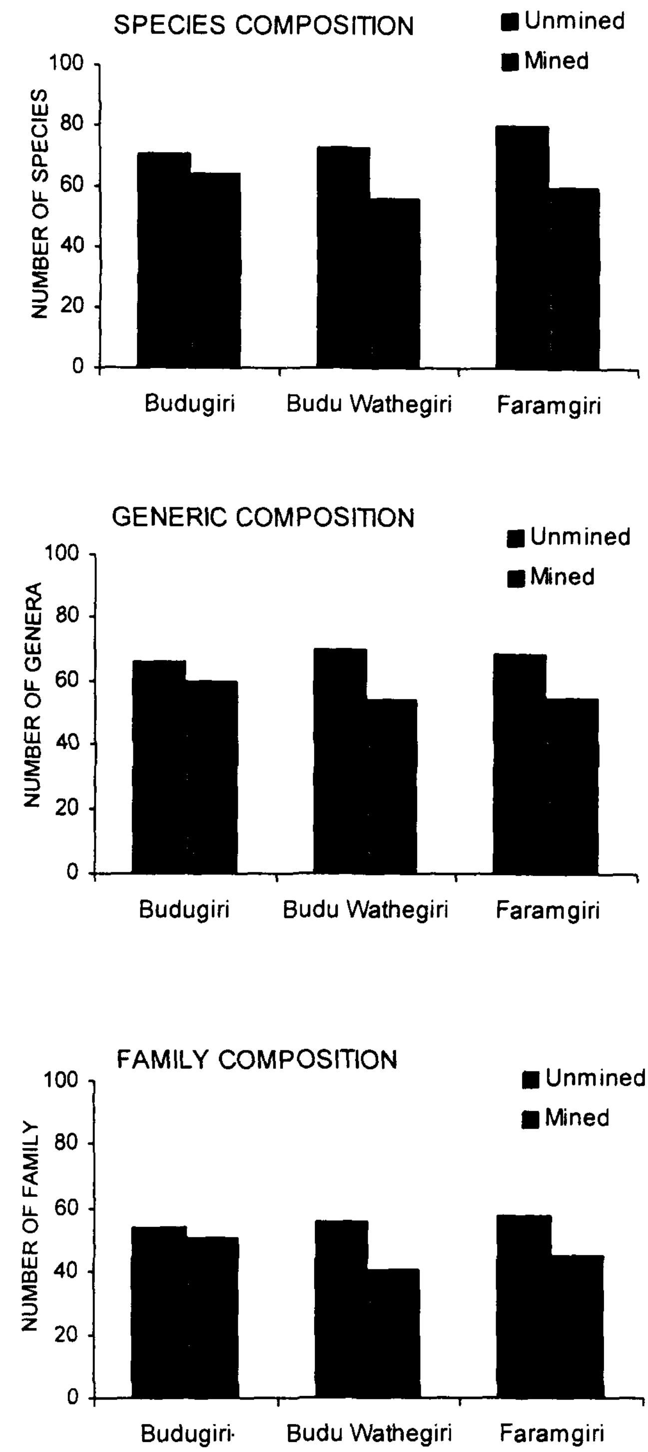


Fig. 4.1 Total number of species, genera and family found in the mined and unmined areas at three sites of Nokrek Biosphere Reserve

failure of initial colonization on mine wastes and attributed it to the lack of propagules capable of growing in such harsh environmental conditions. Similarly. Leisman (1957) and Gibson *et al.* (1985) stressed the importance of surrounding vegetation and the dissemination efficiency of propagules in spoil seed banks for rapid colonization of mined areas. Bradshaw & Chadwick (1980) working on the colliery spoils also reported that the number of species colonizing on spoil was influenced by its pH. Decline in pH in mine spoils is one of the serious problems associated with coal mining activity. Lowering of pH strongly affects the plant growth in various ways including the availability of a large number of essential nutrients in the soil.

Table 4.1 Species composition in mined and unmined areas at three sites in Nokrek Biosphere Reserve

Species Composition	Budugiri		Budu Wathegiri		Faramgiri	
	Unmined	Mined	Unmined	Mined	Unmined	Mined
Tree						
Number of species	38	25	31	26	44	25
Number of genera	35	24	29	26	36	20
Number of families	26	20	20	19	28	16
Shrub						
Number of species	5	6	16	13	18	17
Number of genera	5	5	15	12	16	17
Number of families	5	5	14	12	14	14
Herb						
Number of species	28	33	26	17	18	18
Number of genera	26	31	26	16	17	18
Number of families	23	26	22	10	16	15

Table 4.2 List of species found in mined and unmined areas in Nokrek Biosphere Reserve

A. Budugiri

Unmined Species	Family	Mined Species	Family
Tree species			
Acacia pennata (Linn.) Willd	Memosaceae	*Acacia pennata* (Linn.) Willd	Memosaceae
Antidesma acuminatum Wall. Ex Wt	Euphorbiaceae	*Albizia chinensis* (Osb.) Merr.	Memosaceae
Aporusa oblonga Muell. -Arg.	Euphorbiaceae	*Alchornea tiliaefolia* Muell.-Arg.	Euphorbiaceae
Artemisia nilagirica (Clarke.) Pamp.	Asteraceae	*Anacardium occidentale* linn.	Anacardiaceae
Casearia kurzii Cl.	Flacourtiaceae	*Aporusa oblonga* Muell. -Arg.	Euphorbiaceae
Castanopsis indica A.DC.	Fagaceae	*Bauhinia variegata* Linn.	Cesalpiniaceae
Castanopsis kurzii (Hance) Biswas	Fagaceae	*Bridelia monoica* (Lour.) Merr.	Euphorbiaceae
Citrus medica Linn.	Rutaceae	*Bridelia stipularis* Bl.	Euphorbiaceae
Clausena heptaphylla (Roxb.) W. & A.	Rutaceae	*Callicarpa arborea* Roxb.	Verbenaceae
Cleidion spiciflorum (Burm.) Merr.	Verbenaceae	*Cordia grandis* Roxb.	Boraginaceae
Daphne composita (L.f.) Gilg	Thymeliaceae	*Duabanga grandiflora* (Roxb.ex.DC.) Walp	Sonneratiaceae
Dysoxylum gobara (Buch.-Ham.) Merr.	Meliaceae	*Echinocarpus murex* Benth.	Elaeocarpaceae
Echinocarpus murex Benth.	Elaeocarpaceae	*Erythrina stricta* Roxb.	Leguminoseae
Ficus gasparriniana Miq.	Moraceae	*Euonymus attenuatus* Laws.	Celastraceae
Garcinia paniculata (G. Don.) Roxb.	Clusiaceae	*Ficus hispida* Linn. f.	Moraceae
Glochidion oblatum Hk.f.	Euphorbiaceae	*Glochidion oblatum* Hk.f.	Euphorbiaceae
Helicia nilagirica Bedd.	Proteaceae	*Macaranga denticulata* (Bl.) Muell.-Arg.	Euphorbiaceae
Homonia riparia Lour.	Euphorbiaceae	*Meliosma wallichii* Planch .ex. Hk.f.	Sabiaceae
Kydia calycina Roxb.	Malvaceae	*Prunus cerasoides* D. Don	Rosaceae
Litsea cubeba Lour.	Lauraceae	*Randia wallichii* Hk.f.	Rubiaceae
Litsea salicifolia (Roxb. Ex Nees) Hk.f.	Lauraceae	*Saurauia nepaulensis* DC.	Saurauiaceae
Macaranga denticulata (Bl.) Muell.-Arg.	Euphorbiaceae	*Schima wallichii* (DC.) Korth.	Theaceae
Macropanax undulatus (Wall ex D. Don) Seem	Araliaceae	*Spondias pinnata* (Linn.f) Kurze.	Anacardiaceae
Maesa indica (Roxb.) Wall.	Myrsinaceae	*Sterculia hamiltonii* (O) Ktze.	Sterculiaceae
Maesa tetrandra (Roxb.) DC.	Myrsinaceae	*Writhtia coccinea* Roxb.	Apocynaceae
Melodinus khasianas Hk.f.	Apocynaceae		
Micromelum integrimum (Roxb.) Wt.&Arn	Rutaceae		
Ostodes paniculata Bl.	Euphorbiaceae		
Picrasma javanica Bl.	Simaroubaceae		
Randia longiflora Lamk.	Rubiaceae		
Rhus javanica Linn.	Anacardiaceae		
Saprosma ternatum Hk.f.	Rubiaceae		
Skimmia laureola (DC.) Sieb ex Walp.	Rutaceae		
Sterculia hamiltonii (O) Ktze.	Sterculiaceae		
Syzygium cumini (Linn.) Skeels	Myrtaceae		
Terminalia bellerica (Gaertn) Roxb.	Combretaceae		
Tetrameles nudiflora R. Br.	Tetramelaceae		
Zizyphus mauritiana Lamk.	Rhamnaceae		
Shrub species			
Ardisia odontophylla DC	Myrsinaceae	*Agapetes variegata* Roxb.	Ericaceae
Calophyllum polyanthum Choisy	Euphorbiaceae	*Citrus* sp.	Rutaceae
Citrus sp.	Rutaceae	*Clerodendrum viscosum* Vent.	Vrbenaceae
Psychotria erratica Hk.f.	Rubiaceae	*Clerodendrum wallichii* Merr.	Verbenaceae
Rubus ellipticus Sm.	Rosaceae	*Dracaena angustifolia* Roxb.	Agavaceae
		Elscholtzia blanda Benth.	Lamiaceae
Herb species			
Arisaema tortuosum (Wall.) Schott.	Fabaceae	*Agapetes variegata* Roxb.	Ericaceae
Asplenium sp.	Aspleniaceae	*Cyperus compressus* Linn.	Cyperaceae
Cyanotis barbata	Commelinaceae	*Desmodium racemosa* (Thunb.) DC.	Fabaceae
Cynotis vaga Lour.	Commelinaceae	*Davallia* sp.	Davalliaceae
Davallia sp.	Davalliaceae	*Digitaria ciliaris* (Reitz.) Koel.	Poaceae

Dischidia nummularia R.Br.	Asclepiadaceae	*Embelia ribes* Burn. F	Myrsinaceae
Elatostemma rupestre (D.Don) Wedd.	Urticaceae	*Eupatorium adenophorum* Spreng.	Asteraceae
Erythroxylum kunthianum Wall. ex Kurz.	Erythroxylaceae	*Eupatorium odoratum* Linn.	Asteraceae
Gleichenia sp.	Glecheniaceae	*Hedyotis scandence* D. Don.	Rubiaceae
Hiptage benghalensis (Linn.) Kurz.	Malpighiaceae	*Hiptage benghalensis* (Linn.) Kurz.	Malpighiaceae
Hoya lanceolata Wall ex D. Don.	Asclepiadaceae	*Ipomea simosa*	Convolvulaceae
Lygodium sp.	Schizaeaceae	*Jasminium lanceolarum* Roxb.	Oleaceae
Marchantia sp.	Marchantiaceae	*Leea crispa* Linn.	Leeaceae
Molineria capitulata Lour.	Hypoxidaceae	*Lygodium* sp.	Schizaeaceae
Olax acuminata Wall.	Oleaceae	*Morinda angustifolia* Roxb.	Rubiaceae
Osmunda javanica	Osmundaceae	*Murrya paniculata* Linn.	Rutaceae
Paedaria foetida Linn.	Poaceae	*Ophiopogon parviflorus* (Hook) f. Hara.	Liliaceae
Piper longum Linn.	Rubiaceae	*Oxalis* sp.	Oxallidaceae
Pogestemon auricularis Hask.	Acanthaceae	*Phyllanthus raticulatus* Poir.	Euphorbiaceae
Polygala glomerata Lour.	Polygonaceae	*Piper thomsonii* Hk.f.	Piperaceae
Psychotria adenophylla Wall.	Rubiaceae	*Plantago major* Hook.f.	Plantaginaceae
Psychotria erratica Hk.f.	Rubiaceae	*Plectranthus ternifolius* D.Don	Lamiaceae
Pteris sp.	Pteridaceae	*Pteris* sp.	Pteridaceae
Smilax ferox Kunth	Smilacaceae	*Sapondus pinnata* (Linn.f.) Kurz.	Anacardiaceae
Strobilanthus discolor Nees.	Acanthaceae	*Selinum striatum* Cl.	Apiaceae
Swertia pulchella D.Don.	Gentianaceae	*Senecio griffithii* Clarke.	Asteraceae
Tacca laevis Roxb.	Taccaceae	*Senecio scandens* Buch.-Ham.ex D.Don	Asteraceae
Vandelia multiflora (Roxb) D. Don.	Scrophulariaceae	*Solanum tora*	Solonaceae
		Stephania japonica (Thunb.) Miers.	Menispermaceae
		Tapiria hirsuta (Roxb.) Hk.f.	Orchidaceae
		Thysanolaena maxima (Roxb.) O. Ktze.	Poaceae
		Triumfetta tomentosa Bojer	Tiliaceae
		Zanthoxylum armatum Hk.F.	Rutaceae

B. Budu Wathegiri

Unmined		**Mined**	
Species	**Family**	**Species**	**Family**
Tree species			
Acacia pennata (Linn.) Willd	Memosaceae	*Acacia pennata* (Linn.) Willd	Memosaceae
Alangium chinensis (Lour.) Harms.	Sapindaceae	*Alangium chinensis* (Lour.) Harms.	Sapindaceae
Albizia chinensis (Osb.) Merr.	Memosaceae	*Albizia chinensis* (Osb.) Merr.	Memosaceae
Antidesma acuminatum Wall. Ex Wt	Euphorbiaceae	*Anacardium occidentale* linn.	Anacardiaceae
Aporusa oblonga Muell. -Arg.	Euphorbiaceae	*Aporusa oblonga* Muell. -Arg.	Euphorbiaceae
Carryota urens Linn.	Arecaceae	*Ardisia paniculata* Roxb.	Myrsinaceae
Casearia kurzii Cl.	Flacourtiaceae	*Bauhinia variegata* Linn.	Cesalpiniaceae
Castanopsis indica A.DC.	Fagaceae	*Beilshmiedia assamica* Meissn.	Lauraceae
Celtis tetrandra Roxb.	Ulmaceae	*Briedellia pubescens* Bl.	Euphorbiaceae
Citrus sp.	Rutaceae	*Callicarpa arborea* Roxb.	Verbenaceae
Dysoxylum gobara (Buch.-Ham.) Merr.	Meliaceae	*Cordia fragrantissima* Kurz.	Boraginaceae
Echinocarpus murex Benth.	Elaeocarpaceae	*Derris robusta* (Roxb. Ex DC.) Benth.	Fabaceae
Ficus racemosa Linn.	Morceae	*Duabanga grandiflora* (Roxb.ex.DC.) Walp	Sonneratiaceae
Garcinia paniculata (G. Don.) Roxb.	Clusiaceae	*Echinocarpus murex* Benth.	Elaeocarpaceae
Homonia riparia Lour.	Euphorbiaceae	*Erythrina stricta* Roxb.	Leguminoseae
Litsea cubeba Lour.	Lauraceae	*Ficus hispida* Linn. f.	Moraceae
Macaranga denticulata (Bl.) Muell.-Arg.	Euphorbiaceae	*Glochidion oblatum* Hk.f.	Euphorbiaceae
Macropanax undulatus (Wall ex D. Don) Seem	Araliaceae	*Macropanax undulatus* Wall ex D. Don Seem	Araliaceae
Maesa indica (Roxb.) Wall.	Myrsinaceae	*Meliosma wallichii* Planch .ex. Hk.f.	Sabiaceae
Mallotus phillipensis (Lam.) Muell.-Arg.	Euphorbiaceae	*Micromelum integrimum* (Roxb.) Wt.&Arn	Rutaceae
Melodinus khasianas Hk.f.	Apocynaceae	*Prunus cerasoides* D. Don	Rosaceae
Micromelum integrimum (Roxb.) Wt.&Arn	Rutaceae	*Randia wallichii* Hk.f.	Rubiaceae
Ostodes paniculata Bl.	Euphorbiaceae	*Sapium baccatum* Roxb.	Elaeocarpaceae
Ostodes sp.	Euphorbiaceae	*Saurauia nepaulensis* DC.	Saurauiaceae
Persea duthiei King. Ex. Hk.f.	Lauraceae	*Schima wallichii* (DC.) Korth.	Theaceae

Picrasma javanica Bl.	Simaroubaceae	*Spondias pinnata* (Linn.f) Kurze.	Anacardiaceae
Randia wallichii Hk.f.	Rubiaceae		
Saprosma ternatum Hk.f.	Rubiaceae		
Skimmia laureola (DC.) Sieb ex Walp.	Rutaceae		
Sterculia hamiltonii (O) Ktze.	Sterculiaceae		
Talauma hodgsonii Hk.f & Th.	Magnoliaceae		
Shrub species			
Acanthopanax aculeatum Seem.	Araliaceae	*Citrus medica* Linn.	Rutaceae
Aeschyranthus acuminatus DC	Gesneriaceae	*Citrus* sp.	Rutaceae
Citrus sp.	Rutaceae	*Cleirodendron wallichii* Merr.	Euphorbiiaceae
Dracaena angustifolia Roxb.	Agavaceae		
Dracaena elliptica Thunb.	Agavaceae	*Combretum acuminatum* Roxb.	Combretaceae
Elsholtzia blanda Benth.	Lamiaceae	*Crotalaria macrophylla* Willd.	Fabaceae
Embelia ribes Burm. F	Myrsinaceae	*Cyathula tomentosa* Miq.	Amaranthaceae
Clerodendrum wallichii Merr.	Verbenaceae	*Desmodium racemosum* (Thunb.) DC	Fabaceae
Erythroxylum kunthianum Wall. ex Kurz.	Erythroxylaceae	*Dracaena angustifolia* Roxb.	Agavaceae
Hiptage benghalensis (Linn.) Kurz.	Malpighiaceae	*Millitia pachycarpa*	Leguminaceae
Lantana camara Linn.	Verbenaceae	*Mussaenda roxburghii* Hk.f.	Rubiaceae
Melastoma malabathricum Linn.	Melastomataceae	*Stephania hernandifolia* (Wild.) Walp.	Menispermaceae
Olax acuminata Wall.	Oleaceae	*Vitex vestuta* Roxb.	Verbenaceae
Olea dioica Roxb.	Oleaceae	*Embelia ribes* Burn. F	Myrsinaceae
Sarchochlamys pulcherrima Gaud.	Urticaceae		
Viburnum foetidum Wall	Caprifoliceae		
Herb species			
Agave sisalana Engelm	Agavaceae	*Agave sisalana* Engelm	Agavaceae
Ainsliaea latifolia (D. Don) Sch.	Asteraceae	*Anaphalis adnata* Wall.ex DC.	Asteraceae
Asplenium sp.	Aspleniaceae	*Asplenium* sp.	Aspleniaceae
Curculigo orchioides Gaertn.	Hypoxidaceae	*Curculigo orchioides* Gaertn.	Hypoxidaceae
Cyanotis cristata (Linn.) D. Don.	Commelinaceae	*Davallia* sp.	Davalliaceae
Cyanotis vaga Lour.	Commelinaceae	*Digitaria ciliaris* (Reitz.) Koel.	Poaceae
Cyperus pilosus Vahal.	Cyperaceae	*Digitaria longiflora* Reitz.	Poaceae
Davallia sp.	Davalliaceae	*Eleusine corocana* (L.) Gaeth	Poaceae
Dischidia nummularia R.Br.	Asclepiadaceae	*Eulalia pallens* Hack.	Poaceae
Galinsoga parviflora Cav.	Asteraceae	*Eupatorium* sp.	Asteraceae
Gleichenia sp.	Glecheniaceae	*Impereta cylindrica* (Linn.) P. Beauv.	Poaceae
Hedychium coccineum Smith	Zinziberaceae	*Osmunda javanica*	Osmundaceae
Hiptage benghalensis (Linn.) Kurz.	Malpighiaceae	*Paedaria foetida* Linn.	Poaceae
Impereta cylindrica (Linn.) P. Beauv.	Poaceae	*Piper* sp.	Piperaceae
Molineria capitulata Lour.	Hypoxidaceae	*Polygala glomerata* Lour.	Polygonaceae
Olax acuminata Wall.	Oleaceae	*Senecio griffithii* Clarke.	Asteraceae
Osmunda javanica	Osmundaceae	*Wrightia coccinea* Roxb.	Rutaceae
Oxalis corniculata Linn.	Oxallidaceae		
Paedaria foetida Linn.	Poaceae		
Piper longum Linn.	Rubiaceae		
Polygala glomerata Lour.	Polygonaceae		
Polygonum capitatum D.Don.	Polygonaceae		
Swertia pulchella D.Don.	Gentianaceae		
Tacca laevis Roxb.	Taccaceae		
Tapiria hirsuta (Roxb.) Hk.f.	Orchidaceae		
Vandelia multiflora (Roxb) D. Don.	Scrophulariaceae		

C. Faramgiri

Unmined Species	Unmined Family	Mined Species	Mined Family
Tree species			
Acacia pennata (Linn.) Willd	Memosaceae	*Albizia chinensis* (Osb.) Merr.	Memosaceae
Albizia chinensis (Osb.) Merr.	Memosaceae	*Aporusa dioica* (Roxb.) Muell. –Agr.	Euphorbiaceae
Alnus nepalensis D.Don	Betulaceae	*Bauhinia variegata* Linn.	Cesalpiniaceae
Antidesma acuminatum Wall. Ex Wt	Euphorbiaceae	*Bridelia stipularis* Bl.	Euphorbiaceae
Antidesma diandrum (Roxb.) Roth	Euphorbiaceae	*Callicarpa arborea* Roxb.	Verbenaceae
Artemisia nilagirica (Clarke.) Pamp.	Asteraceae	*Camellia cauduca* Br.	Theaceae
Baccaurea sapida (Roxb.) Muel.-Arg.	Euphorbiaceae	*Castanopsis indica* A.DC.	Fagaceae
Beilshmiedia fagifolia Nees.	Lauraceae	*Castanopsis kurzii* (Hance) Biswas	Fagaceae
Beilshmiedia roxburghiana Nees.	Lauraceae	*Castanopsis purpurella* (Miq.) Balak	Fagaceae
Bridelia stipularis Bl.	Euphorbiaceae	*Celastrus robustus* Roxb.	Celastraceae
Calophyllum polyanthum Choisy	Euphorbiaceae	*Duabanga grandiflora* (Roxb.ex.DC.) Walp	Sonneratiaceae
Camellia sinensis (Linn.) O.Ktze	Theaceae	*Erythrina stricta* Roxb.	Leguminoseae
Carryota urens Linn.	Arecaceae	*Ficus hispida* Linn. f.	Moraceae
Castanopsis hystrix	Fagaceae	*Ficus racemosa* Linn.	Morceae
Castanopsis indica A.DC.	Fagaceae	*Macaranga denticulata* (Bl.) Muell.-Arg.	Euphorbiaceae
Castanopsis kurzii (Hance) Biswas	Fagaceae	*Maesa tetrandra* (Roxb.) DC.	Myrsinaceae
Castanopsis purpurella (Miq.) Balak	Fagaceae	*Meliosma wallichii* Planch .ex. Hk.f.	Sabiaceae
Celtis tetrandra Roxb.	Ulmaceae	*Prunus wallichii* Steud.	Rosaceae
Daphne composita (L.f.) Gilg	Thymeliaceae	*Randia fasciculata* DC.	Rubiaceae
Derris robusta (Roxb. Ex DC.) Benth.	Fabaceae	*Randia longiflora* Lamk.	Rubiaceae
Dysoxylum gobara (Buch.-Ham.) Merr.	Meliaceae	*Randia wallichii* Hk.f.	Rubiaceae
Echinocarpus murex Benth.	Elaeocarpaceae	*Sapium baccatum* Roxb.	Elaeocarpaceae
Euonymous lawsonii Cl & Pr.	Celastraceae	*Saurauia nepaulensis* DC.	Saurauiaceae
Ficus elastica Roxb. Ex Horneum.	Moraceae	*Schima wallichii* (DC.) Korth.	Theaceae
Ficus hispida Linn. f.	Moraceae	*Spondias pinnata* (Linn.f) Kurze.	Anacardiaceae
Ficus racemosa Linn.	Morceae		
Gaultheria fragrantissima Wall	Ericaceae		
Glycosmis arborea (Roxb.) DC.	Rutaceae		
Helicia nilagirica Bedd.	Proteaceae		
Homonia riparia Lour.	Euphorbiaceae		
Ilex odorata D.Don.	Aquifoliaceae		
Lindera caudata Benth.	Lauraceae		
Litsea cubeba Lour.	Lauraceae		
Litsea salicifolia (Roxb. Ex Nees) Hk.f.	Lauraceae		
Macaranga denticulata (Bl.) Muell.-Arg.	Euphorbiaceae		
Macropanax undulatus (Wall ex D. Don) Seem	Araliaceae		
Maesa indica (Roxb.) Wall.	Myrsinaceae		
Melodinus khasianas Hk.f.	Apocynaceae		
Micromelum integrimum (Roxb.) Wt.&Arn	Rutaceae		
Ostodes paniculata Bl.	Euphorbiaceae		
Picrasma javanica Bl.	Simaroubaceae		
Randia longiflora Lamk.	Rubiaceae		
Saprosma ternatum Hk.f.	Rubiaceae		
Skimmia laureola (DC.) Sieb ex Walp.	Rutaceae		
Shrub species			
Aeschyranthus acuminatus DC.	Gesneriaceae	*Agapetes variegata* Roxb.	Ericaceae
Casearia vareca Roxb.	Flacourtiaceae	*Baliospermum calycina* Muell.-Arg.	Euphorbiaceae
Casia alata Linn.	Ceasalpiniaceae	*Citrus medica* Linn.	Rutaceae
Citrus medica Linn.	Rutaceae	*Combretum acuminatum* Roxb.	Combretaceae
Citrus sp.	Rutaceae	*Cyathula tomentosa* Miq.	Amaranthaceae
Croton caudatus Geisel.	Euphorbiaceae	*Elastostema rupestre* (D. Don) Wedd.	Urticaceae
Cyathula tomentosa Miq.	Amaranthaceae	*Embelia ribes* Burm. F	Myrsinaceae
Desmodium racemosa (Thunb.) DC.	Fabaceae	*Jasminium adenophyllum* DC.	Oleaceae
Dracaena angustifolia Roxb.	Agavaceae	*Lantana camara* Linn.	Verbenaceae

Dracaena elliptica Thunb.	Agavaceae	*Melastoma malabathricum* Linn.	Melastomataceae
Embelia ribes Burn.	Myrsinaceae	*Mimosa pudica* Linn.	Memosaceae
Elsholtzia blanda Benth.	Lamiaceae	*Olax acuminata* Wall.	Oleaceae
Erythroxylum kunthianum Wall. ex Kurz.	Erythroxylaceae	*Olea dentata* Wall.ex DC.	Oleaceae
Glycosmis arborea (Roxb.) DC	Rutaceae	*Smilax ferox* Kunth	Smilacaceae
Hedyotis scandence D. Don.	Rubiaceae	*Sonerila maculata* Roxb.	Melastomataceae
Pogestemon auricularis Hask.	Acanthaceae	*Sterculia roxburghii* Wall.	Sterculiaceae
Psychotria erratica Hk.f.	Rubiaceae	*Glycosmis arborea* (Roxb.) DC	Rutaceae
Smilax ferox Kunth	Smilacaceae		

Herb species

Asplenium sp.	Aspleniaceae	*Agapetes variegata* Roxb.	Ericaceae
Curculigo orchioides Gaertn.	Hypoxidaceae	*Anaphalis adnata* Wall.ex DC.	Asteraceae
Cynodon ternatus A. Rich.	Cyperaceae	*Asplenium* sp.	Aspleniaceae
Cyanotis vaga Lour.	Commelinaceae	*Curculigo orchioides* Gaertn.	Hypoxidaceae
Cyperus pilosus Vahal.	Cyperaceae	*Cyanotis barbata*	Commelinaceae
Davallia sp.	Davalliaceae	*Cyperus compressus* Linn.	Cyperaceae
Galinsoga parviflora Cav.	Asteraceae	*Eupatorium adenophorum* Spreng.	Asteraceae
Gleichenia sp.	Glecheniaceae	*Gleichenia* sp.	Glecheniaceae
Hedychium coccineum Smith	Zinziberaceae	*Inula cappa* (Buch.-Ham. ex D.Don.) DC.	Asteraceae
Lycopodium sp	Lycopodiaceae	*Ophiopogon parviflorus* (Hook) f. Hara.	Liliaceae
Piper longum Linn.	Rubiaceae	*Piper griffithii* C.DC.	Piperaceae
Polygala glomerata Lour.	Polygonaceae	*Plantago major* Hook.f.	Plantaginaceae
Polygonum capitatum D.Don.	Polygonaceae	*Polygala glomerata* Lour.	Polygonaceae
Pteris sp.	Pteridaceae	*Prunus cerasoides* D.Don.	Rosaceae
Swertia pulchella D.Don.	Gentianaceae	*Pteris* sp.	Pteridaceae
Tacca laevis Roxb.	Taccaceae	*Senecio griffithii* Clarke.	Asteraceae
Thysanolaena agrostis Nees.	Poaceae	*Solanum tora*	Solonaceae
Vandelia multiflora (Roxb) D. Don.	Scrophulariaceae	*Swertia pulchella* D.Don.	Gentianaceae
		Thysanolaena maxima (Roxb.) O. Ktze.	Poaceae

Table 4.3 Plant species found exclusively in unmined and mined areas of the Nokrek Biosphere Reserve

Unmined	Mined
Tree species	
Antidesma acuminatum Wall. Ex Wt	*Alchornea tiliaefolia* Muell.-Arg.
Artemisia nilagirica (Clarke.) Pamp.	*Anacardium occidentale* linn.
Casearia kurzii Cl.	*Bauhinia variegata* Linn.
Citrus medica Linn.	*Bridelia monoica* (Lour.) Merr.
Clausena heptaphylla (Roxb.) W. & A.	*Callicarpa arborea* Roxb.
Cleidion spiciflorum (Burm.) Merr.	*Cordia grandis* Roxb.
Daphne composita (L.f.) Gilg	*Duabanga grandiflora* (Roxb.ex.DC.) Walp
Dysoxylum gobara (Buch.-Ham.) Merr.	*Erythrina stricta* Roxb.
Ficus gasparriniana Miq.	*Euonymus attenuatus* Laws.
Garcinia paniculata (G. Don.) Roxb.	*Meliosma wallichii* Planch .ex. Hk.f.
Helicia nilagirica Bedd.	*Prunus cerasoides* D. Don
Homonia riparia Lour.	*Saurauia nepaulensis* DC.
Kydia calycina Roxb.	*Schima wallichii* (DC.) Korth.
Litsea cubeba Lour.	*Spondias pinnata* (Linn.f) Kurze.
Litsea salicifolia (Roxb. Ex Nees) Hk.f.	*Writhtia coccinea* Roxb.
Maesa indica (Roxb.) Wall.	
Melodinus khasianas Hk.f.	
Ostodes paniculata Bl.	
Picrasma javanica Bl.	
Rhus javanica Linn.	
Saprosma ternatum Hk.f.	
Skimmia laureola (DC.) Sieb ex Walp.	
Sterculia hamiltonii (O) Ktze.	
Syzygium cumini (Linn.) Skeels	
Terminalia bellerica (Gaertn) Roxb.	
Tetrameles nudiflora R. Br.	
Zizyphus mauritiana Lamk.	
Shrub species	
Ardisia odontophylla DC	*Agapetes variegata* Roxb.
Calophyllum polyanthum Choisy	*Clerodendrum viscosum* Vent.
Psychotria erratica Hk.f.	*Clerodendrum wallichii* Merr.
Rubus ellipticus Sm.	*Elscholtzia blanda* Benth.
Herb species	
Arisaema tortuosum (Wall.) Schott.	*Agapetes variegata* Roxb.
Cynotis vaga Lour.	*Cyperus compressus* Linn.
Dischidia nummularia R.Br.	*Desmodium racemosa* (Thunb.) DC.
Elatostemma rupestre -(D.Don) Wedd.	*Digitaria ciliaris* (Reitz.) Koel.
Erythroxylum kunthianum Wall. ex Kurz.	*Embelia ribes* Burn. F
Hoya lanceolata Wall ex D. Don.	*Eupatorium adenophorum* Spreng.
Marchantia sp.	*Eupatorium odoratum* Linn.

Molineria capitulata Lour.	*Hedyotis scandence* D. Don.
Olax acuminata Wall.	*Ipomea simosa*
Piper longum Linn.	*Jasminium lanceolarum* Roxb.
Pogestemon auricularis Hask.	*Leea crispa* Linn.
Psychotria erratica Hk.f.	*Morinda angustifolia* Roxb.
Smilax ferox Kunth	*Murrya paniculata* Linn.
Strobilanthus discolor Nees.	*Ophiopogon parviflorus* (Hook) f. Hara.
Tacca laevis Roxb.	*Oxalis* sp.
Vandelia multiflora (Roxb) D. Don.	*Phyllanthus raticulatus* Poir.
	Piper thomsonii Hk.f.
	Plantago major Hook.f.
	Plectranthus ternifolius D.Don
	Sapondus pinnata (Linn.f.) Kurz.
	Selinum striatum Cl.
	Senecio griffithii Clarke.
	Senecio scandens Buch.-Ham.ex D.Don
	Solanum tora
	Stephania japonica (Thunb.) Miers.
	Thysanolaena maxima (Roxb.) O. Ktze.
	Triumfetta tomentosa Bojer
	Zanthoxylum armatum Hk.F.

COMMUNITY CHARACTERISTICS

DENSITY

The total plant density in mined areas ranged between 3250 and 4161 stems per ha while that in the unmined areas ranged between 6720 and 7260 stems ha $^{-1}$. The density of trees, shrubs and herbs in mined areas were significantly lower than the unmined areas at all the three sites (Fig. 4.2).

The unmined areas had greater plant diversity compared to the mined stands because of acidic pH, moisture stress and nutrient property of the latter. Lyngdoh (1995) and Das Gupta's (1999) works lend support to the present findings.

DOMINANCE PATTERN

The dominance was different for tree, shrub and herb components. The dominance was concentrated in one or two species in case of shrub and herb, while in case of trees, dominance was distributed more or less evenly among many species. The dominant species in mined and unmined areas even at the same site were also different except that in Faramgiri, where *Ficus racemosa* was the dominant tree species both in mined and unmined areas. The dominant tree species in the unmined areas at three sites was also different. At Budugiri, *Kydia calycina* and *Dysoxylum gobara* were dominant and codominant, while at Budu Wathegiri, *Ostodes paniculata* and *Persea duthei* were dominant and codominant, respectively. However, in mined areas there was some similarity in dominant species composition. At Budugiri mined areas *Bridelia monoica*

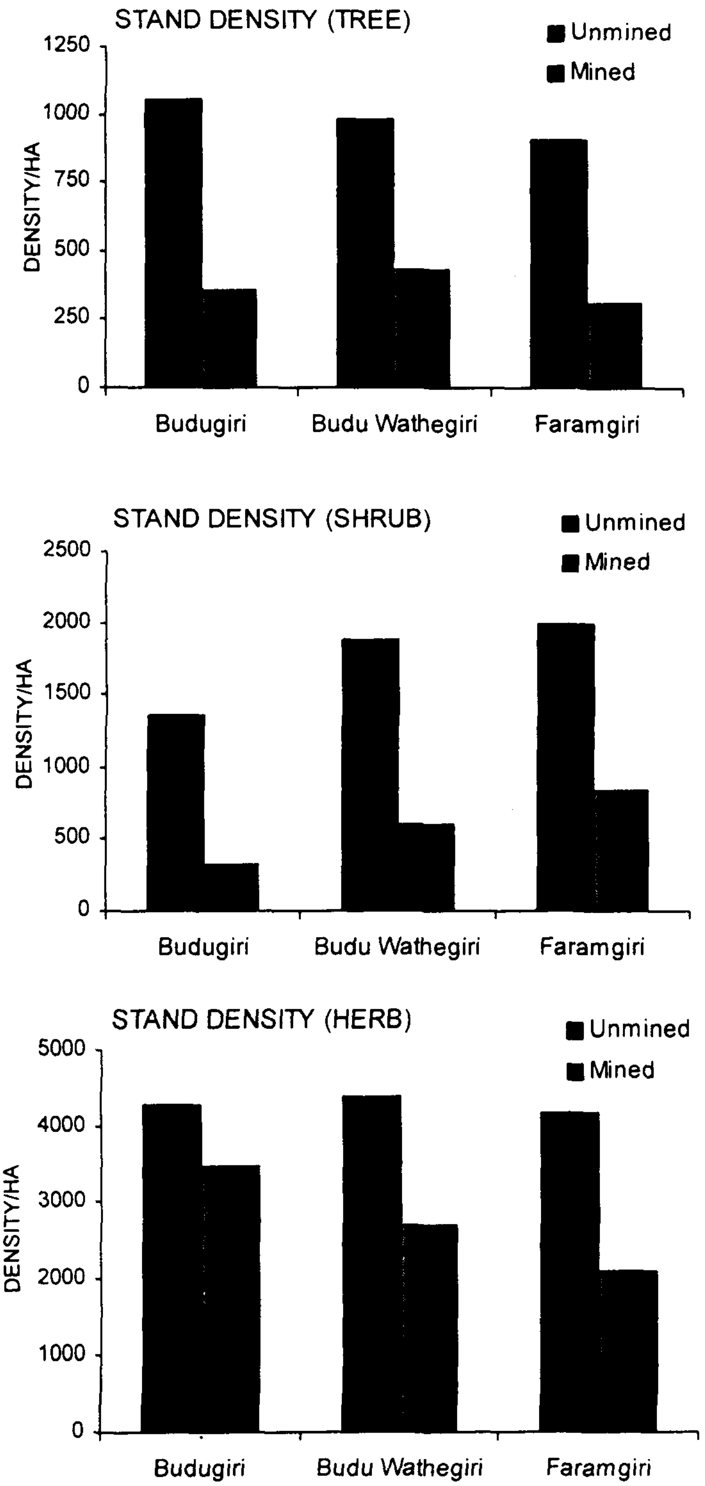


Fig. 4.2 Stand density (stem ha^{-1}) as affected by mining at three sites of Nokrek Biosphere Reserve

was the dominant tree species. *Schima wallichii, Bauhinia variegata* and *Spondias pinnata* were codominant species. *Ficus hispida* was dominant at Faramgiri mined site. *Ficus racemosa, Meliotus wallichii* and *Schima wallichii* were codominance at this site. *Schima wallichii* and *Spondius pinnata* were dominant in mined sites at Budu Wathegiri while *Ficus hispida* and *Meliotus wallichii* were codominance at this site. The common important tree species found at all the three mined sites were, *Schima wallichii, Spondius pinnata, Bauhinia variegata, Ficus hispida* and *Meliotus wallichii.* The common important tree species in the unmined sites were *Dysoxylum gobara, Ostodes paniculata* and *Macropanax undulatus. Citrus* sp. *Hiptage benghalensis, Clerodendrum wallichii, Elsholtzia blanda, Psychotria erratica* were the dominant shrub species in the unmined areas while in the mined areas *Clerodendrum wallichii, Agapetes variegata, Millitia pachycarpa, Desmodium racemosa, Lantana camara, Olea dentana* were dominant. Among the herb species *Davallia* sp. *Piper longrum, Asplenium* sp. were the dominant in unmined areas while in the mined areas *Eupatorium adenophorum, Pteris* sp., *Thysanolaena maxima, Asplenium* sp., *Eleusine corocana* and *Inula cappa* were dominant species.

Dominance-diversity curves have been used to interprete the dominance of different species in the community in relation to resource apportionment and niche space (Whittaker 1975). The curves (Fig. 4.3) in the unmined sites resemble the log normal curve 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

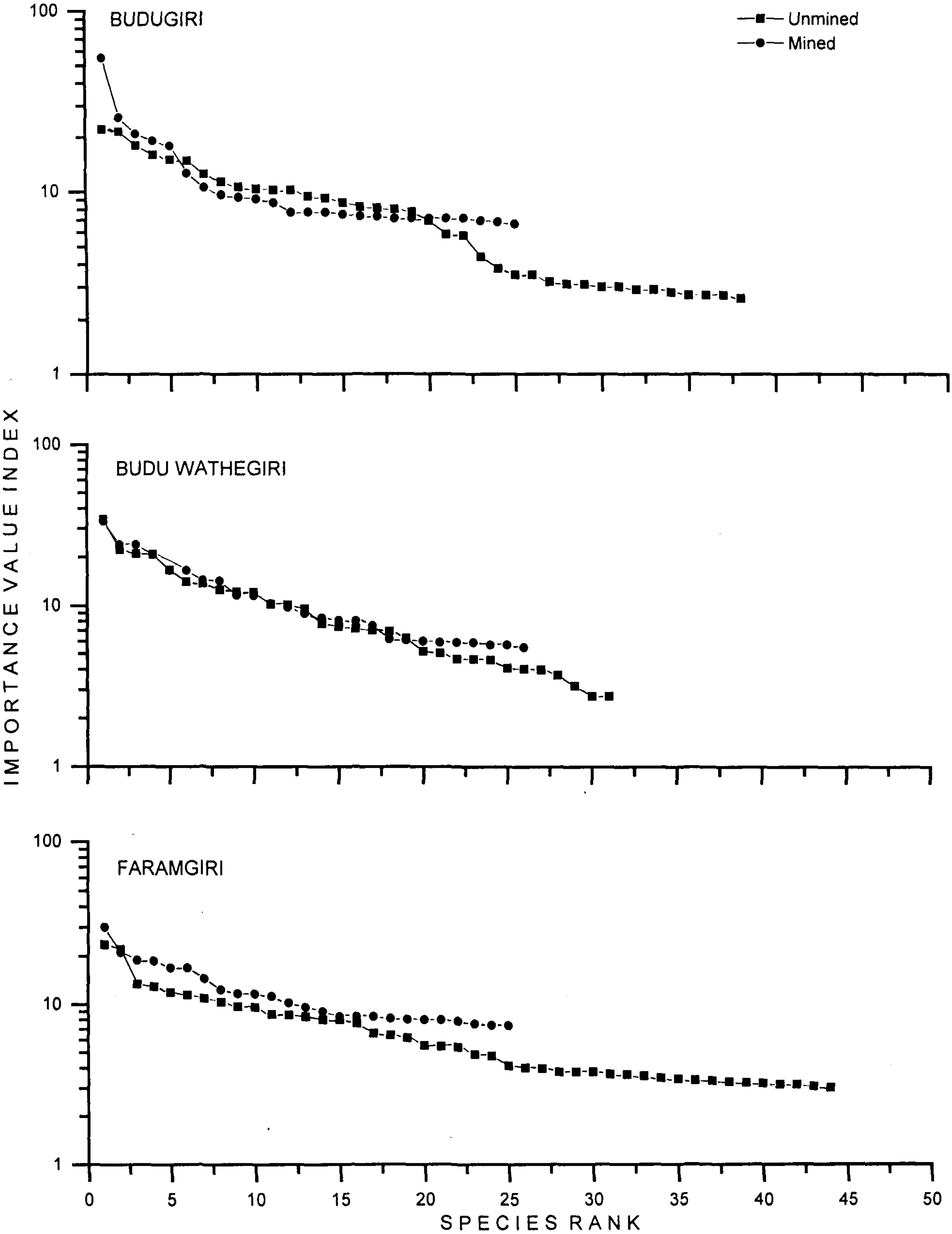


Fig. 4.3 Dominance-diversity curves of tree species in unmined and mined areas in Nokrek Biosphere Reserve.

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 stressed 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 4.4 Importance Value Index of tree species found in the mined and unmined areas at three sites in Nokrek Biosphere Reserve

	Importance Value Index					
	Budugiri		Budu Wathegiri		Faramgiri	
Tree Species	Unmined	Mined	Unmined	Mined	Unmined	Mined
Acacia pennata	3	6.8	6.9	5.7	3.6	-
Alangium chinensis	-	-	14.1	5.9	-	-
Albizia chinensis	-	7.1	13.7	10.3	3.7	16.9
Alchornea tiliaefolia	-	7.1	-	-	-	-
Alnus nepalensis	-	-	-	-	3.6	-
Anacardium occidentale	-	12.6	-	14.2	-	-
Antidesma acuminatum	10.2	-	7.7	-	3.2	-
Antidesma diandrum	-	-	-	-	5.5	-
Aporusa dioica	-	-	-	-	-	11.6
Aporusa oblonga	4.4	10.5	12.2	11.6	-	-
Ardisia paniculata	-	-	-	11.5	-	-
Artemisia nilagirica	18	-	-	-	3.3	-
Bauhinia variegata	-	20.8	-	16.5	-	7.4
Baccaurea sapida	-	-	-	-	10.9	-
Beilshmiedia assamica	-	-	-	7.5	-	-
Beilshmiedia fagifolia	-	-	-	-	3.2	-
Beilshmiedia roxburghiana	-	-	-	-	4.1	-
Bridelia monoica	-	55.2	-	-	-	-
Briedellia pubescens	-	-	-	6.2	-	-
Bridelia stipularis	-	7.7	-	-	8	8.4
Callicarpa arborea	-	9.6	-	8	-	11.2
Calophyllum polyanthum	-	-	-	-	3.8	-
Camellia cauduca	-	-	-	-	-	7.8
Camellia sinensis	-	-	-	-	3.4	-
Carryota urens	-	-	10.1	-	22	-
Casearia kurzii	8.2	-	34	-	-	-
Castanopsis hystrix	-	-	-	-	3.1	-
Castanopsis indica	14.8	-	10.2	-	11.5	9.0
Castanopsis kurzii	9.4	-	-	-	13.4	8.1
Castanopsis purpurella	-	-	-	-	6.6	8.4
Celastrus robustus	-	-	-	-	-	12.3
Celtis tetrandra	-	-	5.1	-	3.4	-
Citrus medica	6.9	-	-	-	-	-
Citrus sp.	-	-	16.6	-	-	-
Clausena heptaphylla	11.3	-	-	-	-	-
Cleidion spiciflorum	2.7	-	-	-	-	-
Cordia fragrantissima	-	-	-	8.1	-	-
Cordia grandis	-	7.3	-	-	-	-
Daphne composita	2.7	-	-	-	3.8	-
Derris robusta	-	-	-	5.7	3.2	-

Duabanga grandiflora	-	7.7	-	8.9	-	14.5
Dysoxylum gobara	21.5	-	3.7	-	11.8	-
Echinocarpus murex	15	7.2	2.7	5.9	8.0	-
Erythrina stricta	-	17.9	-	33.2	-	10.21
Euonymus attenuatus	-	9.1	-	-	-	-
Euonymous lawsonii	-	-	-	-	9.6	-
Ficus elastica	-	-	-	-	4.8	-
Ficus gasparriniana	3.2	-	-	-	-	-
Ficus hispida	-	6.9	-	20.7	3.3	30.1
Ficus racemosa	-	-	4.6	-	23.5	18.7
Garcinia paniculata	7.7	-	3.2	-	-	-
Gaultheria fragrantissima	-	-	-	-	7.6	-
Glochidion oblatum	2.9	7.2	-	5.9	-	-
Glycosmis arborea	-	-	-	-	8.7	-
Helicia nilagirica	2.6	-	-	-	5.5	-
Homonia riparia	3.0	-	5.2	-	4.7	-
Ilex odorata	-	-	-	-	5.4	-
Kydia calycina	22.1	-	-	-	-	-
Lindera caudata	-	-	-	-	3.9	-
Litsea cubeba	3.5	-	7.0	-	3.1	-
Litsea salicifolia	8.7	-	-	-	3.3	-
Macaranga denticulata	3.8	6.6	7.4	-	8.6	7.3
Macropanax undulatus	10.3	-	20.8	5.5	12.9	-
Maesa indica	15.9	-	9.5	-	9. 7	-
Maesa tetrandra	10.6	-	-	-	-	7.5
Mallotus phillipensis	-	-	4.6	-	-	-
Meliosma wallichii	-	8.7	-	16.6	-	21.1
Melodinus khasianas	5.7	-	4.6	-	6.4	-
Micromelum integrimum	10.2	-	12.1	9.8	8.4	-
Ostodes paniculata	9.2	-	22.2	-	3.5	-
Ostodes sp.	-	-	4.1	-	-	-
Persea duthiei	-	-	21.0	-	-	-
Picrasma javanica	3.1	-	3.9	-	4.0	-
Prunus cerasoides	-	7.7	-	14.3	-	-
Prunus wallichii	-	-	-	-	-	9.6
Randia fasciculata	-	-	-	-	-	7.9
Randia longiflora	8.0	-	-	-	3.8	8.4
Randia wallichii	-	7.5	6.2	6.1	-	8.2
Rhus javanica	3.5	-	-	-	-	-
Sapium baccatum	-	-	-	8.4	-	11.6
Saprosma ternatum	2.9	-	7.2	-	10.3	-
Saurauia nepaulensis	-	7.3	-	6.0	-	7.9
Schima wallichii.	-	25.8	-	23.8	-	18.9
Skimmia laureola	8.1	-	12.5	-	6.2	-
Spondias pinnata	-	19.1	-	23.8	-	16.9
Sterculia hamiltonii	3.1	9.3	2.7	-	-	-

Syzygium cumini	2.7	-	-	-	-	-
Talauma hodgsonii	-	-	4.0	-	-	-
Terminalia bellerica	12.4	-	-	-	-	-
Tetrameles nudiflora	2.8	-	-	-	-	-
Writhtia coccinea	-	7.2	-	-	-	-
Zizyphus mauritiana	5.8	-	-	-	-	-
	300	**300**	**300**	**300**	**300**	**300**

'-'Indicates absence of the species

Table 4.5 Importance Value Index of shrub species found in the mined and unmined areas at three sites in Nokrek Biosphere Reserve

	Importance Value Index					
	Budugiri		Budu Wathegiri		Faramgiri	
Shrub species	**Unmined**	**Mined**	**Unmined**	**Mined**	**Unmined**	**Mined**
Acanthopanax aculeatum	-	-	7.3	-	-	-
Aeschyranthus acuminatus	-	-	14.2	-	-	-
Agapetes variegata	-	64.6	-	-	-	23.3
Ardisia odonophylla	51.9	-	-	-	27.2	-
Baliospermum calycina	-	-	-	-	-	11.9
Casia alata	-	-	-	-	22.1	-
Citrus medica	-	-	-	16.3	29.1	11.9
Citrus sp.	109.4	36.2	13.47	19.9	6.46	-
Clerodendrum viscosum	-	43.0	-	-	-	-
Clerodendrum wallichii	-	69.9	50.6	17.9	-	-
Combretum acuminatum	-	-	-	17.1	-	13.9
Croton caudatus	-	-	-	-	6.4	-
Cyathula tomentosa	-	-	-	22.4	16.9	13.9
Desmodium racemosa	-	-	-	44.7	8.4	-
Dracaena angustifolia	-	30.3	27.9	23.7	13.8	-
Dracaena elliptica	-	-	32.2	-	18.1	-
Elscholtzia blanda	-	55.5	8.7	-	42.9	-
Embelia ribes	-	-	-	19.9	9.6	11.9
Erythroxylum kunthianum	-	-	30.1	-	16.9	-
Glycosmis arborea	-	-	-	-	15.1	16.4
Hedyotis scandence	-	-	-	-	5.6	-
Hiptage benghalensis	-	-	63.3	-	-	-
Jasminium adenophyllum	-	-	-	-	-	11.9
Lantana camara	-	-	-	-	-	43.9
Melastoma malabathricum	-	-	-	-	-	11.9
Millitia pachycarpa	-	-	-	56.2	-	-
Mimosa pudica	-	-	-	-	-	12.8
Mussaenda roxburghii	-	-	-	23.7	-	-
Olax acuminata	-	-	11.5	-	-	27.7
Olea dentata	-	-	-	-	-	42.7

Olea dioica	-	-	22.4	-	-	-
Pogestemon auricularis	-	-	-	-	25.4	-
Psychotria adenophylla	-	-	-	-	8.4	-
Psychotria erratica	84.9	-	-	-	13.7	-
Rubus ellipticus	52.92	-	-	-	-	-
Sarchochlamys pulcherrima	-	-	11.4	-	-	-
Smilax ferox	-	-	-	-	14.1	15.1
Sonerila maculata	-	-	-	-	-	16.4
Stephania hernandifolia	-	-	-	15.6	-	-
Sterculia roxburghii	-	-	-	-	-	13.9
Viburnum foetidum	-	-	7.0	-	-	-
Vitex vestuta	-	-	-	22.4	-	-
	300	**300**	**300**	**300**	**300**	**300.000**

'-'Indicates absence of the species

Table 4.6 Importance Value Index of herb species in the mined and unmined sites at three sites in Nokrek Biosphere Reserve

	Importance Value Index					
	Budugiri		Budu Wathegiri		Faramgiri	
Shrub species	**Unmined**	**Mined**	**Unmined**	**Mined**	**Unmined**	**Mined**
Agapetes variegata Roxb.	-	1.0	-	-	-	8.8
Agave sisalana Engelm	-	-	0.1	0.8	-	-
Ainsliaea latifolia (D. Don) Sch.	-	-	0.9	-	-	-
Anaphalis adnata Wall.ex DC.	-	-	-	13.2	-	12.6
Arisaema tortuosum (Wall.) Schott.	0.7	-	-	-	-	-
Asplenium sp.	32.6	-	31.8	18.3	34.1	8.9
Curculigo orchioides Gaertn.	-	-	1.8	8.6	1.9	7.9
Cyanotis barbata	4.9	-	-	-	-	11.7
Cyanotis cristata (Linn.) D. Don.	-	-	4.8	-	-	-
Cynodon ternatus A. Rich.	-	-	-	-	5.3	-
Cynotis vaga Lour.	0.9	-	0.9	-	0.9	-
Cyperus compressus Linn.	-	10.2	-	-	-	5.9
Cyperus pilosus Vahal.	-	-	22.3	-	23.8	-
Davallia sp.	46.0	-	44.7	28.0	47.4	-
Dendrocalamus sp.	-	-	-	2.1	-	-
Desmodium racemosa (Thunb.) DC.	-	11.1	-	-	-	-
Digitaria ciliaris (Reitz.) Koel.	-	-	-	2.2	-	-
Digitaria longiflora Reitz.	-	-	-	14.0	-	-
Dischidia nummularia R.Br.	0.7	-	0.7	-	-	-
Dracaena angustifolia Roxb.	-	9.8	-	-	-	-
Dracaena elliptica Thunb.	-	5.4	-	-	-	-
Elatostema rupestre (D.Don) Wedd.	1.2	-	-	-	-	-
Eleusine corocana (L.) Gaeth	-	-	-	21.3	-	-
Embelia ribes Burn. F	-	2.5	-	-	-	-

Erythroxylum kunthianum Wall. ex Kurz.	0.9	-	-	-	-	-
Eulalia pallens Hack.	-	-	-	21	-	-
Eupatorium adenophorum Spreng.	-	16.8	-	-	-	6.7
Eupatorium odoratum Linn.	-	8.2	-	-	-	-
Eupatorium sp.	-	-	-	6.9	-	-
Galinsoga parviflora Cav.	-	-	0.9	-	0.9	-
Gleichenia sp.	0.7	-	0.7	-	0.8	14.9
Hedychium coccineum Smith	-	-	1.5	-	1.6	-
Hedyotis scandence D. Don.	-	1.6	-	-	-	-
Hiptage benghalensis (Linn.) Kurz.	0.9	9.3	0.9	-	-	-
Hoya lanceolata Wall ex D. Don.	2.2	-	-	-	-	-
Impereta cylindrica (Linn.) P. Beauv.	-	-	1.3	11.4	-	-
Inula cappa (Buch.-Ham. ex D.Don.) DC.	-	-	-	-	-	16.4
Ipomea simosa	-	3.8	-	-	-	-
Jasminium lanceolarum Roxb.	-	8.5	-	-	-	-
Leea crispa Linn.	-	6.2	-	-	-	-
Lycopodium sp	-	-	-	-	25.6	-
Lygodium sp.	24.4	6.2	-	-	-	-
Marchantia sp.	0.9	-	-	-	-	-
Molineria capitulata Lour.	1.4	-	3.7	-	-	-
Morinda angustifolia Roxb.	-	8.1	-	-	-	-
Murrya paniculata Linn.	-	3.3	-	-	-	-
Olax acuminata Wall.	2.8	-	17.3	-	-	-
Ophiopogon parviflorus (Hook) f. Hara.	-	3.5	-	-	-	2.9
Osmunda javanica	3.8	-	0.7	10.4	-	-
Oxalis corniculata Linn.	-	-	10.5	-	-	-
Oxalis sp.	-	2.5	-	-	-	-
Paedaria foetida Linn.	0.7	-	43.4	0.8	-	-
Phyllanthus raticulatus Poir.	-	7.5	-	-	-	-
Piper griffithii C.DC.	-	-	-	-	-	4.6
Piper longum Linn.	44.2	-	0.7	-	46.7	-
Piper sp.	-	-	-	5.8	-	-
Piper thomsonii Hk.f.	-	2.7	-	-	-	-
Plantago major Hook.f.	-	0.8	-	-	-	33.0
Plectranthus ternifolius D.Don	-	2.8	-	-	-	-
Pogestemon auricularis Hask.	1.5	-	-	-	-	-
Polygala glomerata Lour.	0.7	-	0.7	13.5	0.8	-
Polygonum capitatum D.Don.	-	-	3.1	-	0.8	-
Pteris sp.	1.7	16.3	-	-	1.8	27.1
Sapondus pinnata (Linn.f.) Kurz.	-	7.1	-	-	-	-
Saprosma ternatum Hk.f.	3.2	-	-	-	-	-
Selinum striatum Cl.	-	14.2	-	-	-	-
Senecio griffithii Clarke.	-	4.0	-	17.5	-	6.5
Senecio scandens Buch.-Ham.ex D.Don	-	0.6	-	-	-	-
Smilax ferox Kunth	17.4	-	-	-	-	-
Solanum tora	-	1.4	-	-	-	4.4

Stephania japonica (Thunb.) Miers.	-	2.5	-	-	-	-
Strobilanthus discolor Nees.	0.7	-	-	-	-	-
Swertia pulchella D.Don.	1.4	-	2.4	-	-	-
Swertia pulchella D.Don.	-	-	-	-	1.4	7.2
Tacca laevis Roxb.	2.4	-	2.5	-	2.6	-
Tapiria hirsuta (Roxb.) Hk.f.	-	0.6	0.7	-	-	-
Thysanolaena agrostis Nees.	-	-	-	-	2.7	-
Thysanolaena maxima (Roxb.) O. Ktze.	-	16.4	-	-	-	20.4
Triumfetta tomentosa Bojer	-	3.3	-	-	-	-
Vandelia multiflora (Roxb) D. Don.	0.7	-	-	-	0.8	-
Wrightia coccinea Roxb.	-	-	-	6.2	-	-
Zanthoxylum armatum Hk.F.	-	2.1	-	-	-	-
	200	**200**	**200**	**200**	**200**	**200**

'-'Indicates absence of the species

SPECIES DIVERSITY

Shannon's diversity index for tree species was low in the mined sites than the unmined sites both at Budugiri and Faramgiri, indicating the adverse impact of mining on tree diversity (Table 4.7). However, at Budu Wathegiri, the trend was reverse. This could be attributed to the existence of bigger trees and causing less damage to the trees during mining operation by the miners. The diversity index for herbs increased with mining suggesting that mining operation enhanced the colonization of certain species in the newly created habitats due to mining.

Table 4.7 Shannon's Species Diversity Index in unmined and mined areas of Nokrek Biosphere Reserve

Plants	Budugiri		Budu Wathegiri		Faramgiri	
	Mined	**Unmined**	**Mined**	**Unmined**	**Mined**	**Unmined**
Tree	2.97	3.42	4.30	3.33	3.13	3.60
Shrub	1.75	1.34	2.39	2.33	2.65	2.74
Herb	2.37	2.25	2.65	2.25	2.62	2.01

IMPACT OF COAL MINING ON TREE POPULATION STRUCTURE

Density-CBH Distribution

The trees of medium girth class dominated both the mined and unmined areas at all the three sites. The trees of younger and older girth classes (i.e, 15-25 cm and >85 cm respectively) were much less in number. The density of trees irrespective of their girth classes was lower in the mined areas than the unmined areas (Fig. 4.4).

The trees of 35-45 cm girth class dominated both the mined and the unmined areas at Budugiri. At Budu Wathegiri area, the trees of 45-55 cm girth class had the highest density. In the mined area, the tree density was much lower and most of the trees (20.93%) were under 75-85 cm girth class. At Faramgiri unmined area, trees of 45-55 cm girth class had the highest density, while in the mined areas, the trees under the girth class of 25-35 cm had the maximum density of 92 trees/ha.

In all the unmined areas, the density was found from the study that density of young and middle size trees was higher than the old trees 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.

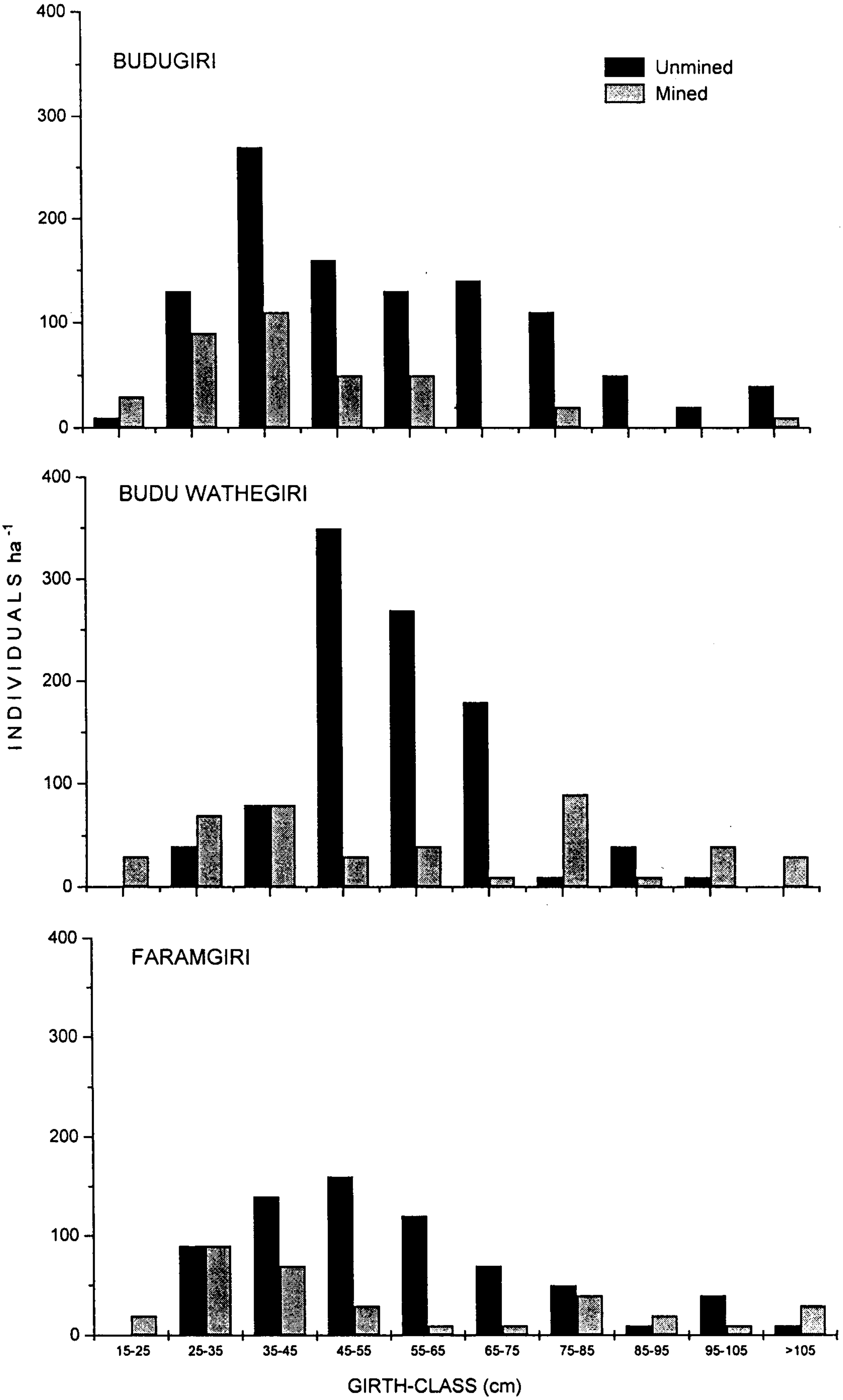


Fig. 4.4. Population structure of tree species in mined and unmined areas at three sites in Nokrek Biosphere Reserve

Basal Cover

The total basal area of trees in the unmined areas was significantly higher ($P<0.01$) than the mined areas at all the three sites. This could be attributed to the higher density as well as the presence of bigger girth class trees in the unmined sites (Fig. 4.5).

The basal area-CBH distribution pattern of tree species in the unmined areas were significantly different from that in the mined areas. In all the mined areas, the trees of smaller CBH classes had very low basal area in comparision to the unmined areas (Fig. 4.6).

An extremely low basal area for younger trees in mined sites indicates the removal of younger trees for mining activities. Such a trend in basal area-CBH distribution leads to the failure of the community to regenerate back naturally. Such forest communities could only be restored with management intervention. Similar trends were also observed by Paijman (1970) in New Guinea, Newbery *et al.* (1992) in Malayasia and Parthasarathi *et al.* (1997) in India for various disturbed forest stands.

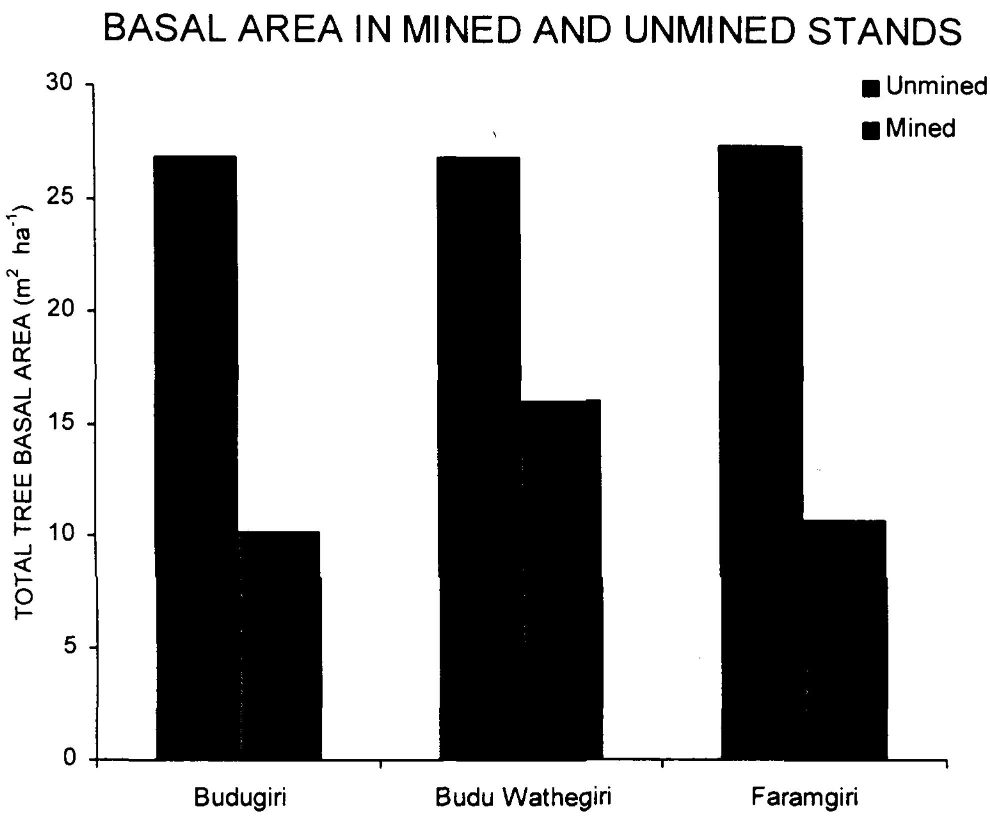


Fig. 4.5 Basal area of tree species in mined and unmined areas of Nokrek Biosphere Reserve

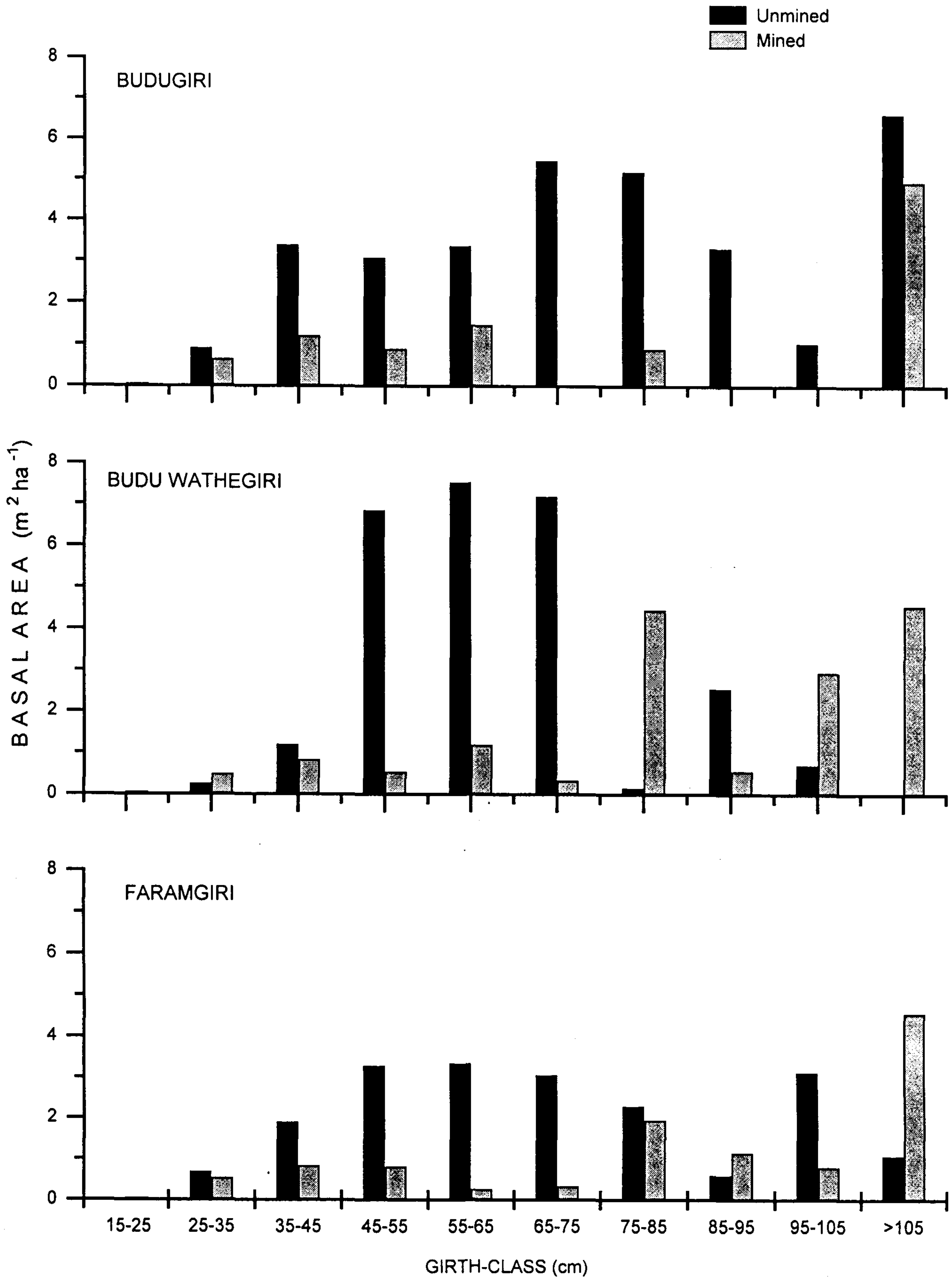


Fig. 4.6 Basal area distribution of tree species in mined and unmined area at three sites in Nokrek Biosphere Reserve

REGENERATION OF TREE SPECIES AS AFFECTED BY MINING

Regeneration status of trees is predicted by the age structure of their populations (Marks 1974, Vablen *et al.* 1979, Pritts & Hancock 1983, Saxena & Singh 1984, Khan *et al.* 1987). Presence of sufficient number of seedlings, saplings and young trees in a given population indicates a successful regeneration (Saxena & Singh 1984). Regeneration of tree species is greatly influenced both by biotic and abiotic factors (Boring *et al.* 1981, Lange & Graham 1983, Aksamit & Irving 1984, Khan *et al.* 1986). These factors may affect the recruitment, survival and growth of tree seedlings and sprouts.

The unmined areas had significantly higher number of species both as seedlings and saplings in comparison to mined areas. The unmined areas at Budugiri had 28 species and the mined areas had 25 species of tree saplings. At Budu Wathegiri, 24 species of saplings were recorded in the unmined area while in the mined area 17 species were recorded. At Faramgiri unmined area 21 species of saplings were recorded and in the mined areas 17 species of sapling were found (Fig.4.7). A maximum of 37 species of seedling were recorded from unmined area at Faramgiri while in the mined areas, a number of 26 species each were recorded from Budugiri and Budu Wathegiri.

Schima wallichii, Acacia pennata, Crotom caudatus, Celastrus championii species were dominant in the mined sites and *Camellia caudata. Micromellum integerimum, Castanopsis indica, Acacia pennata, Echinocarpus murex* species were dominant in

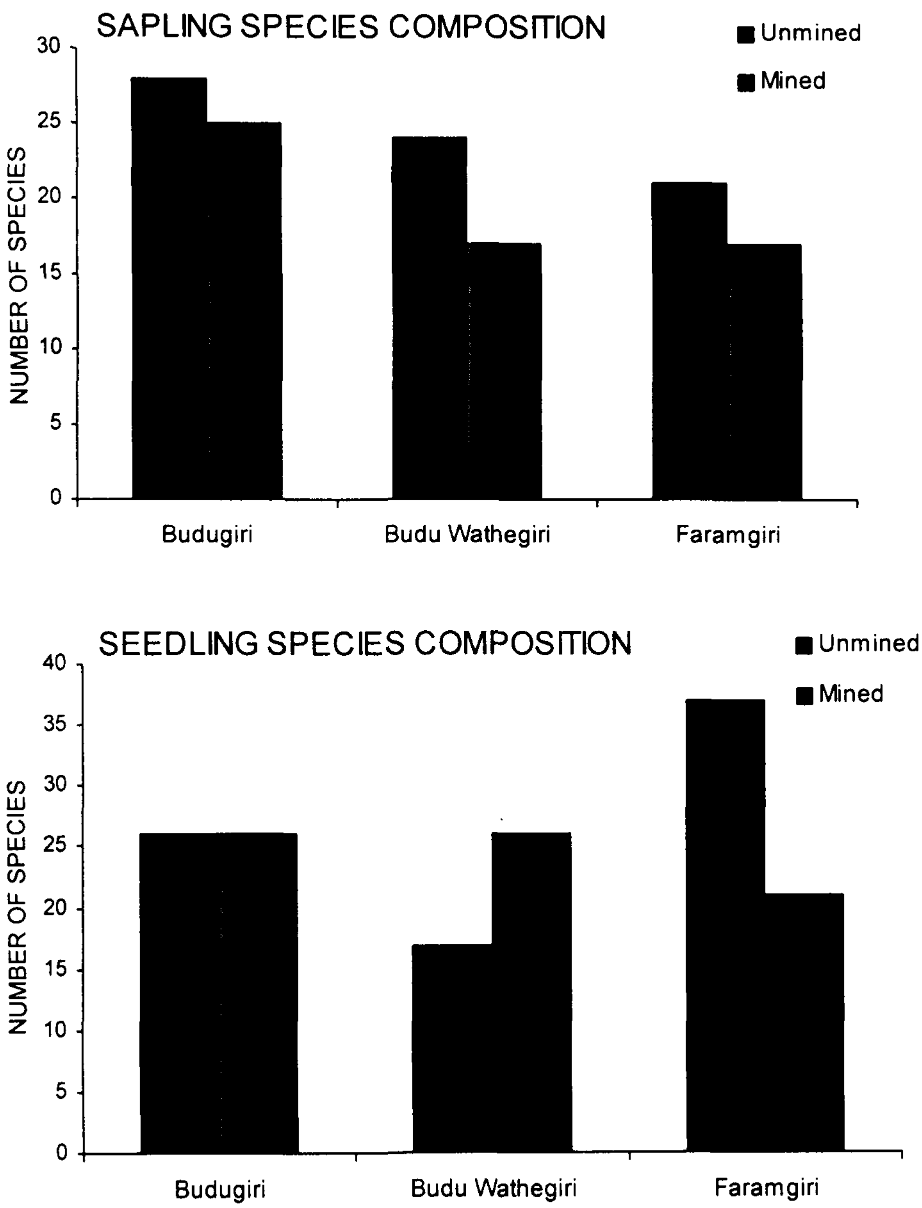
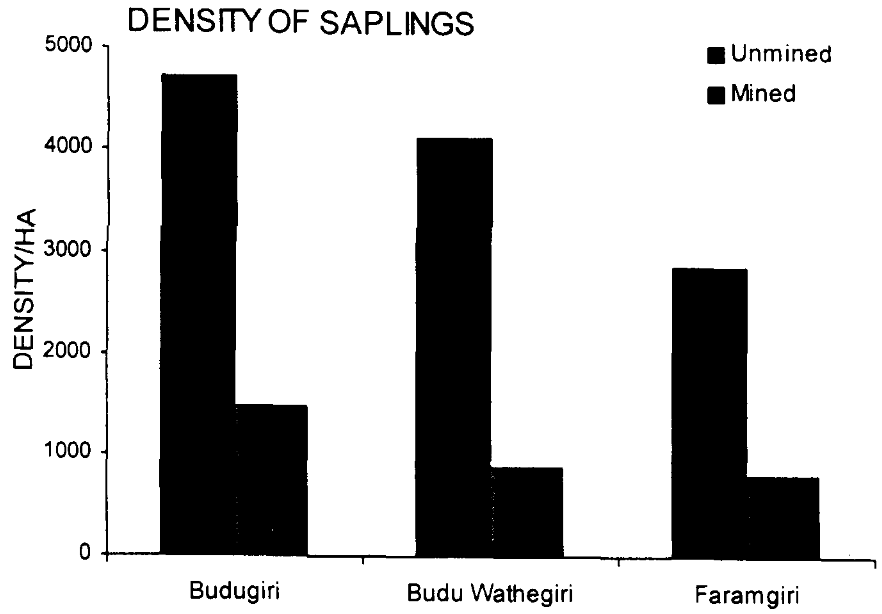


Fig. 4.7 Species composition of sapling and seedlings at three sites of Nokrek Biosphere Reserve

the unmined sites during seedling phase. However, during sapling phase *Vitex vestuta, Commelina sikkimensis, Kydia calycina* species were dominant in mined and *Ostodes paniculata, Ficus elastica, Homonia riparia, Psychotria adenophylla* species were dominant in unmined sites.

The seedlings and saplings densities were also much higher in the unmined sites than the mined sites at all the three locations. The maximum sapling density in the unmined areas was 4,720 stems/ha, which was recorded from Budu Wathegiri site, while at mined site it was only 1480 stems/ha, recorded from the same site. The maximum seedling density of 2247 stems/ha from unmined areas was recorded from Faramgiri while that from mine area, it was 2447 stems/ha, which was also recorded from Faramgiri (Fig. 4.8).



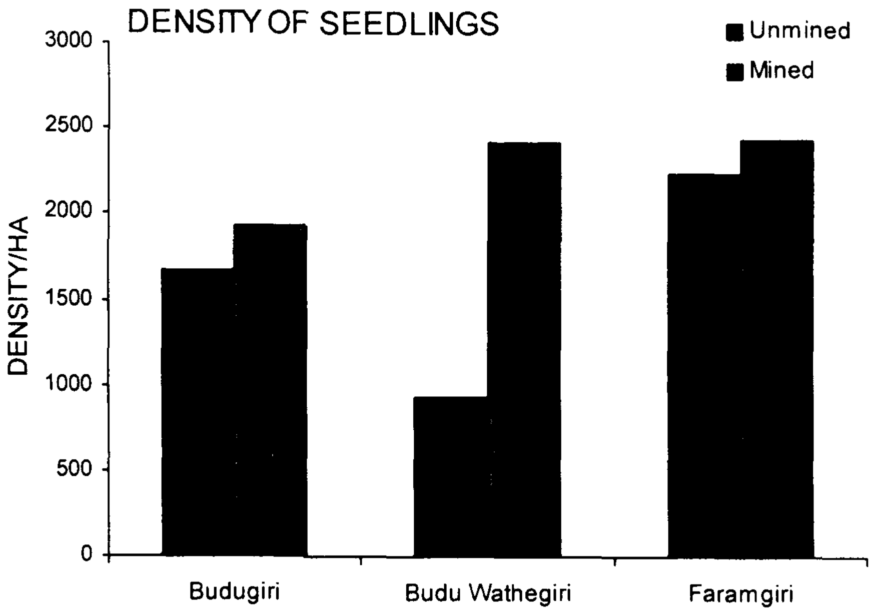


Fig. 4.8 Density of saplings and seedlings as affected by mining at three sites of Nokrek Biosphere Reserve

Table 4.8 Sapling density (stems ha^{-1}) in the unmined and mined areas of Nokrek Biosphere Reserve

Sapling Species	Budugiri Unmined	Budugiri Mined	Budu Wathegiri Unmined	Budu Wathegiri Mined	Faramgiri Unmined	Faramgiri Mined
	Stems ha $^{-1}$					
Acacia pennata (Linn.) Willd.	160	80	400	80	200	-
Albizia chinensis (Osb.) Merr.	120	-	-	-	120	-
Alchornea tiliaefolia Muell.-Arg.	-	-	-	-	-	40
Alnus nepalensis D.Don.	-	-	320	-	-	-
Antidesma diandrum Roxb.	-	-	-	40	-	-
Aporusa aurea Hk.f.	-	-	-	40	-	-
Aporusa oblonga Muell. Arg.	-	40	160	-	-	40
Ardisia floribunda DC	-	-	120	-	-	-
Artemesia nilagirica (Clarke.) Pamp.	-	-	80	40	80	-
Artemesia parviflora Roxb.	-	80	-	-	-	-
Callicarpa arborea Roxb.	-	40	-	-	-	-
Callicarpa rubella Lindl.	-	-	80	80	-	-
Calophyllum polyanthum Choisy	200	-	-	-	-	-
Camellia caudata Wall.	360	-	200	-	-	-
Carryota urens Linn.	-	40	240	-	80	-
Casearia vareca Roxb.	-	-	-	-	-	80
Casia alata Linn.	-	-	-	-	-	80
Castanopsis indica A.DC.	-	-	480	-	40	-
Castanopsis kurzii (Hance) Biswas	40	-	240	-	80	-
Celastrus championii Benth.	-	-	-	-	-	80
Celastrus robustus Roxb.	280	-	-	-	-	-
Celtis tetrandra Roxb.	-	40	-	-	-	-
Cinnamomum tamala Fr. Nees.	120	-	-	-	-	-
Cleidion spiciflorum (Burm.) Merr.	240	-	-	-	-	-
Clerodendrum viscosum Vent.	-	-	-	-	-	40
Clerodendrum wallichii Merr.	-	-	-	-	-	40
Combretum acuminatum Roxb.	-	-	-	40	-	-
Crotom caudatus Geisel.	-	-	-	-	-	40
Cryptolepsis sinensis (Lour.) Merr.	200	-	-	-	-	-
Daphne composita (Linn.f.) Gilg.	-	40	-	-	-	-
Daphne involucrata Wall.	-	-	-	-	-	40
Derris robusta (Roxb. Ex DC.) Benth.	-	-	-	40	-	40
Diospyros stricta Roxb.	280	-	-	-	-	-
Drypetis lancifolia Hk.f.	-	-	-	-	-	40
Duabanga grandiflora (Roxb.ex.DC.)	-	120	-	40	-	-
Dysoxylum binectariferum Hk.f. et Bedd.	-	-	360	-	160	-
Dysoxylum gobara (Buch.-Ham.)Merr.	40	-	-	40	80	-
Echinocarpus murex Benth.	240	40	-	40	360	-
Elaeagnus latifolia Linn.	-	40	-	-	-	-
Elaeocarpus floribundus Bl.	-	-	-	-	-	40

Elsholtzia blanda Benth.	-	-	40	-	-	-
Engelhardtia spicata Leschen ex Bl.	-	-	-	40	-	-
Euonymous lawsonii Cl & Pr.	-	40	-	-	-	-
Ficus hispida Linn.f.	-	-	40	40	40	-
Ficus racemosa Linn.	-	-	-	-	280	-
Garcinia paniculata (G.Don.) Roxb.	120	-	-	-	-	-
Gaultheria fragrantissima Wall	360	-	-	-	-	-
Glochidion lanceolarium (Roxb.) Voigt.	-	40	-	40	-	-
Glochidion oblatum Hk.f.	200	-	-	-	-	-
Glycosmis arborea (Roxb.) DC.	80	40	-	-	-	-
Helicia nilagirica Bedd.	400	-	-	-	80	-
Homonoia riparia Lour	-	40	-	-	-	-
Kydia calycina Roxb.	40	-	-	-	-	-
Lindera caudata Benth.	-	-	-	-	240	40
Litsea khasyana Miessn	160	-	-	-	-	-
Litsea salicifolia (Roxb. ex Nees) Hk.f.	120	-	-	-	-	-
Macaranga denticulata (Bl.) Muell.	-	40	-	-	200	40
Macropanax undulatus (Wall ex D.Don.)	-	-	200	-	200	-
Maesa indica (Roxb.) Wall.	80	80	80	-	160	-
Mallotus phillipensis (Lam.) Muell.-Arg.	-	-	80	-	80	40
Meliosma wallichii Planch. ex Hk.f.	-	40	-	40	80	40
Micromellum integerimum (Roxb.)	520	40	-	-	120	-
Ostodes paniculata Bl.	-	40	200	-	-	-
Picrasma javanica Bl.	-	40	-	-	-	-
Prunus nepaulensis (Ser.) Steud.	-	-	280	-	-	-
Psychotria denticulata Wall	-	-	200	-	-	-
Randia longiflora Lamk.	40	80	-	-	-	-
Randia wallichii Hk.f.	-	-	40	-	-	-
Rhus acuminata DC.	-	-	-	40	-	-
Rhus javanica Linn.	-	40	-	-	-	-
Sapium baccatum Roxb.	-	80	-	40	-	-
Saprosma ternatum Hk.f.	120	-	40	-	-	-
Saurauia nepaulensis DC	-	-	-	-	-	40
Schima wallichii (DC.) Korth.	-	200	-	160	-	-
Skimmia laureola	40	-	-	-	-	-
Skimmia laureola (DC.) ex Walp.	-	-	200	-	40	-
Symplocos lucida Thunb.	-	-	40	-	-	-
Symplocos racemosa Roxb.	40	-	-	-	-	-
Syzygium cuminii (Linn.) Skeels	-	80	-	-	-	-
Talauma hodgsonii Hk.f. & Th.	-	-	-	-	160	-
Terminalia bellerica (Gaertn) Roxb.	80	-	-	-	-	-
Tetrameles nudiflora R. Br.	40	-	-	-	-	-
Total	**4720**	**1480**	**4120**	**880**	**2880**	**800**

'-'Indicates absence of the species

Table 4.9 Seedling density (stems ha^{-1}).in the unmined and mined stands in Nokrek Biosphere Reserve

	Stems ha^{-1}					
	Budugiri		Budu Wathegiri		Faramgiri	
Seedling Species	Unmined	Mined	Unmined	Mined	Unmined	Mined
Acacia pruinescens Kurz.	-	-	44	-	-	-
Aeschyranthus DC.	-	-	19	-	-	-
Alangium chinense (Lour.) Harms.	-	-	-	163	-	-
Alchornea tiliaefolia Muel.-Arg.	-	-	-	6	-	-
Anacardium occidentale Linn.	-	56	-	-	-	-
Aporusa dioica (Roxb.) Muell.-Arg	-	-	-	44	-	-
Aporusa oblonga Muel. Arg.	-	13	-	-	-	44
Ardisia odontophylla DC.	6	-	-	-	-	-
Artemisia parviflora Roxb.	25	-	-	-	-	-
Bauhinia variegata Linn.	-	131	-	19	-	-
Bridelia stipularis Bl.	-	19	-	31	-	19
Callicarpa arborea Roxb.	-	63	-	-	-	-
Callicarpa rubella Lindl.	6	-	6	156	6	-
Calophyllum polyanthum Choisy	-	-	56	-	56	-
Camellia caudata Wall.	44	-	-	-	-	-
Camellia sinensis (Linn.) O. Ktze.	-	-	-	-	44	-
Carryota urens Linn.	106	-	-	125	106	-
Castanopsis indica A. DC.	56	-	56	-	56	-
Castanopsis kurzii (Hance) Biswas	118	-	-	-	119	-
Celastrus championii Benth.	25	-	-	-	25	-
Celastrus robustus Roxb.	-	-	-	69	-	-
Cleidion javanica (Burm.) Merr.	-	-	-	-	-	106
Cleidion spiciflorum (Burm.) Merr.	50	-	-	56	50	-
Cleirodendron wallichii Merr.	-	-	-	44	-	-
Commelina sikkimensis Clarke.	-	-	-	231	-	-
Cordia fragrantissima Kurz.	-	-	-	144	-	-
Cordia grandis Roxb.	-	44	-	-	-	-
Cyathula tomentosa Miq.	-	-	-	44	-	81
Daphne composita (L.f.) Gilg.	-	-	-	-	94	-
Daphne involucrata Wall	-	-	94	-	-	-
Derris robusta (Roxb ex DC.) Benth.	18	-	19	125	19	225
Dillienia indica Linn.	-	-	-	100	6	-
Dimocarpus longan Lour.	6	-	-	-	6	-
Diospyros lancifolia Roxb.	-	-	-	119	-	-
Diospyros stricta Roxb.	-	-	-	-	6	-
Diospyros undulata DC.	6	-	-	-	6	-
Dischidia nummularia R.Br.	-	-	6	-	-	-
Dracaena angustifolia Roxb.	-	-	56	-	-	-
Dracaena elliptica Thunb.	-	-	38	-	-	-
Duabanga grandiflora (Roxb. ex. DC)	-	44	-	-	-	-

Dysoxylum binectariferum Hk.f. et Bedd.	-	-	-	-	6	75
Dysoxylum gobara (Buch.-Ham.)Merr.	-	81	-	-	-	-
Echinocarpus murex Benth.	-	163	13	-	13	44
Elaeocarpus sikkimensis Hk.f.	56	-	-	-	56	-
Elatostemma rupestre (D.Don) Wedd.	-	-	-	-	-	294
Elscholtzia blanda Benth.	-	56	-	-	-	-
Embelia ribes Burn. F	-	-	-	150	-	-
Erithrina stricta Roxb.	-	81	-	-	-	-
Erythroxylum kunthianum Wall. Ex Kurz.	-	-	13	-	13	-
Euonymus attenuatus Laws.	-	19	-	-	-	-
Ficus elastica Roxb ex Horneum.	-	-	163	-	163	-
Ficus hispida Linn. F.	-	-	-	88	-	-
Ficus sp.	-	119	-	-	-	-
Garcinia acuminata Planch.	-	-	-	-	13	-
Garcinia cawa Roxb. Ex. DC	13	-	13	-	-	-
Gleichenia sp.	6	-	-	-	-	-
Glochidion oblatum Hk.f.	-	44	-	-	-	-
Glycosmis arborea (Roxb.) DC	-	69	-	-	-	19
Hedyotis scandence D. Don.	-	-	19	-	19	81
Helicia nilagirica Bedd.	-	-	44	-	44	-
Hiptage benghalensis (Linn.) Kurz.	13	-	-	13	13	-
Homonia riparia Lour.	-	113	94	81	94	44
Ilex embelioides Hk.f.	6	-	-	-	-	-
Ilex odorata D. Don.	-	-	-	-	6	-
Kydia calycina Roxb.	-	-	-	-	-	406
Litsea cubeba Lour.	-	56	-	-	-	-
Litsea khasyana Miessn	-	-	-	-	-	319
Litsea salicifolia (Roxb ex Nees) Hk.f.	13	-	-	-	13	-
Macaranga denticulata (Bl.) Muell.-Arg.	37	156	-	-	38	-
Macropanax undulatus (Wall ex D.Don.) Seem.	6	-	-	-	-	-
Maesa indica (Roxb.) Wall.	44	6	-	-	6	-
Maesa tetrandra (Roxb) DC.	44	-	-	-	-	-
Meillitia pachycarpa	-	-	-	19	-	-
Melastoma malabathricum Linn.	-	-	-	144	-	256
Meliosma wallichii Planch.ex Hkf.	-	-	-	-	-	44
Micromellum integerimum (Roxb.)	406	-	69	-	44	-
Mimosa pudica Linn.	-	-	-	-	-	113
Ostodes paniculata Bl.	360	88	81	-	-	56
Paedaria foetida Linn.	-	-	-	-	31	-
Persea duthiei King ex Hk.f.	144	-	-	-	144	-
Picrasma javanica Bl.	-	-	-	31	-	75
Pogestemon auricularis Hask.	-	-	-	-	13	-
Psychotria adenophylla Wall.	-	-	-	-	88	-
Psychotria erratica Hk.f.	-	-	-	-	644	-
Randia fasciculata DC.	-	-	-	-	-	13

Randia wallichii Hk.f.	-	56	-	-	-	-
Sapium baccatum Roxb.	-	81	-	-	-	-
Saprosma ternatum Hk.f.	56	-	31	-	56	-
Schima wallichii (DC) Korth.	-	81	-	-	-	50
Smilax ferox Kunth	-	-	-	-	325	81
Spondius pinnata (Linn.f) Kurze.	-	-	-	81	-	-
Sterculia hamiltonii (O) Ktze.	-	113	-	-	-	-
Sterculia roxburghii Wall.	-	-	-	-	6	-
Terminalia bellerica (Gaertn.) Roxb	-	-	-	56	-	-
Treversia palmata Roxb.	-	138	-	-	-	-
Vitex vestuta Roxb.	-	-	-	281	-	-
Zanthoxylum armatum Hk.F.	-	38	-	-	-	-
Total	**1670**	**1928**	**934**	**2420**	**2247**	**2447**

'-'Indicates absence of the species

IMPACT OF MINING ON DISTRIBUTION PATTERN

Plant populations exhibit three patterns of spatial distribution – contagious or clumped, random and uniform or regular. Patchhiness, 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 reproductive 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.

Most tree species showed contagious distribution pattern both in the unmined (89.5%, 62.5% and 86.3%) and mined (95.8%, 88.5% and 100%) areas at Budugiri, Budu Wathegiri and Faramgiri, respectively (Table 4.10).

Table 4.10 Proportion (%) of tree species under different distribution pattern in the unmined and mined areas of Nokrek Biosphere Reserve

Distribution Pattern	Budugiri		Budu Wathegiri		Faramgiri	
	Unmined	Mined	Unmined	Mined	Unmined	Mined
Regular	0	0	0	0	2.3	0
Random	10.5	4.2	37.5	11.5	11.4	0
Contagious	89.5	95.8	62.5	88.5	86.3	100

The contagious distribution pattern for most tree species indicated the mosaicness of the forest stands. The increase in contagiousness of more species due to mining suggests the increase in patchness of the natural vegetation due to mining.

IMPACT OF COAL MINING ON SOIL CHARACTERISTICS

Following coal mining the physico-chemical properties of soil get altered. Such alterations in soil characteristics influence plant growth and vegetation characteristics. Mined areas suffer from impediments like low organic matter content, nutrient deficiency and moisture retention stress. Mining process inflicts incalculable damage to the land surface irrespective of the mode of extraction employed. High acidity due to oxidation of iron pyrites (FeS_2) is an important factor limiting plant growth in the coal mined areas (Chadwick 1973, Doubleday 1974, Caruccio 1975, Armiger *et al.* 1976, Bennet *et al.* 1976). High rainfall permits more pyritic oxidation thereby exhibiting excessively acidic soil pH. High acidity in mine spoils causes dysfunction in plant growth, impaired absorption of P, Ca, Mg and K and increased availability of aluminium (Al), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and nickel (Ni) often in toxic proportions. The acidity also creates unfavorable biotic conditions like reduced N-fixation and mycorrhizal activity, and increase in fungal pathogens (Black 1968, Tucker *et al.* 1987).

Paucity of essential plant nutrients particularly nitrogen (Handley *et al.* 1978, Bradshaw and Chadwick 1980) and phosphorus (Iverson & Wali 1992) is another factor which limits plant growth in coal mined areas. Nitrogen is essential for plant growth as it is a constituent of all proteins and nucleic acids. It is generally absorbed by the plants as ammonium or as nitrate ions. Lack of mineralizable organic-N and lower mineralization rate affect the availability of N to plants in coal mined areas (Reeder &

Berg 1977). Phosphorus as arthophosphate plays a fundamental role in a very large number of enzymatic reactions that depend on phosphorylation. It is essential for cell division and for the development of meristematic tissues. Plants take up phosphorus almost exclusively as inorganic phosphate ions. Prasad & Shukla (1985) reported N, P and K deficiency in coal mined areas at Dhanpuri, Madhya Pradesh. Deficiency of nitrogen and phosphorus has been attributed to their unavailability in acidic condition and their susceptibility to leaching processes (Richardson & Dicker 1972, Gemmel 1973, Iverson & Wali1982).

The mine spoils present a rigorous habitat, generally characterized by high temperature, moisture stress and surface instability, which favour soil erosion. The steep slopes as well as barren conditions pave the way for low water storage in soil. Evaporation and continuous run-off also result in water loss. Insufficient availability of water for plant growth is also encountered on the mined spoils due to preponderance of sand.

The physico-chemical properties of coal mined areas have engaged the attention of a number of workers viz. Kimber *et al.* (1978), Schafer & Nielsen (1979), Pederson *et al.* (1980), Bell & Ungar (1981) and Power (1978). In India, studies have been conducted by Mathur *et al.* (1982-85), Soni *et al.* (1989), Jha & Singh (1992) and Pandey *et al.* (1993). A few studies on edaphic aspects of coal mined areas with a focus on mine spoils have been conducted in high altitude areas of Jaintia Hills of Meghalaya (Uma Shankar *et al.* 1993, Lyngdoh 1995, Das Gupta 1999). However, impact of coal mining on physico-chemical characteristics of tropical soil in Meghalaya has been little understood. The present study analyses the effect of coal mining on the soil characteristics of Nokrek Biosphere Reserve.

METHODS

Three sites were selected in the Nokrek Biosphere Reserve, viz., Budugiri, Budu Wathegiri and Faramgiri for studying the impact of coal mining on soil characteristics. For each site, three composite soil samples were collected both from mined and adjacent unmined areas. Soil samples from three depths viz., 0-10 cm, 10-20 cm and 20-30 cm during three seasons i.e., pre-monsoon, monsoon and post-monsoon were collected. The study was conducted for two years period i.e., during 2000 and 2002. Thus in total 54 soil samples for each season and each year were collected. The soil samples were air dried and sieved through 0.2 mm sieve and stored for analysis.

A digital pH metre was used to determine soil pH in 1:2.5 suspension of soil and distilled water (Anderson & Ingram 1993). Soil moisture content was gravimetrically determined by drying 10 gm of freshly sieved soil at 105° C for 24 hours in a hot air oven (Allen *et al.* 1974). Soil texture was analysed by Bouyoucos hydrometer method (Allen *et al.* 1974). Air-dried and sieved (0.5 mm) soils were used for total Kjeldahl nitrogen (TKN), and available-P. TKN was determined by digesting the soil sample with concentrated H_2SO_4 using Kjeltab as catalyst in a block digester. Soil organic carbon was determined by rapid titration method (Walkley & Black 1934) and soil organic matter was estimated by multiplying the organic carbon content by 1.724 assuming that soil organic carbon contains 58% carbon (Allen *et al.* 1974). Available phosphorus was determined by molybdenum blue method after extracting the soil P in 0.5 M sodium bicarbonate solution (Anderson & Ingram 1993).

Analysis of Variance (ANOVA) was performed on the data to test the variability due to site, mining activity and depth. 3-way fixed effect ANOVA model was used for analysis (Zar 1974).

RESULTS AND DISCUSSION:

pH: The soil pH in the unmined areas ranged between 5.89-6.64. The soil became more acidic in mined areas. In the mined areas it ranged between 4.02 and 5.93 and in the unmined areas it varied between 5.89 and 6.64 (Table 4.11). The soil pH was significantly ($P<0.01$) lower in all the mining sites than the unmined sites in all the seasons and across all the depths. The post-monsoon soil pH was significantly lower ($P<0.01$) than the pre-monsoon and monsoon soil pH. The top layers of soils (0-10 cm) had significantly lower soil pH than the sub-soils (10-20 and 20-30 cm) (Table 4.12).

The soils of the area in general were acidic in reaction. and the sites affected by coal mining were more acidic than the unmined sites. The increase in acidity due to mining has been attributed to the oxidation of iron pyrites (Caruccio 1975, Johnson & Bradshaw 1979). Similar observation was also made by Lyngdoh (1995). Decline of pH in mined areas is one of the serious problems associated with coal mining activity. Lowering of pH strongly affects plant growth in various ways including the availability of a large number of essential nutrients in the soil. The continual acidification generally results in the die back of even well established vegetation. The gradual rise of pH in depth as found in this study was also recorded by Pandey (1993).

Table 4.11 Soil pH in the unmined and mined areas in different depths and seasons in the Nokrek Biosphere Reserve

Depth (cm)	Pre-monsoon						Monsoon						Post-monsoon					
	Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri	
	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M
0-10	6.35 ± 0.07	4.65 ± 0.13	6.64 ± 0.20	4.45 ± 0.10	6.22 ± 0.16	4.64 ± 0.09	6.34 ± 0.19	5.60 ± 0.29	6.51 ± 0.18	5.82 _ 0.17	6.37 ± 0.29	5.53 ± 0.30	5.99 ± 0.20	4.51 ± 0.10	6.13 ± 0.16	4.02 _ 0.10	5.89 ± 0.07	4.24 ± 0.16
10-20	6.32 ± 0.12	5.58 ± 0.04	6.36 ± 0.23	5.41 ± 0.22	6.54 ± 0.24	5.54 ± 0.21	6.43 ± 0.19	5.82 ± 0.15	6.37 ± 0.19	5.46 _ 0.14	6.64 ± 0.20	5.63 ± 0.10	6.26 ± 0.07	4.11 ± 0.23	6.09 ± 0.09	4.28 _ 0.27	6.32 ± 0.16	4.09 ± 0.27
20-30	6.39 ± 0.18	5.4 ± 0.21	6.11 ± 0.17	5.41 ± 0.21	6.01 ± 0.13	5.34 ± 0.21	6.37 ± 0.18	5.93 ± 0.21	6.49 ± 0.29	5.68 _ 0.17	6.51 ± 0.32	5.73 ± 0.10	5.90 ± 0.13	5.19 ± 0.11	5.99 ± 0.28	4.97 _ 0.12	6.17 ± 0.28	5.27 ± 0.16

Table 4.12 Results of Analysis of Variance (ANOVA) to test the variability in Soil pH due to mining activity, site and depth

Source of Variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F ratio**
General Mean	1	1756.93	1756.97	-
Mining effects	1	18.28	18.28	881.82**
Site effects	2	0.71	0.35	17.08**
Depth effects	2	5.34	2.67	128.74**
Mining-Site	2	1.06	0.53	25.65**
Mining –Depth	2	1.45	0.73	35.03**
Site-Depth	4	0.70	0.17	8.39**
Mining-Site-Depth	4	1.07	0.27	12.89**
Residual	36	0.75	0.02	-
Total	**54**	**1786.32**	**33.08**	

Soil Moisture Content: The soil moisture content significantly reduced as depth increased ($P<0.05$). In the mined areas the soil moisture ranged between 4.96% and 13.49%. The minimum percentage of soil moisture in the unmined areas was 26.27 while maximum was 42.62% (Table 4.13). The soil moisture content, however, did not vary significantly due to mining activities and site differences (Table 4.14).

Studies on impact of coal mining on soil moisture content are rare. However, Brenner (1984) reported that organic matter and moisture contents of the mine spoils are pivotal in determining the ultimate success of reclamation on surface mines. He further observed that the upper layer of a 15 year old surface mine had 33.7% moisture in comparison to 8.1%, 18.4% and 17.5% in 12, 24 and 26 cm soil depth respectively. The fluctuations of soil moisture with depth in the present study also showed a similar trend. Baig (1992) reported severe moisture deficiency on spoils during the growing season ranging from 6.3% in 30 to 55 year to 4.9% in a 2-8 year old coal mine spoils. Barnhisel *et al.* (1969) also reported similar results from eastern Kentucky coal mine spoils.

Table 4.13 Soil Moisture Content in the unmined and mined areas in different depths and seasons in the Nokrek Biosphere Reserve

Depth (cm)	Pre-monsoon						Monsoon						Post-monsoon					
	Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri	
	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M
0-10	31.24 ± 1.65	5.31 ± 0.46	26.27 ± 4.45	5.05 ± 0.59	32.32 ± 3.22	5.99 ± 0.68	40.48 ± 2.81	12.99 ± 0.58	38.84 ± 1.58	12.5 ± 0.63	39.14 ± 2.31	13.49 ± 0.89	29.41 ± 1.49	9.10 ± 0.51	27.24 ± 1.09	6.42 _ 0.72	29.24 ± 1.45	5.54 ± 0.61
10-20	32.91 ± 2.02	5.02 ± 0.39	30.00 ± 3.66	5.13 ± 0.27	30.42 ± 3.88	5.31 ± 0.33	39.78 ± 1.57	9.83 ± 0.39	41.68 ± 1.45	9.97 ± 0.71	42.62 ± 1.34	10.04 ± 0.67	28.54 ± 1.01	6.12 ± 0.54	28.91 ± 0.99	6.12 _ 0.66	28.13 ± 0.96	6.06 ± 0.54
20-30	35.83 ± 1.83	5.55 ± 0.42	31.21± 2.52	4.96 ± 0.40	37.67 ± 2.17	6.20 ± 0.75	38.05 ± 2.54	9.10 ± 0.91	35.40 ± 1.87	9.56 ± 0.98	39.59 ± 2.24	9.22 ± 1.08	27.42 ± 1.52	6.54 ± 0.50	26.84 ± 1.46	9.29 _ 0.46	26.42 ± 1.46	6.47 ± 0.52

Table 4.14 Results of Analysis of Variance (ANOVA) to test the variability in Soil Moisture Content due to mining activity, site and depth

Source of Variation	Degree of freedom	Sum of squares	Mean sum of squares	F ratio
General Mean	1	60799.98	60799.98	-
Mining effects	1	3.62	3.62	0.08
Site effects	2	180.10	90.06	2.07
Depth effects	2	298.21	149.11	3.42*
Mining-Site	2	955.26	477.63	10.95**
Mining –Depth	2	332.41	166.21	3.81*
Site-Depth	4	210.03	52.51	1.20
Mining-Site-Depth	4	438.61	109.65	2.51
Residual	36	1569.71	43.60	-
Total	**54**	**64787.95**	**1199.78**	

Soil Texture: The percentage of sand in the soil was much higher in the unmined areas than the mined areas. In the mined areas soil texture is sandy loam and had more clay content than the unmined areas (Table 4.15).

Dollhopf *et al.* (1981) suggested that when clay content in the mined site was greater than 40%, it caused low permeability, low infiltration rate, structural and compaction problem. If sand content was greater than 70%, the mined spoils retained insufficient water for plant growth. In the present study, in general the soil had low water retention capacity due to high percentage of sand. This was also observed by Lyngdoh (1995) and Das Gupta (1999). Eyre (1968) reported that the loss of finer soil particles, especially clay component increases the proportion of sand in the soil during the early developmental stage of soil due to disturbance.

Table 4.15 Soil Texture in the unmined and mined areas in different depths and seasons in the Nokrek Biosphere Reserve

Site:	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texural Class
Unmined	0-10	1.69 ± 0.16	4.88 ± 0.18	93.23 ± 0.21	Sandy
	10-20	1.57 ± 0.18	5.06 ± 0.19	93.08 ± 0.32	Sandy
	20-30	1.35 ± 0.04	4.97 ± 0.28	93.67 ± 0.31	Sandy
Mined	0-10	9.52 ± 0.18	4.79 ± 0.17	85.70 ± 0.24	Sandy loam
	10-20	8.81 ± 0.38	4.76 ± 0.33	86.43 ± 0.62	Sandy loam
	20-30	8.71 ± 0.28	4.42 ± 0.26	86.87 ± 0.36	Sandy loam

Nitrogen (%): The coal mining had significant impact on soil nitrogen content. Due to mining, the total nitrogen content was significantly ($P<0.01$) reduced. In the unmined sites, total soil nitrogen ranged between 0.27% and 0.74% while it was reduced to 0.02% to 0.44% in the mined sites (Table 4.16). The nitrogen content was also significantly lower ($P<0.01$) in the deep soils than the top soils (Table 4.17).

Williams (1975), Johnson *et al.* (1976) and Down & Stocks (1977) reported that most of the mined areas are deficient in nitrogen content. At low pH, nitrate is not available to plants as nitrification is lowered with the increase in acidity. The activity of nitrifying bacteria, which are responsible for production of nitrate (the most readily absorbable form of nitrogen by plants), is lowered drastically at pH 5 or below. In such highly acidic soil ammonium nitrogen becomes dominant form of mineral nitrogen (Cornfield 1952, William 1975, Reeder & Berg 1977). The production of ammonium-nitrogen and its uptake helps the plants to sustain their life in very acidic soils. The depletion of total nitrogen content due to mining is in conformity with the findings of earlier studies including that of Lyngdoh (1995). Similar results have been reported by Li & Danofield (1994), Thomas *et al.* (1983), Jha (1990) and Baig (1992). Besides leaching, low vegetal cover could be another reason for lower nitrogen concentration in mined areas. Cornwell & Stone (1968), Power *et al.* (1978) and Reeder & Berg (1977), however, noted a higher concentration of nitrogen in mine spoils and opined that the increased concentration of nitrogen might be due to its release during partial destruction of the silicate lattices by acids generated during the spoil weathering

Table 4.16 Percentage of Nitrogen content in the unmined and mined areas in different depths and seasons in the Nokrek Biosphere Reserve

Depth (cm)	Pre-monsoon						Monsoon						Post-monsoon					
	Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri		Budugiri		udu Wathegiri		Faramgiri	
	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M
0-10	0.38 ± 0.01	0.12 ± 0.01	0.37 ± 0.03	0.10 ± 0.01	0.39 ± 0.04	0.14 ± 0.03	0.74 ± 0.01	0.04 ± 0.01	0.63 ± 0.03	0.04 ± 0.01	0.71 ± 0.02	0.04 ± 0.01	0.63 ± 0.03	0.12 ± 0.01	0.61 ± 0.03	0.15 _ 0.05	0.61 ± 0.02	0.23 ± 0.11
10-20	0.31 ± 0.03	0.11 ± 0.01	0.32 ± .06	0.11 ± 0.01	0.27 ± 0.04	0.12 ± 0.01	0.59 ± 0.01	0.13 ± 0.02	0.61 ± 0.02	0.13 ± 0.02	0.59 ± 0.02	0.09 ± 0.02	0.56 ± 0.04	0.20 ± 0.01	0.56 ± 0.03	0.23 _ 0.10	0.57 ± 0.03	0.27 ± 0.13
20-30	0.38 ± 0.03	0.11 ± 0.01	0.41 ± 0.04	0.02 ± 0.01	0.32 ± 0.04	0.11 ± 0.01	0.65 ± 0.03	0.13 ± 0.01	0.61 ± 0.02	0.44 ± 0.24	0.61 ± 0.02	0.13 ± 0.01	0.58 ± 0.04	0.10 ± 0.01	0.57 ± 0.04	0.10 _ 0.01	0.62 ± 0.03	0.1 ± 0.01

Table 4.17 Results of Analysis of Variance (ANOVA) to test the variability in percentage Nitrogen content due to mining activity, site and depth

Source of Variation	Degree of freedom	Sum of squares	Mean sum of squares	F ratio
General Mean	1	5.87	5.87	-
Mining effects	1	2.08	2.08	781.50**
Site effects	2	0.00	0.00	0.45
Depth effects	2	0.28	0.14	53.52**
Mining-Site	2	0.30	0.02	6.33**
Mining –Depth	2	0.16	0.08	30.34**
Site-Depth	4	0.03	0.10	2.96**
Mining-Site-Depth	4	0.05	0.10	4.65**
Residual	36	0.10	0.00	-
Total	**54**	**8.61**	**0.16**	

Phosphorus: The mining did not have a significant impact on the phosphorus content of the soil. The phosphorus concentration in the mined areas varied between 8.0 and 21.67% while in the unmined areas it ranged between 16.0 and 24.6% (Table 4.18).

Most mined wastes are poor in phosphorus due to leaching and the lack of binding power of phosphorus. Very low pH also causes breakdown of the clay minerals and may release micro-nutrients beyond the toxic level (Chadwick *et al.* 1969). Soluble phosphorus is fixed by these micro-nutrients changing it into a complex insoluble compound which is unavailable for uptake by plants (Brady 1984). Low extractable phosphorus in acid soil at the mining sites could also be the result of such a reaction in the soil (Pandey 1993). Phosphorus content was low in mined areas during pre-monsoon and post-monsoon seasons. The findings of the present study is in agreement with the findings of Lyngdoh (1995) and Das Gupta (1999). Iverson & Wali (1982) also observed a similar trend and opined that phosphorus could be a limiting factor during early succession and colonization stage surface mined lands. Inadequate phosphorus has been reported to adversely affect the plant growth (Safaya & Wali 1979).

Table 4.18 Phosphorus content in the unmined and mined areas in different depths and seasons in the Nokrek Biosphere Reserve

Depth (cm)	Pre-monsoon						Monsoon						Post-monsoon					
	Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri	
	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M
0-10	19.56 ± 2.32	16.33 ± 1.57	20.4 ± 1.71	16.8 ± 1.52	21.4 ± 2.27	14.2 ± 1.04	17.44 ± 1.61	18.56 ± 0.41	16.8 ± 1.46	18.2 ± 0.72	16.0 ± 1.49	17.6 ± 1.50	23.78 ± 0.74	8.56 ± 0.80	19.8 ± 1.58	8.6 ± 0.90	24.6 ± 1.61	8.0 ± 0.88
10-20	20.78 ± 1.10	18.44 ± 0.77	20.4 ± 1.85	18.8 ± 1.55	21.2 ± 2.24	19.6 ± 0.69	18.78 ± 1.91	18.33 ± 1.51	18.8 ± 1.82	19.0 ± 0.53	21.0 ± 2.37	19.6 ± 0.90	21.44± 2.19	9.22 ± 0.78	21.8 ± 2.17	9.4 ± 0.69	20.0 ± 2.58	8.8 ± 0.86
20-30	19.89± 1.72	18.33 ± 1.42	19.6 ± 1.43	18.4 ± 1.43	20.6 ± 1.54	19.6 ± 1.34	20.0 ± 1.06	21.67 ± 1.47	19.8 ± 1.01	21.2 ± 1.59	21.0 ± 0.85	20.8 ± 2.02	23.89 ± 1.39	8.89 ± 0.74	22.8 ± 1.14	9.2 ± 0.83	24.0 ± 0.71	8.2 ± 0.43

Table 4.19 Results of Analysis of Variance (ANOVA) to test the variability in Phosphorus content due to mining activity, site and depth

Source of Variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F ratio**
General Mean	1	22554.31	22554.31	-
Mining effects	1	3.84	3.84	0.13
Site effects	2	8.09	4.05	0.14
Depth effects	2	40.93	20.46	0.71
Mining-Site	2	38.40	19.20	0.67
Mining –Depth	2	59.68	29.84	1.03
Site-Depth	4	26.10	6.53	0.23
Mining-Site-Depth	4	25.65	6.41	0.22
Residual	36	1039.23	28.87	-
Total	**54**	**23796.24**	**440.67**	

Soil Organic Matter and Carbon: The percentage of soil organic matter and carbon drastically reduced due to mining. In the mined areas it ranged between 0.44 and 1.36% while in the unmined areas it varied between 2.60 and 6.17% (Table 4.20). The soil organic matter and carbon decreased significantly with increasing depths ($P<0.01$). The soil organic carbon content also varied significantly ($P<0.05$) among different sites and seasons studied.

Williams (1975), Johnson *et al.* (1976), Down & Stocks (1977) and Johnson & Bradshaw (1979) reported that most of the coal mined areas are deficient in organic matter. Accumulation of litter and microbial activity in the unmined areas might have contributed to the higher organic matter content (Jones *et al.* 1993). This observation is in the line with Lyngdoh (1995). Williams (1975), Johnson *et al.* (1982), Down & Stocks (1977) and Johnson & Bradshaw (1979) reported that most of the coal mined areas are deficient in organic matter and nitrogen. In contrast, Toy & Shay (1987) found that there was no significant difference in organic matter content between the mined areas and natural soils in Northern Great Plains of USA.

Thomas *et al.* (1985) found predictably low percentage of organic carbon in eight Illinois mined stands. Soni *et al.* (1989) also obtain similar results from a rock phosphate mined stand in Dehra Dun, India.

Table 4.20 Percentage of Soil Organic Matter in the unmined and mined areas in different depths and seasons in the Nokrek Biosphere Reserve

Depth (cm)	Pre-monsoon						Monsoon						Post-monsoon					
	Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri	
	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M
0-10	6.17 ± 0.25	0.97 ± 0.06	5.72 ± 0.35	0.95 ± 0.06	5.98 ± 0.49	0.97 ± 0.06	4.89 ± 0.25	0.71 ± 0.12	4.62 ± 0.32	0.44 ± 0.10	5.86 ± 0.38	0.61 ± 0.16	3.52 ± 0.26	.88 ± 0.06	3.58 ± 0.21	0.89 ± 0.06	3.25 ± 0.19	0.89 ± 0.07
10-20	5.85 ± 0.38	1.26 ± 0.23	5.67 ±0.37	1.26 ± 0.23	5.86 ± 0.48	1.36 ± 0.23	4.89 ± 0.19	0.91 ± 0.08	4.19 ± 0.27	1.03 ± 0.10	4.377 ± 0.24	0.83 ± 0.07	2.75 ± 0.13	.91 ± 0.41	2.67 ± 0.31	0.86 ± 0.06	3.03 ± 0.23	0.90 ± 0.08
20-30	5.38 ± 0.58	1.11 ± 0.10	5.02 ± 0.36	0.99 ± 0.08	5.22 ± 0.34	1.15 ± 0.11	4.23 ± 0.20	1.22 ± 0.14	4.35 ± 0.33	1.08 ± 0.16	3.84 ± 0.18	1.26 ± 0.18	2.64 ± 0.09	1.26 ± 0.17	2.60 ± 0.41	1.09 ± 0.10	2.65 ± 0.41	1.23 ± 0.17

Table 4.21 Results of Analysis of Variance (ANOVA) to test the variability in percentage of Soil Organic Matter content due to mining activity, site and depth

Source of Variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F ratio**
General Mean	1	399.24	399.24	-
Mining effects	1	152.64	152.64	2203.63**
Site effects	2	0.62	0.31	4.47*
Depth effects	2	19.21	9.61	138.68**
Mining-Site	2	3.34	1.67	24.13**
Mining –Depth	2	14.23	7.11	102.71**
Site-Depth	4	0.80	0.20	2.89*
Mining-Site-Depth	4	0.25	0.06	0.90
Residual	36	2.49	0.07	-
Total	**54**	**592.82**	**10.98**	-

Table 4.22 Percentage of Soil Organic Carbon in the unmined and mined areas in different depths and seasons in the Nokrek Biosphere Reserve

Depth (cm)	Pre-monsoon						Monsoon						Post-monsoon					
	Budugiri		*Budu Wathegiri*		*Faramgiri*		Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri	
	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M
0-10	3.50 ± 0.16	0.56 ± 0.04	3.32 ± 0.28	0.56 ± 0.05	3.48 ± 0.28	0.56 ± 0.05	2.87 ± 0.16	0.47 ± .15	2.81 ± 0.20	0.36 ± 0.10	2.81 ± 0.27	0.36 ± 0.10	1.95 ± 0.16	0.50 ± 0.04	1.62 ± 0.23	0.52 ± 0.04	1.62 ± 0.23	0.52 ± 0.04
10-20	3.29 ± 0.24	0.78 ± 0.15	3.40 ± 0.49	0.78 ± 0.15	3.4 ± .49	0.78 ± 0.15	2.31 ± 0.08	0.45 ± 0.05	2.54 ± 0.15	0.48 ± 0.04	2.54 ± 0.15	0.48 ± 0.04	1.54 ± 0.08	0.56 ± 0.04	1.76 ± 0.14	0.52 ± 0.05	1.76 ± 0.14	0.52 ± 0.05
20-30	3.17 ± *0.37*	0.71 ± *0.08*	3.03 ± *0.26*	0.69 ± *0.07*	3.03 ± 0.20	0.69 ± 0.07	2.41 ± 0.13	0.61 ± 0.09	2.23 ± 0.12	0.73 ± 0.10	2.23 ± 0.14	0.73 ± 0.10	1.43 ± 0.06	0.90 ± 0.10	1.64 ± 0.22	0.71 ± 0.10	1.64 ± 0.22	0.71 ± 0.10

Table 4.23 Results of Analysis of Variance (ANOVA) to test the variability in percentage of Soil Organic Carbon content due to mining activity, site and depth

Source of Variation	***Degree of freedom***	**Sum of squares**	***Mean sum of squares***	***F ratio***
General Mean	1	129.33	129.33	-
Mining effects	1	48.34	48.34	6257.73**
Site effects	2	0.03	0.02	2.19
Depth effects	2	6.53	3.26	422.49**
Mining-Site	2	0.76	0.38	49.51**
Mining –Depth	2	5.54	2.77	358.87**
Site-Depth	4	0.16	0.04	5.10**
Mining-Site-Depth	4	0.09	0.02	3.07*
Residual	36	0.28	0.01	-
	54	**191.07**	**3.54**	

C/N Ratio: The C/N ratio varied significantly ($P<0.01$) among different sites. However, it did not vary due to mining activity. In the mined areas it ranged between 3.27 and 10.23 and in the unmined areas it ranged between 2.33 and 19.11 (Table 4.24).

Maithani (1996) reported uneven C/N ratio in the soil depths in degraded forest regrowth. Generally, C/N ratio of 6.4 is considered to be ideal for any soil system and forest. Acea & Carballas (1990) obtained C/N ratio of humid zone soils ranging from 10-19. Similarly, Haron *et al.* (1998) recorded a C/N ratio ranging from 8.8 to 16.0.

Table 4.24 C/N ratio in the unmined and mined areas in different depths and seasons in the Nokrek Biosphere Reserve

Depth (cm)	Pre-monsoon						Monsoon						Post-monsoon					
	Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri		Budugiri		Budu Wathegiri		Faramgiri	
	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M	UM	M
0-10	8.71 ± 0.58	4.27 ± 0.34	10.67 ± 0.38	4.23 ± 0.09	8.4 ± 0.28	3.72 ± 0.46	2.84 ± 0.19	10.23 ± 2.70	4.74 ± 0.24	3.69 ± 0.92	4.55 ± 0.18	9.83 ± 2.26	3.45 ± 0.24	6.44 ± 0.25	3.58 ± 0.39	5.90 ± 0.26	3.13 ± 0.16	5.33 ± 0.48
10-20	10.37 ± 0.32	7.22 ± 1.02	17.04 ± 2.14	7.65 ± 1.69	19.11 ± 2.67	7.9 ± 0.74	2.53 ± 0.01	4.07 ± 0.22	3.86 ± 0.07	3.27 _ 0.09	4.56 ± 0.37	4.54 ± 0.56	2.87 ± 0.01	4.70 ± 0.25	3.27 _ 0.18	5.58 _ 0.45	3.16 ± 0.09	4.97 ± 0.41
20-30	7.09 ± 0.80	6.26 ± 0.43	8.72 ± 0.37	5.67 ± 0.29	9.57 ± 0.47	6.29 ± 0.60	2.4 ± 0.05	5.46 ± 0.48	4.07 ±0.22	4.22 _ 0.19	3.78 ± 0.27	4.94 ± 0.60	2.33 ± 0.05	6.12 ± 0.20	3.41 _ 0.62	4.89 _ 0.43	3.10 ± 0.47	8.54 ± 0.92

Table 4.25 Results of Analysis of Variance (ANOVA) to test the variability in C/N ratio due to mining activity, site and depth

Source of Variation	Degree of freedom	Sum of squares	Mean sum of squares	F ratio
General Mean	1	1863.73	1863.73	0.21
Mining effects	1	0.54	0.54	2.21
Site effects	2	11.25	5.62	36.39**
Depth effects	2	185.43	92.71	3.82*
Mining-Site	2	19.47	9.73	32.93**
Mining –Depth	2	167.79	83.90	8.99**
Site-Depth	4	91.66	22.92	1.51
Mining-Site-Depth	4	15.36	3.84	-
Residual	36	91.71	**2.55**	-
	54	**2446.93**	**45.31**	-

IMPACT OF COAL MINING ON WATER QUALITY

Water is one of the most important and basic natural resources. It is not only the one of the most essential commodities for our day to day life, but the development of this natural resource also plays a crucial role in economic and social development processes. Water is used by nature for maintaining climatic balance of the globe.

Water is one of the most stable compounds as well as a universal solvent. Thus, as it occurs in different locations it always maintains its affinity to take materials (in association) into solution. Out of the total water available in the globe. about 98% of it is not suitable for human consumption (Table 4.26). Only the water in fresh water lakes, underground aquifer, rivers and stream channels can be readily collected and used for human consumption (Ghosh, 2002). Hence, though water is omnipresent, water suitable for human consumption is a rare commodity. The quality and distribution of water over different regions of the world is uneven and causes problems of scarcity and suitability. It is therefore imperative that man develops, uses and manages this scarce commodity as rationally and efficiently as possible.

Table 4.26 Global Water Resource

Sl. No.	Source	Quantity		Remarks
		X $10^{15}m^3$	%	
1.	Oceans	1350.00	97.20	Saline
2.	Ice-caps & glacier	29.00	2.0959	
3.	Ground water (<1 km depth)	4.20	0.30	Partly saline
4.	Ground water (>1 km depth)	4.20	0.30	Partly saline
5.	Fresh water lakes	0.125	0.009	
6.	Saline lakes & inland seas	0.104	0.007	Salline
7.	Soil moisture	0.067	0.005	
8.	Atmospheric vapour	0.013	0.0009	
9.	Water in living biomass	0.003	0.0002	
10.	Water in stream channel	0.001	0.00007	

Water, because of being universal solvent, collects whatever contaminant it meets on its way. Thus, sources of water pollution are many. Even rainfall a natural process collects suspended solids, dissolved solids and results changing in pH of the water. It creates surface runoff that collects soil/rock debris, decaying organic matter, domestic waste and chemicals from the land surface and thus gets polluted. Human activities including different industries, suspended solids, dissolved solids, oil & grease, heavy and trace elements, organic matter, different chemicals and bacteria change pH of the water. The pollutants produced by mining and related activities are being listed in Table 4.27.

Table 4.27 Water pollution due to mining

	Activity/Source	Pollutants
Opencast (OC) Mining	a. Removal of vegetation	i. Suspended solids ii.Dissolved solids iii.Heavy metals iv.Oil & grease v. Change in pH
	b. Removal of top & sub-soil	Same as above
	c. Drilling & blasting	Same as above
	d. Overburden dumps, soil & coal stacks	Same as above plus bacteria
Underground (UG) Mining	a. Strata water	i. Suspended solids ii. Dissolved solids iii. Heavy metals iv. Change in pH
	b. Water from stowing	i. Suspended solids ii.Dissolved solids
	c. Water from surface	i. Suspended solids ii.Dissolved solids iii. Chemicals and fertilizers iv. Bacteria v.Change in pH
	d. Other underground sources	i. Suspended solids ii. Dissolved solids iii. Oil & grease iv. Organic matter v. Bacteria

Coal mining and its allied industries constitute one of the major pollution sources in and around mining areas. Opencast coal mining results in serious disruption of surface topography and water course, whereas underground mining is associated with lowering of ground water table. Acid mine drainage is also a very common phenomenon in underground mining (Chakrabotry *et al.* 2002). Many studies have been conducted so far to describe the water pollution due to coal mining (Dhaneswar 1972, Tripathi *et al.* 1980, Singh 1985, Singh *et al.* 1995, Indratna *et al.* 1995, Nath 1992). The potential of a coal seam to produce acid drainage is governed by many factors: its relation to land surface, the water table, the climatic pattern, the hydrology pattern and geology of the area. The most important for these is the sulphur content of the coal seams and associated strata (Singh, 2002). The problem of acid mine drainage in the high organic sulphur tertiary coals of north-east India coal mines are extremely complex and variable. The acid mine drainage production commences with very high rainfall about 400 cm annually in the region and this rain water flows from hill to quarry and finally percolates into the underground mines (Rawat *et al.* 2002).

Acid mine drainage is produced when the sulphides present in coal react with air and water to form sulphuric acid. This reaction involves the following steps:

i. Oxidation of sulphide (FeS_2) in presence of water forms sulphuric acid (H_2SO_4).

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$$

ii. Ferrous sulphate in presence of sulphuric acid and oxygen oxidizes to produce water-soluble ferric sulphate in presence of a mediator bacteria 'Thiobacillus Ferro-Oxidants' which greatly accelerates it.

$$4FeSO_4 + 2H_2SO_4 = 2Fe_2(SO_4)_3 + 2H_2O$$

iii. The ferric ion produced combines with hydroxyl ion of water to form ferric hydroxide. This is insoluble in acid and precipitates.

$$Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 4H_2SO_4$$

The sulphuric acid produced is not of very high concentration due to further reactions with other minerals.

The bacteria 'Thiobacillus Ferro-Oxidants' can thrive in highly acidic environment and can function even at a very low pH (0.9) (Nath 1992).

Damage to water resources caused by mining and related activities starts with extraction of minerals and continues upto its beneficiation. The effects of mining on water resources may be listed as follows:

- Damage to water table due to alteration of topography by excavation and overburden dumping.
- Drying up and disruption of water resources due to subsidence.
- Damage of quality and quantity of surface water and ground water resources due to dumping of overburden and spoils (sometimes on the surface water body itself) or spreading of overburden through rolling and washing, by physical presence of these and hence chemical pollution.
- Loss of ground water through capillary rise because of higher evaporation of soil moisture through barren land surface produced due to mining.
- Pollution of ground water and surface water due to release of toxic mine effluents.
- Loss of ground water storage capacity due to aquifer compression because of decrease in pressure in aquifer zone due to huge ground water withdrawal from mining sites.
- Adverse effect on water table and surface water bodies, due to change in topography and pumping out of ground water.

Mining needs excavation, spoil and overburden dumping. New surfaces are created as mined out faces and dumps slopes. These offer potential surface for erosion. If not properly protected, these are washed by rain water and redistributed surface runoff to result 'siltation'. These cause reduction in infiltration rate and volume of surface water bodies. This invites flood hazard, turbidity of the water, and may even cause drying up of surface water bodies and diversion of streams.

The spreading of overburden and spoil on surrounding land damages greenery, thereby their physical existence besides causing serious water pollution in the nearby water bodies. Damage to greenery is also caused by vacating the land for mining, rehabilitation of men and others, direct excavation, overburden and spoil dumping. All these mining activities also cause damage to underground water tables.

The southern part of Nokrek Biosphere Reserve where coal mining is going on through unscientific subsurface mines, the water quality is being degraded. The seepage water oozing out of various coal mine tunnels and the washing from coal dumps where dug out coal is dumped for transportation, are drained into adjoining water bodies and causes deterioration of the quality of the water.

METHODS

Water samples were collected during three seasons viz., pre-monsoon, monsoon and post-monsoon over a period of two years from three locations i.e., upstream, downstream and mining site in three coal mining areas viz., Budugiri, Budu Wathegiri and Faramgiri. Water samples were collected in clean polythene bottles and sealed, and then brought to laboratory and analysed on the following day. D.O. was analysed on the site itself. pH and conductivity were done by using a pH meter and a Conductivity meter, respectively. Sodium and potassium were estimated by using a Flame Photometer. Nutrients like nitrate, sulphate and phosphate were estimated by using Spectrophotometer. Other parameters such as calcium, magnesium, and total hardness were analysed by following A.P.H.A. (1985) and dissolved oxygen by Modified Winkler's Method.

Analysis of Variance (ANOVA) was performed on the data to test the variability due to site, mining activity and season. 3-way fixed effect ANOVA model was used for analysis (Zar 1974).

RESULTS AND DISCUSSION

The temporal and spatial variations in various physico-chemical parameters of water are discussed below:

pH: The pH of natural water is controlled by the carbon dioxide/bicarbonate equilibrium, and usually ranges from 4.0 to 9.0. The majority of surface water is slightly basic (pH>7), due to the presence of bicarbonates and carbonates. Acidity affects chemical and biological processes taking place in water by dissociation of organic and inorganic molecules. A lower pH may enhance corrosion.

pH values of water in the study sites indicated its acidic nature and did not show any definite pattern of temporal changes in any of the sites. pH of the water in the upstream areas was in the range of 6.80 to 7.6 which became highly acidic in the mining site, that ranged between 3.23 and 3.80. Further down the mined site, the pH had a range of 3.62 to 5.27, which was still lower than the pH obtained in the upstream point (Table 4.28). The result of ANOVA revealed a significant decrease ($P<0.01$) in water pH due to mining and among sites of collection ($P<0.05$) (Table 4.29). The decrease in pH value of water was due to seepage of mine water from coal mine tunnels. This conforms with the findings of Rai (1996) and Jhinran (1982). Jhinran (1982) attributed such a condition to decreased photosynthetic activity due to low uptake of CO_2. Rawat *et al.* (1982) observed very high acidic water (pH 2.3-4.0) in the coal mines of northeast India. The occurrence of acidic character in the mine drainage has been attributed to the pyretic (FeS_2) content in the coal and associated strata (Rawat *et al.* 1982).

Table 4.28 Water pH in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	7.08 ± 0.02	4.81 ± 0.07	3.35 ± 0.07	6.9 ± 0.18	4.0 ± 0.08	3.80 ± 0.04	7.5 ± 0.04	3.62 ± 0.05	3.45 ± 0.10
Budu Wathegiri	6.80 ± 0.14	4.80 ± 0.14	3.40 ± 0.09	7.05 ± 0.02	5.27 ± 0.08	3.65 ± 0.10	7.2 ± 0.01	4.75 ± 0.25	3.75 ± 0.05
Faramgiri	6.94 ± 0.02	3.85 ± 0.30	3.63 ± 0.08	7.60 ± 0.11	3.90 ± 0.14	3.60 ± 0.04	7.06 ± 0.04	4.05 ± 0.07	3.23 ± 0.86

Table 4.29 Result of Analysis of Variance (ANOVA) to test the variability in water pH due to mining activity, site and season

Source of Variation	Degree of freedom	Sum of squares	Mean sum of squares	F ratio
General Mean	1	1361.42	1361.42	-
Mining effects	2	131.34	65.67	565.23**
Site effects	2	0.8	0.4	3.46*
Season effects	2	0.35	0.18	1.51
Mining-Site	4	2.93	0.73	6.31**
Mining – Season	4	0.72	0.18	1.55
Site- Season	4	0.35	0.09	0.75
Mining-Site- Season	8	1.76	0.22	1.89
Residual	27	3.14	0.12	-
Total	**54**	**1502.81**	**27.83**	-

Specific Conductivity: Conductivity of water is regarded as an important index of biological productivity and is a valuable measure of ionic concentration in various aquatic ecosystems (Jhingran 1982). Conductivity is measure of the ability of water to conduct an electric current by migration of solute ions. Therefore, conductivity is proportional to the ionic strength of the water. This mostly depends upon the nature of the various dissolved ionized substances, their actual and relative concentrations, and temperature. Most of the inorganic acids, bases, and salts such as hydrochloric acid, sodium carbonate and sodium chloride are relatively good conductors. Most organic compounds, such as sucrose and benzene, that do not dissociate in aqueous solutions, are very poor conductors. The standard unit of electrical conductivity is the Siemens (S) per metre. In order to avoid the expression of results in small decimal fractions, a smaller unit, the milli-Siemens per centimetre (μS/cm) is generally used. Freshly prepared distilled water has a conductivity of 0.1 to 0.2 μS/cm or even less. The electrical conductivity of most fresh and treated waters is in the range of 5 to 50 μS/cm. The values for highly mineralized waters goes up to 100 μS/cm and even higher. Some industrial wastes may have conductivities even more than 1000 μS/cm.

The conductivity of water at different sites ranged between 24 and 197.5 μS/cm during the study period in different study sites. The marked variation in specific conductivity values among upstream, downstream and mining sites of the study area indicated the differences in the amount of iodizeable salts dissolved in these waters. The water samples from downstream and mined channels showed significantly high ($P<0.01$) specific conductance. This is in striking contrast to very low conductivity in the upstream natural and undisturbed waters. These variations apparently resulted due to influx of large quantities of dissolved salts due to coal mining. Conductivity of the water in the upstream areas was in the range of 24.0 to 75.0, which became more in the mining sites that ranged between 187.5 and 197.5. Further down the mined site, the conductivity was in the range of 122.5 and 197.5, which was much higher than the conductivity obtained in the upstream point (Table 4.30). The findings of the upstream areas are identical with the findings of Bhattacharya (1980) and Thapa (1981). The last two instances were apparently due to influx of seepage from various coal mines. These high values of conductivity agree with findings of Sharma *et al.* (1993).

Table 4.30 Specific Conductivity in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	75 ± 1.63	190 ± 4.08	188 ± 5.65	24 ± 0.94	190 ± 4.71	197.5 ± 0.68	48.5 ± 1.64	197.5 ± 0.68	197.5 ± 0.68
Budu Wathegiri	41.5 ± 1.15	190 ± 4.91	197.5 ± 0.68	31.5 ± 1.64	149 ± 2.12	187.5 ± 5.89	36 ± 1.08	122.5 ± 14.06	197.5 ± 0.68
Faramgiri	33 ± 2.04	187 ± 5.89	197.5 ± 0.68	25.5 ± 1.17	180 ± 9.42	197.5 ± 0.68	34 ± 0.94	190 ± 4.71	197.5 ± 0.68

Table 4.31 Result of Analysis of Variance (ANOVA) to test the variability in Specific Conductivity content due to mining activity, site and season

Source of Variation	Degree of freedom	Sum of squares	Mean sum of squares	F ratio
General Mean	1	1066817.00	1066817.00	-
Mining effects	2	280323.50	140161.80	1851.45**
Site effects	2	1402.13	701.06	9.26**
Season effects	2	1176.50	588.25	7.77**
Mining-Site	4	1861.75	465.4	6.15**
Mining – Season	4	891.75	222.94	2.94**
Site- Season	4	843.13	210.78	2.78*
Mining-Site- Season	8	2566.63	320.83	4.24**
Residual	27	2044.00	75.70	-
Total	**54**	**1357926.00**	**25146.78**	-

Total Alkalinity: Total alkalinity is regarded as an important index of aquatic biological productivity (Moyle 1946, Alikunhi 1957, Wetzel 1983). Alkalinity of water may be defined as its capacity to neutralize a strong acid. It has been characterized by the presence of hydroxyl (OH^-) ions capable of combining with hydrogen (H^+) ions. A number of bases such as carbonates, bicarbonates, hydroxides, phosphates, nitrates, silicates and borates contribute to the alkalinity. In natural waters carbonates, bicarbonates, and hydroxides are regarded to be the predominant bases. Natural waters with high alkalinity have been generally rich in phytoplankton. In highly productive waters the alkalinity level could be above 100 mg/l.

Alkalinity values showed high variation (0 to 32.0 mg/l) among different water samples collected from different sites. Alkalinity of the water in the upstream areas was in the range of 13.5 and 32.0 mg/l. which became significantly lower in the mining sites ($P<0.01$) that ranged between 0 to 5.0 mg/l. Further down the mined sites the alkalinity was in the range of 0 to 22.5 mg/l, which was still much lower than the alkalinity obtained at the upstream point (Table 4.32). The waters of downstream and mined sites had very low alkalinity, which could be attributed to the presence of bicarbonate ions in water. Such condition is a pointer of low productive level of the water bodies. The alkalinity also varied significantly ($P<0.05$) among three sites studied (Table 4.33). Earlier studies from Jaintia Hills of Meghalaya had an alkalinity range between 5.8 and 53.6 mg/l (Sharma *et al.* 1993).

Table 4.32 Total Alkalinity in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	26.5 ± 0.70	7 ± 1.41	5 ± 2.35	18.5 ± 1.17	2.5 ± 1.17	0 ± 0.0	21.5 ± 0.23	4.75 ± 0.10	0 ± 0.0
Budu Wathegiri	32 ± 0.94	8 ± 1.88	0 ± 0.0	20.5 ± 0.70	22.5 ± 4.47	0 ± 0.0	21.5 ± 2.59	13 ± 6.1	0 ± 0.0
Faramgiri	25.81 ± 0.52	0 ± 0.0	0 ± 0.0	13.5 ± 0.23	0 ± 0.0	0 ± 0.0	23 ± 2.35	7.0 ± 3.29	0 ± 0.0

Table 4.33 Result of Analysis of Variance (ANOVA) to test the variability in Total Alkalinity due to mining activity, site and season

Source of Variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F ratio**
General Mean	1	5470.23	5470.23	-
Mining effects	2	4534.57	2267.28	70.19**
Site effects	2	274.56	137.28	4.25*
Season effects	2	75.12	37.56	1.16
Mining-Site	4	287.19	71.80	2.22
Mining – Season	4	301.46	75.37	2.33
Site- Season	4	152.63	38.16	1.18
Mining-Site- Season	8	185.37	23.17	0.72
Residual	27	873.13	32.30	-
Total	**54**	**12153.25**	**225.06**	-

Total Hardness: The total hardness of water is defined as the sum of the calcium and magnesium concentration in milligrams per litre. Hardness of water is not a specific constituent but is a variable and complex mixture of cations and anions. It is caused by dissolved polyvalent metallic ions. The degree of hardness of water has been classified in terms of the equivalent $CaCo_3$ concentration as follows:

Soft	0 - 60 mg/l
Medium	60 – 120 mg/l
Hard	120 – 180 mg/l
Very hard	> 180 mg/l

The total hardness among different water samples showed wide range of variations. It ranged between 21 and >300 mg/l having lower values in the upstream areas and much lower values in the mined that ranged between 60 and >300 mg/l. Further down the mined site, in the downstream areas the total hardness recorded was in the range of 53 and 153 mg/l (Table 4.34). The total hardness of water significantly increased ($P<0.01$) with mining activities and also varied significantly ($P<0.01$) among different seasons (Table 4.35). The results of the present investigation showed much wider range of total hardness of water in comparison to the result of the study conducted by Sharma *et al.* (1993) also recorded a range between 82.0 and 90.1 mg/l at Sobshreih and Bapung coal mined areas.

Table 4.34 Total Hardness in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	29 ± 0.47	153 ± 3.77	137.5 ± 5.89	21 ± 1.41	67.5 ± 2.5	155 ± 11.78	22.5 ± 1.77	125 ± 2.35	100 ± 4.71
Budu Wathegiri	33.5 ± 0.71	100 ± 2.35	>300 ± 0.0	29 ± 2.25	63.5 ± 8.05	>300 ± 0.0	29.5 ± 1.06	87.5 ± 1.17	>300 ± 0.0
Faramgiri	31 ± 0.47	130 ± 2.35	147.5 ± 15.3	26 ± 0.81	53 ± 0.47	60 ± 9.4	26 ± 1.63	97.5 ± 5.89	>300 ± 5.07

Table 4.35 Result of Analysis of Variance (ANOVA) to test the variability in Total Alkalinity due to mining activity, site and season

Source of Variation	Degree of freedom	Sum of squares	Mean sum of squares	F ratio
General Mean	1	596400.50	596400.5	-
Mining effects	2	233147.00	116573.50	125.73**
Site effects	2	30224.69	15112.34	16.30**
Season effects	2	10337.44	5168.72	5.57**
Mining-Site	4	83711.50	20927.88	22.57**
Mining – Season	4	6309.75	1577.44	1.70
Site- Season	4	7278.00	1819.50	1.96
Mining-Site- Season	8	15070.75	1883.84	2.03
Residual	27	25033.50	927.17	-
Total	**54**	**100751.00**	**18657.65**	-

Calcium and Magnesium: Calcium and magnesium are the most abundant cations found in fresh waters and hence, they are important contributors to the total hardness of the medium (Grimshaw & Hadson 1970, Khan & Zutshi 1980, Jhingran 1982). Among these, calcium is required as a micro nutrient by algae and aquatic plants while magnesium is a conservation ion (Wetzel, 1983).

In the present study the calcium hardness varied between 8.06 and 87.3 mg/l in different water samples collected from three different sites of Nokrek Biosphere Reserve. Calcium content in the water in the upstream areas was in the range of 8.06 and 13.5 mg/l, which became significantly higher ($P<0.01$) in the mining sites and ranged between 11.3 and 61.7 mg/l. In the downstream areas, the calcium content was in the range of 6.8 and 87.3 mg/l (Table 4.36). The concentration of calcium also showed significant variations ($P<0.01$) among different seasons studied. It was generally higher in the pre and post monsoon seasons than the monsoon season (Table 4.37). Sharma *et al.* (1993) in their study in Jaintia Hills recorded calcium concentration that ranged from 3.6 to 43.5 mg/l. In another study in Jharia coal fields of Bihar, Sharma (2000) recorded calcium concentration in the range 40-76 mg/l.

Magnesium hardness ranged between 3.14 and 47.2 mg/l. Magnesium content in the water in the upstream areas was in the range of 3.14 and 8.7 mg/l, which significantly increased ($P<0.01$) to 18.5 to 47.2 mg/l in the mining sites. The magnesium content in the downstream areas was in the range of 9.5 and 26.1 mg/l (Table 4.38). Sharma (2000) recorded magnesium content of 70-105 mg/l at Jharia coal field

Table 4.36 Calcium content in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	8.7 ± 0.16	87.3 ± 3.41	61.15 ± 7.96	8.06 ± 1.15	6.8 ± 0.76	11.3 ± 4.33	12 ± 0.23	17.5 ± 0.91	16.5 ± 1.41
Budu Wathegiri	13.5 ± 0.94	45.3 ± 3.2	61.7 ± 6.24	11 ± 0.7	17.5 ± 0.94	57.5 ± 2.8	9.65 ± 1.48	28.8 ± 3.2	45.6 ± 0.0
Faramgiri	12.7 ± 0.35	60 ± 2.35	51.19 ± 8.95	8.2 ± 1.22	13.5 ± 2.4	20.6 ± 2.78	9.05 ± 0.25	33.7 ± 4.00	49.7 ± 2.71

Table 4.37 Result of Analysis of Variance (ANOVA) to test the variability in Calcium content due to mining activity, site and season

Source of Variation	Degree of freedom	Sum of squares	Mean sum of squares	F ratio
General Mean	1	44902.15	44902.15	-
Mining effects	2	9712.41	4856.21	39.61**
Site effects	2	416.79	208.39	1.70
Season effects	2	7225.19	3612.60	29.46**
Mining-Site	4	1678.42	419.60	3.42*
Mining – Season	4	3868.71	967.18	7.89**
Site- Season	4	2222.76	555.69	4.53**
Mining-Site- Season	8	1778.80	222.35	1.81
Residual	27	3310.53	122.61	-
Total	**54**	**75115.75**	**1391.03**	-

Table 4.38 Magnesium content in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	5.2 ± 0.21	22.7 ± 3.27	18.5 ± .049	3.14 ± 0.06	14.7 ± 0.47	34.9 ± 3.91	3.97 ± 0.12	26.1 ± 0.80	20.2 ± 0.80
Budu Wathegiri	8.7 ± 1.79	10.34 ± 3.04	41.44 ± 9.22	4.46 ± 0.44	10.93 ± 1.77	46.75 ± 6.29	4.45 ± 0.32	19.7 ± 1.50	47.2 ± 6.88
Faramgiri	4.4 ± 0.03	12.5 ± 1.22	23.3 ± 1.58	3.95 ± 0.46	9.5 ± .68	9.57 ± 1.61	4.84 ± 0.40	15.45 ± 0.49	37.1 ± 10.51

Table 4.39 Result of Analysis of Variance (ANOVA) to test the variability in Calcium content due to mining activity, site and season

Source of Variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F ratio**
General Mean	1	15988.09	15988.09	-
Mining effects	2	6221.67	3110.84	27.51**
Site effects	2	603.82	301.91	2.67
Season effects	2	204.84	102.42	0.91
Mining-Site	4	1471.43	367.86	3.25*
Mining – Season	4	195.36	48.84	0.43
Site- Season	4	245.05	61.26	0.54
Mining-Site- Season	8	790.09	98.76	0.87
Residual	27	3053.56	113.09	-
Total	**54**	**28773.90**	**532.85**	-

Chloride: Chloride is regarded as a valuable indicator for water quality (Wetzel, 1983). It is also a conservative ion but plays metabolically active role in the photosynthesis of water and phosphorylation in autotrophs. Chloride anion is generally present in natural waters. The presence of chloride in natural waters can be attributed to dissolution of salt deposits and effluents from industries. These sources may result in local contamination of both surface and ground water. Chloride content of 250 mg/l and above makes water salty in taste. A concentration of 250 mg/l may be detectable in some waters containing sodium ions. On the other hand, the typical salty taste may be absent in water containing 1000 mg/l chloride when calcium and magnesium ions are predominant. A high concentration of chloride is regarded as an indicator of pollution. In the present study the general concentration of chloride ions ranged between 4.75 and 170 mg/l. Chloride content in the water in the upstream areas was low and was in the range of 4.75 and 12.10 mg/l. The chloride concentration was well within the limits usually found in natural fresh waters (Wetzel 1983). The chloride content became significantly higher ($P<0.01$) in the mining sites that ranged between 20 and 170 mg/l. Further down the mined site the chloride content was in the range of 22.5 and 54 mg/l, which was still much higher than the chloride obtained in the upstream point (Table 4.40). Rai (1996) recorded chloride concentration in the range of 7.6-30.1 mg/l in the coal mining areas of Jaintia Hills. Sharma *et al.* (1993) recorded 93.9 mg/l of chloride in Bapung stream of Bapung coal mine areas.

Table 4.40 Chloride content in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	4.75 ± 0.11	23.5 ± 0.70	20 ± 1.41	5.75 ± 0.11	30.5 ± 2.12	162.5 ± 31.81	12.10 ± 1.66	29.25 ± 2.71	102.5 ± 8.24
Budu Wathegiri	10 ± 0.23	43.5 ± 0.70	170 ± 4.71	8.00 ± 0.70	28.5 ± 3.06	160 ± 18.85	7.3 ± 0.80	47.5 ± 3.06	128 ± 33.94
Faramgiri	4.75 ± 0.35	54 ± 0.94	50.5 ± 5.89	7.15 ± 0.16	22.5 ± 1.17	20 ± 2.35	9.5 ± 0.94	49 ± 3.29	112.5 ± 41.24

Table 4.41 Result of Analysis of Variance (ANOVA) to test the variability in Chloride content due to mining activity, site and season

Source of Variation	Degree of freedom	Sum of squares	Mean sum of squares	F ratio
General Mean	1	122789.40	122789.40	-
Mining effects	2	80447.25	40223.62	27.40**
Site effects	2	10118.40	5059.20	3.45*
Season effects	2	1427.00	713.50	0.49
Mining-Site	4	17719.02	4429.75	3.02*
Mining – Season	4	3057.06	764.27	0.52
Site- Season	4	9275.56	2318.89	1.58
Mining-Site- Season	8	12263.41	1532.93	1.04
Residual	27	39637.94	1468.07	-
Total	**54**	**2967354.00**	**5495.09**	-

Phosphate: Presence of phosphate in water has great significance. It is an essential nutrient needed primarily for the growth of plants and often acts as a limiting factor. The presence of phosphate in large quantities in fresh waters indicates pollution. The phosphate content can arise from industrial effluents or from domestic sewage. Phosphate promotes growth of nuisance-causing micro organisms. Though phosphate posses problems in surface waters, its presence is necessary for biological degradation of waste waters.

The present study showed low phosphate concentration (0.01 to 0.18 mg/l) in the study area (Table 4.42). This is similar with the findings of Sharma *et al.* (1993), who recorded a phosphate range of 0.08-2.2 mg/l at Thadlaskein coal mine areas. The phosphate concentration in the water samples collected from different sampling stations did not show any significant variation ($P<0.05$), thereby suggesting little impact of coal mining in phosphate concentration. The phosphate concentration also did not vary among different seasons of the year.

Table 4.42 Phosphate content in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	0.01 ± 0.0	0.03 ± 0.01	0.10 ± 0.01	0.01 ± 0.0	0.05 ± 0.01	0.07 ± 0.01	0.01 ± 0.0	0.02 ± 0.0	0.09 ± 0.01
Budu Wathegiri	0.06 ± 0.02	0.05 ± 0.01	0.01 ± 0.0	0.05 ± 0.02	0.02 ± 0.01	0.04 ± 0.01	0.04 ± 0.01	0.05 ± 0.01	0.06 ± 0.01
Faramgiri	0.06 ± 0.01	0.07 ± 0.01	0.06 ± 0.01	0.02 ± 0.01	0.08 ± 0.03	0.18 ± 0.07	0.04 ± 0.01	0.06 ± 0.01	0.07 ± 0.01

Table 4.43 Result of Analysis of Variance (ANOVA) to test the variability in Phosphate content due to mining activity, site and season

Source of Variation	Degree of freedom	Sum of squares	Mean sum of squares	F ratio
General Mean	1	0.14	0.14	-
Mining effects	2	0.02	0.01	2.51
Site effects	2	0.01	0.01	2.37
Season effects	2	0.00	0.00	0.14
Mining-Site	4	0.01	0.00	1.18
Mining – Season	4	0.01	0.00	0.51
Site- Season	4	0.01	0.00	0.46
Mining-Site- Season	8	0.01	0.00	0.72
Residual	27	0.08	0.00	-
Total	**54**	**0.29**	**0.01**	-

Nitrate: In water the most important source of nitrate is biological oxidation of nitrogenous organic matter. There are nitrifying bacteria, which are known to play significant role in oxidation of such organic matter. There are certain nitrogen-fixing bacteria and algae, which are having capacity to fix molecular nitrogen in the form of nitrates. Nitrate is an important plant nutrient. The high concentration of nitrate in water indicates pollution. When it is present in excess it causes ubiquitous growth of algae, often present in blooms.

The present study observed that the nitrate concentration in the study area ranged from 0.03 to 0.77 mg/l. Nitrate content in the water in the upstream areas was in the range of 0.03-0.10 mg/l, which significantly increased ($P<0.01$) in the mining sites to 0.03- 0.77 mg/l. In the downstream areas it was in the range of 0.05 to 0.45 mg/l (Table 4.44). Nitrate concentration was also significantly different ($P<0.05$) among different seasons of the year (Table 4.45). These results are identical with the findings of Sharma *et al.* (1993), who recorded a range of 0.002 to 1.1 mg/l. However, Sharma (2000) recorded very high concentration of nitrate in the Jharia coal field, which ranged between 7.02 to 23.12 mg/l.

Table 4.44 Nitrate content in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			**Monsoon**			**Post-Monsoon**		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	0.06 ± 0.02	0.44 ± 0.01	0.55 ± 0.02	0.03 ± 0.01	0.14 ± 0.06	0.16 ± 0..06	0.07 ± 0.01	0.42 ± 0.01	0.34 ± 0.01
Budu Wathegiri	0.09 ± 0.01	0.05 ± 0.01	0.04 ± 0.01	0.04 ± 0.01	0.45 ± 0.01	0.52 ± 0.08	0.05 ± 0.01	0.08 ± 0.01	0.09 ± 0.01
Faramgiri	0.10 ± 0.02	0.12 ± 0.01	0.07 ± 0.01	0.03 ± 0.01	0.38 ± 0.07	0.77 ± 0.07	0.05 ± 0.01	0.08 ± 0.01	0.03 ± 0.01

Table 4.45 Result of Analysis of Variance (ANOVA) to test the variability in Nitrate content due to mining activity, site and season

Source of Variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F ratio**
General Mean	1	2.11	2.11	-
Mining effects	2	0.54	0.27	13.57**
Site effects	2	0.05	0.02	1.17
Season effects	2	0.19	0.09	4.71*
Mining-Site	4	0.04	0.01	0.46
Mining – Season	4	0.22	0.05	2.71
Site- Season	4	0.57	0.14	7.10**
Mining-Site- Season	8	0.50	0.06	3.13*
Residual	27	0.54	0.02	-
Total	**54**	**4.77**	**0.09**	-

Sulphate: Sulphate ions usually occur in natural waters. Many sulphate compounds are readily soluble in water. Most of them originate from the oxidation of sulfide ores and solution of gypsum and anhydrite. The presence of shales, particularly those rich in organic compounds, and existence of industrial wastes are the other source of sulphate pollution. Atmospheric sulfur dioxide formed by the combustion of fossil fuels and emitted by the metallurgical roasting processes may also contribute to the sulphate compounds in water. Sulfur trioxide (SO_3) produced by the photolytic oxidation of sulfur dioxide comes with water vapours to form sulphuric acid which is precipitated as acid rain or snow. Sulfur bearing minerals are common in most sedimentary rocks and when it is weathered gypsum (calcium sulphate) is dissolved and sulfide minerals are partly iodized, giving rise to a soluble form of sulphate that is carried away by water.

In the present study, sulfur concentration ranged between 0.08 and 39.75 mg/l in different water samples collected from different sites (Table 4.46). However, variation in sulphate concentration due to mining, seasons and sites was not significant ($P<0.05$) (Table 4.47). Sharma *et al.* (1993) recorded the sulphate content at Sohshreih which ranged from 6.8 to 37.3 mg/l and 17.5-43.8 mg/l at Bapung coal mined areas. Sharma (2000) recorded the sulphate concentration of Lodna coal washery that ranged from 9-30 mg/l. Rai (1996) recorded very low content of sulphur in the coal mine fields of Jaintia Hills which was in the range of 0-9.5mg/l.

Table 4.46 Sulphate content in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	0.52 ± 0.03	21.69 ± 0.38	16.09 ± 0.66	0.08 ± 0.01	17.95 ± 0.73	34.10 ± 2.63	0.51 ± 0.02	28.0 ± 3.2	30.50 ± 0.90
Budu Wathegiri	0.70 ± 0.02	14.15 ± 0.63	20.50 ± 0.47	0.79 ± 0.11	12.50 ± 1.40	20.89 ± 6.30	0.74 ± 0.07	24.60 ± 5.18	30.80 ±2.45
Faramgiri	1.0 ± 0.02	33.75 ± 5.30	39.75 ± 5.30	0.70 ± 0.02	12.60 ± 1.8	23.50 ± 4.24	0.70 ± 0.02	22.0 ± 4.94	23.75 ± 1.06

Table 4.47 Result of Analysis of Variance (ANOVA) to test the variability in Sulphate content due to mining activity, site and season

Source of Variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F ratio**
General Mean	1	13878.13	13878.13	-
Mining effects	2	6706.16	3353.08	50.59
Site effects	2	123.27	61.64	0.93
Season effects	2	169.58	84.79	1.28
Mining-Site	4	75.86	18.96	0.29
Mining – Season	4	241.35	60.34	0.91
Site- Season	4	693.79	173.45	2.62
Mining-Site- Season	8	466.89	58.36	0.88
Residual	27	1789.72	66.29	-
Total	**54**	**24144.75**	**447.13**	-

Sodium: The concentration of sodium ions becomes remarkably high in saline and backish water. This high concentration of sodium limits the biological diversity due to osmotic stress. Sodium salt is highly soluble in water and causes softness. If the sodium content is very high, it makes the water salty in taste and unfit for human consumption. High sodium content in irrigation water brings about puddling of soil. Because of this water intake of soil gets reduced and it becomes hard in which germination of seed becomes difficult.

The sodium concentration in the water samples collected from different sites ranged between 1.23 and 5.09 mg/l (Table 4.48). The sodium concentration did not show any significant variation due to mining, season and site differences. Sharma (2000) recorded a high concentration of sodium content in the coal mines of Jharia which ranged from 16 to 72 mg/l.

Table 4.48 Sodium content in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	2.042 ± 0.74	5.09 ± 1.05	1.67 ± 0.39	1.43 ± 0.27	2.35 ± 0.54	2.75 ± 0.87	1.65 ± 0.40	4.25 ± 0.47	1.23 ± 0.12
Budu Wathegiri	2.90 ± 0.28	2.95 ± 0.02	2.75 ± 0.11	2.0 ± 0.23	2.0 ± 0.23	3.40 ± 0.50	2.65 ± 0.04	2.70 ± 0.04	2.35 ± 0.11
Faramgiri	3.65 ± 0.02	3.80 ± 0.32	1.85 ± 0.49	2.20 ± 0.14	4.25 ± 0.28	4.50 ± 0.47	2.80 ± 0.32	2.0 ± 0.23	2.55 ± 0.25

Potassium: In natural waters potassium cation has lesser concentration than sodium. Although it occurs in small amounts, it plays an important role in the metabolism of fresh water biota and is regarded to be an important micronutrient.

The potassium concentration in the study area ranged from 2.75 to 27.25 mg/l. In the upstream areas, it was in the range of 2.75 to 5.50 mg/l, which was significantly higher ($P<0.01$) in the mining sites (6.0 to 25.5 mg/l). Further down the mined site, the potassium concentration was in the range of 5.75 to 27.25 mg/l, which was much higher than the potassium in the upstream point (Table 4.49). The potassium concentration also showed significant variation ($P<0.01$) among different seasons of the year (Table 4.50). Sharma (2000) observed a range of 6.5-27.4 mg/l of potassium concentration in water of Jharia coal fields.

Table 4.49 Sulphate content in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	5.25 ± 1.06	27.25 ± 5.03	8.25 ± 1.88	2.75 ± 0.07	13.0 ± 0.23	11.75 ± 2.94	3.55 ± 0.21	20.50 ± 1.17	6.0 ± 0.38
Budu Wathegiri	3.15 ± 0.16	13.95 ± 0.74	23.50 ± 0.70	5.0 ± 0.59	12.60 ± 0.04	18.50 ± 1.64	4.15 ± 0.16	8.0 ± 0.70	15.25 ± 1.29
Faramgiri	5.50 ± 0.23	19.5 ± 0.70	25.50 ± 0.23	2.90 ± 0.04	5.75 ± 1.06	7.65 ± 2.28	3.60 ± 0.28	6.85 ± 0.30	16.0 ± 0.94

Table 4.50 Result of Analysis of Variance (ANOVA) to test the variability in Sulphate content due to mining activity, site and season

Source of Variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F ratio**
General Mean	1	6485.69	6485.69	-
Mining effects	2	1316.98	658.49	31.42**
Site effects	2	13.08	6.54	0.31
Season effects	2	375.12	187.56	8.95**
Mining-Site	4	668.06	167.02	7.97**
Mining – Season	4	143.20	35.80	1.71
Site- Season	4	164.86	41.22	1.97
Mining-Site- Season	8	231.11	28.89	1.38
Residual	27	565.88	20.96	-
Total	**54**	**9963.98**	**184.52**	-

Dissolved Oxygen: All living organisms are dependent upon oxygen in one form or another to maintain the metabolic processes that produce energy for growth and reproduction. Aerobic processes are the subjects of greatest interest because of their need for free oxygen. The concentration of dissolved oxygen (D.O.) in natural and waste water depends on physical, chemical and biological processes in the water. Since D.O. is essential for the biota of ecosystem, and for the aerobic degradation of organic pollution, the measurement of D.O. is important in waste water treatment. Non-polluted surface waters are generally saturated with dissolved oxygen. Due to the presence of oxygen demanding pollutants like organic waste, rapid depletion of dissolved oxygen takes place. Oxydizable inorganic substances, such as hydrogen sulphide, ammonia, nitrites and ferrous iron also bring about a wide decrease in dissolved oxygen. Organisms are having specific oxygen requirements, low dissolved oxygen has been proved to be lethal for many of the organisms.

The dissolved oxygen in the study area showed a wide range of variation varying from 0 to 9.60 mg/l. D.O. content in the water in the upstream areas was in the range of 3.5-9.6 mg/l, which reduced to 0-3.1 mg/l in the mining sites. In the down stream areas, the D.O. was in the range of 0.55 and 5.5 mg/l (Table 4.51). However, ANOVA did not show any significant variation due to mining, season and site differences. Sharma *et al.* (1993) recorded a D.O. ranging from 2.2 to 10.4 while studying the physio-chemical properties of aquatic system in coal mines of Jaintia Hills district of Meghalaya. Chakraborty *et al.* (2002) recorded D.O of Damudar River amidst the coal mining areas of Bihar, which ranged from 0-7.1 mg/l.

Table 4.51 Dissolved Oxygen content in the Upstream, Downstream and Mining Sites in different seasons in the Nokrek Biosphere Reserve

	Pre-Monsoon			Monsoon			Post-Monsoon		
	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site	Up stream	Down stream	Mining Site
Budugiri	7.5 ± 1.06	2.5 ± 1.03	2.00 ± 0.54	9.6 ± 0.07	2.5 ± 0.23	1.2 ± 0.94	9.5 ± 0.21	1.1 ± 0.17	0.8 ± 0.38
Budu Wathegiri	9.45 ± 0.16	3.5 ± 0.74	1.5 ± 0.70	8.6 ± 0.59	4.0 ± 0.04	1.4 ± 0.64	8.7 ± 0.16	0.55 ± 0.70	0 ± 0.00
Faramgiri	3.5 ± 0.23	1.5 ± 0.04	0 ± 0.00	7.6 ± 0.04	5.5 ± 1.06	3.1 ± 0.28	8.8 ± 0.28	0.9 ± 0.30	0.25 ± 0.24

(a)

(b)

Plate 3 Landscape destruction due to coal mining within Nokrek Biosphere Reserve (a) and damage to soil system of Nokrek Biosphere Reserve due to coal mining activities (b).

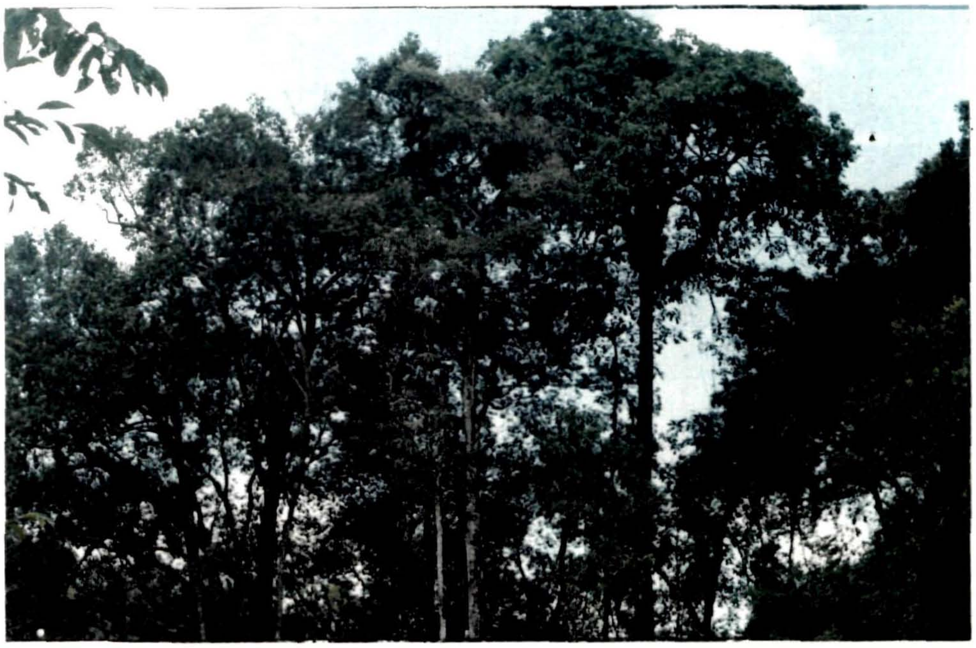


Plate 4 An inside view of the forests in Nokrek Biosphere Reserve.

Plate 5 A view of the canopy of the semi-evergreen forest found in unmined areas of Nokrek Biosphere Reserve.

(a)

(b)

Plate 6 Damage to natural vegetation of Nokrek Biosphere Reserve due to coal mining activities: Destruction of vegetation due to road construction for transportation of coal (a) and for piling of extracted coal (b).

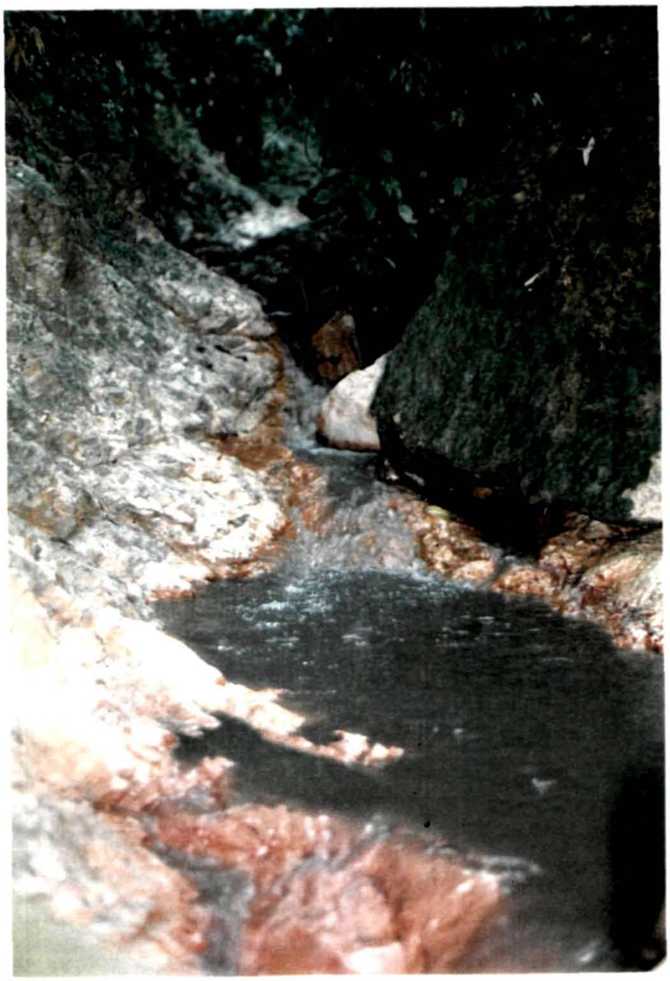


Plate 7 Impact of coal mining on aquatic ecosystems: Photographs showing the poor water quality in the downstream areas of the coal mines in Nokrek Biosphere Reserve.

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CHAPTER-V

GENERAL DISCUSSION

In the entire Garo Hills, the total reserve of coal has been estimated to be 359 million tonnes and a considerable portion of it is found in the southern part of Nokrek Biosphere Reserve. The unscientific extraction of coal in unorganized sector within the Biosphere Reserve is going on and the area of coal mining in this region is increasing day by day since the beginning of mining in 1985. The annual extraction of coal from the Biosphere Reserve has been estimated to be about 4,32,000 tonnes.

The Nokrek Biosphere Reserve is formed over gneissic rock with old inlier, Sela group and Jaintia and Simsang Series with ultra-basic in deep shades rocks. The coal beds are of Lower Eocene geological horizon, which are mostly found along with Jaintia and Simsang series.

More than 75% of the area of the Biosphere Reserve falls between 9° and 22° slope. The relief characteristic of the area reveals that more than 70% of the area of the Biosphere Reserve has relative relief between <100m and 200m. More than 78% of the total area of the Biosphere Reserve has the drainage density between 5 and 9 km per sq. km. The drainage frequency map of the study area reveals that more than 40% of the area has 8 to 10 stream per sq. km.

Due to extensive coal mining, large areas of Nokrek Biosphere Reserve has been turned into degraded land, creating unfavourable habitat conditions for plant growth.

Mining of coal caused massive damage to landscape and biological communities. It was found that the number of tree species got reduced due to mining. The unfavourable habitat conditions prevailing in the coal mined areas might have reduced the regeneration of many tree species, thereby reducing the number of tree species in the mined areas. Similar observations were made in the studies conducted in the coal mining areas in different parts of the world (Cornwell 1971, Fyles *et al.* 1985, Game *et al.* 1982, Singh & Jha 1987, Jha & Singh 1990). The number of shrub species recorded was much less in comparison to trees and herbs. Although the number of tree and shrub species was reduced due to mining, the number of herb species colonizing the mined areas was found higher than the unmined sites. This could be due to the better ability of herbaceous species to adapt to the disturbed habitats. Besides, certain herb species invaded the newly created habitats due to mining. Fifteen among tree, 4 among shrub and 28 among herb species were found only in mined sites, while 27 tree species, 4 shrub species and 16 herb species were found exclusively in the unmined sites. The density of trees, shrubs and herbs also got reduced due to mining. The works of Lyngdoh (1995) and Das Gupta (1999) in Jaintia Hills coal fields of Meghalaya had more or less similar observations. The basal area of tree species in the unmined areas was significantly higher than in the mined areas. The dominance was shared by many species both at mined and unmined areas. In unmined sites, *Castanopsis kurzii, Ficus racemosa, Ostodes paniculata, Dysoxylum gobara, Caryota urens, Persea duthei* and *Macropanax undulatus* were dominant tree species, while *Bridelia monoica, Schima* *wallichii, Ficus hispida, Spondias pinnata, Meliosma wallichii* and *Bauhinia variegata* were dominant trees in the mined sites. *Citrus* sp., *Hiptage benghalensis, Clerodendrum wallichii, Elsholtzia blanda* and *Psychotria erratica* were the dominant shrub species in the unmined areas while in the mined areas *Clerodendrum wallichii, Agapetes variegata, Millitia pachycarpa, Desmodium racemosa, Lantana camara* and *Olea dentana* were dominant. Among the herb species, *Davallia* sp., *Piper longrum* and *Asplenium* sp. were the dominant in unmined areas and in the mined areas *Eupatorium adenophorum, Pteris* sp., *Thysanolaena maxima, Asplenium* sp., *Eleusine corocana* and *Inula cappa* were dominant species. Shannon's diversity index for tree species was low in the mined sites than the unmined sites at Budugiri and Faramgiri. However, at Budu Wathegiri, the trend was reverse. This could be attributed to the existence of bigger trees and causing less damage to the trees during mining operation. The herb species diversity ($\bar{H}$) however, increased with mining activity. The density-CBH distribution of tree species indicated that the density of trees irrespective of their girth class were lower in the mined sites than the unmined sites. The basal area of tree species in the unmined areas was significantly higher than the mined areas. This trend was also observed by Paijman (1970) in New Guinea, Newbery *et al.* (1992) in Malayasia and Parthasarathi *et al.* (1997) in India for disturbed forest stands. Unmined sites had better tree regeneration than the mined sites. The seedling and sapling densities were much higher in the unmined sites than the mined sites. The seedlings of *Schima wallichii, Acacia pennata, Crotom caudatus* and *Celastrus championii* species were dominant in the mined sites and *Camellia caudata*, *Micromellum integerimum*, *Castanopsis indica*, *Acacia pennata*, *Echinocarpus murex* species were dominant in the unmined sites. However, during sapling phase, *Vitex vestuta*, *Commelina sikkimensis*, *Kydia calycina* species were dominant in mined and *Ostodes paniculata*, *Ficus elastica*, *Homonia riparia* and *Psychotria adenophylla* species were dominant in unmined sites. Most of the tree species showed contagious distribution pattern both at unmined and mined sites. Due to mining, the contagiousness increased. This is in agreement with the findings of Rao *et al.* (1990), who observed that due to disturbance contagiousness increased. Webb *et al.* (1967), Ashton (1972) and Austin *et al.* (1972) indicated that in the absence of major disturbances, soil and water conditions play significant roles in controlling such distribution pattern.

All the soil physico-chemical characteristics were adversely affected due to coal mining. Due to mining pH got reduced drastically, thereby increasing the acidic nature of soil. Bradshaw & Chadwick (1980) reported that decline in pH in mined areas is one of the serious problems associated with coal mining activity. Lowering of pH strongly affects the plant growth in various ways including the availability of a large number of essential nutrients in the soil. The mining had an adverse impact on soil moisture content as the soil moisture regime of the soil got depleted. The moisture stress could be due to the exposed surface, sandy texture and paucity of litter in the mined areas resulting in elevated soil temperature and enhanced rate of evaporation from the soil surface (Richardson 1975, Lyngdoh 1995). The severe acidity observed in the mined areas of Nokrek Biosphere Reserve conforms with the reports of Chadwick (1973), Johnson & Bradshaw (1979) and Baig (1992). Soil moisture content and soil nutrient levels are thought to be related to the organic matter content and rate of N, P and K accumulation. The low amount of soil organic matter and organic carbon in the mined areas as observed in the present study agrees with the findings of many studies carried out elsewhere (Lyngdoh 1995, Uma Sankar *et al.* 1993 and Safaya & Wali 1979). Lyngdoh (1995), Down & Stock (1977), Thomas *et al.* (1985) reported low level of organic carbon in the mined areas and attributed it to the delay in vegetation establishment on the mine spoils. Besides, the organic carbon content in the mined areas is low because soil particles on the surface are generally brought from deeper horizon, which are devoid of any organic matter. The concentration of nitrogen, phosphorus and soil organic matter were extremely low in all the sites which hampered plant colonization and subsequent succession. The C/N ratio was drastically reduced in the mined areas as compared to the unmined areas. Similar trend in C/N ratio was also observed by Haron *et al.* (1998).

The water quality was also affected due to mining. The water in mined areas was highly acidic and the conductivity increased due to mining. Jhinran (1982) attributed such condition to decreased photosynthetic activity due to low intake of CO_2. Rawat *et al.* (1982) observed very high acidic water in the coal mines of north-east India. The hardness of the water, calcium and magnesium concentration increased in the mined areas. Sharma *et al.* (1993) in his study in Jaintia Hills of Meghalaya found similar results while Sharma (2000) recorded high magnesium content in the Jharia coal fields of Bihar. The concentration of chloride, phosphate, nitrate, sulphate, sodium and potassium increased due to mining. This is in agreement with the works of Rai (1996), Sharma *et al.* (1993), Sharma (2000). The D.O. content was very low in the water passing through the mined areas. The finding of the present study lends the support of the works of Sharma *et al.* (1993) and Chakraborty *et al.* (2002).

The present study highlights several environmental problems relating to coal mining in Nokrek Biosphere Reserve. The geomorphology, soil, vegetation and water got altered due to coal mining. The extent of alteration in several sites was very significant and if allowed to continue, the impact of mining on the flora, fauna and landscape of the Biosphere Reserve could be devastating. The finding of this study is expected to be useful for formulating effective management strategy for controlling the coal mining in the buffer zone ecosystems of the Biosphere Reserve. Besides, the finding may provide important clues for reclamation of mined areas.

SUMMARY

In the entire Garo Hills, the total reserve of coal has been estimated to be 359 million tonnes and a considerable portion of it is found in the southern part of Nokrek Biosphere Reserve. The unscientific extraction of coal in unorganized sector within the Biosphere Reserve is going on and the area of coal mining in this region is increasing day by day since the beginning of mining in 1985. The annual extraction of coal from the Biosphere Reserve has been estimated to be in the tune of 4,32,000 tonnes. Coal mining activity started within the Nokrek Biosphere Reserve from the Darenggiri area. At present, coal is being extracted from 18 mining sites. These are: Darenggiri, Jatragiri, Rongragiri, Khamalgiri, Rongmagiri, Budu Wathegiri, Budugiri, Gopgiri, Khibalamagiri, Khakijagiri, Faramgiri, Anchenggiri, Rongphakgiri, Rongmigiri, Rongrugiri, Ruabangagiri, Bandarigiri and Rongdianchengiri. The thickness of the seam of coal ranges from 0.45 m to 2.00 m. The Nokrek Biosphere Reserve is formed over the gneissic rock with old inlier, Sela group and Jaintia and Simsang Series with ultra-basic in deep shades rocks. Coal beds are of Lower Eocene geological horizon, which are mostly found along with Jaintia and Simsang series.

The geomorphological analysis of Nokrek Biosphere Reserve revealed that if coal mining is extended further inside the Biosphere Reserve the land degradation could reach to an alarming stage. As evident from the results of slope, relief and drainage density analysis substantial areas of the Biosphere Reserve falls under 9° to 22°, <100m to 200m and 5-9 km per sq. km categories respectively, which are highly vulnerable to erosion losses. Mining activities in such areas is bound to accelerate the above processes. The studies relating to drainage suggest that the coal mining activities at upper catchment would directly effect the streams and rivers in the higher order, which may be located far from the actual mining.

Extensive coal mining activities in the buffer zone of Nokrek Biosphere Reserve have led to the degradation of land and creation of landscape dotted with mine spoils. The impact of such activities on the vegetation, soil and water qualities of Nokrek Biosphere Reserve was significant.

The total number of species was much less in the mined areas than unmined areas. Trees and shrubs showed a drastic reduction in their species composition due to coal mining. The density of trees, shrubs and herbs in mined areas were significantly lower than the unmined areas at all the three sites. The basal area of trees follows the same trend as density. The dominance of plant species was shared by many species both at unmined and mined sites. Fifteen species among tree, 4 among shrubs and 28 among herb species only were found in mined sites, while 27 tree species, 4 shrub species and 16 herb species were found only in the unmined sites. Shannon's diversity index for tree species was low in the mined sites which indicates adverse impact of mining. The number of species regenerating (i.e., seedling and sapling) was more in the unmined sites than the mined sites. The seedling and sapling density were also quite high in the unmined areas. Many species which were found in the unmined areas and were native to the locality could not regenerate due to mining resulting into the local extinction. However, certain species colonized the areas following mining. The colonization of these secondary successional species is an agreement with the intermediate disturbance hypothesis that justifies the higher species diversity due to the disturbances of mild intensity.

All the soil physico-chemical characteristics were adversely affected due to mining. The soil became more acidic in the mined areas and the soil moisture regime of the soil got depleted. The nitrogen, phosphorus and soil organic matter were less in the mined areas than that of unmined areas. The C/N ratio was drastically reduced due to the mining. The deterioration in soil physico-chemical properties would have detrimental effect on the soil flora, fauna and micro-organisms. The impact of mining was felt even upto the depth of 30 cm suggesting that coal mining would adversely affect even the growth of higher plants.

The water quality was also affected due to mining. The water in mined areas was highly acidic and the conductivity increased due to mining. The hardness of the water, calcium and magnesium concentration increased in the mined areas. The concentration of chloride, phosphate, nitrate, sulphate, sodium and potassium increased due to mining. The D.O. content was very low in the water passing through the mined areas. The impact of pollutants from mining was more acute during post and pre monsoon seasons than the monsoon season. The above results indicate that the coal mining alters the water quality of the water bodies to the extent that could be detrimental to the survival of aquatic life in the stream and rivers, even further downstream.

The present study revealed that coal mining has adversely affected the vegetation, soil characteristics and water quality in the coal mined areas of Nokrek Biosphere Reserve. The information gathered on various aspects of vegetation and colonization of plants in mined areas would be helpful in revegetating the mined areas. The studies on the physico-chemical properties of soil and water is useful in the assessment of the status of ecosystem health of the Biosphere Reserve.

From the above discussion it is evident that the mining activities in the buffer zone of Nokrek Biosphere Reserve is detrimental to the flora, fauna and general environment of the Biosphere Reserve. Therefore, such activities within the Biosphere Reserve have to be strictly regulated to avoid further damage to the Biosphere Reserve. Scientific mining has to be taken up in a restricted manner so that with a minimum damage to the Biosphere Reserve. Appropriate rehabilitation measures using the plants that grow in the mined areas need to be taken up in the mined affected areas. The findings of the study could be quite useful while formulating the Biosphere Reserve Management Plan.

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