SUMMARY

The present study deals with the characterisation of plant biodiversity of Darjiling Hills using remote sensing and GIS techniques. The Darjiling part of Eastern Himalaya is experiencing an alarming rate of habitat destruction due to population explosion and other human related activities. A detailed inventory of vegetation cover will provide baseline information on the biological resources. Integration of spatial with non-spatial data in the form of maps is effective in addressing problems that will help in formulating conservational planning. It is in this context that the present study has been initiated for vegetation mapping, disturbance and biological richness mapping in Darjiling hills. The mapping has been done at regional level with an output generation of 1:250,000 scale.

Darjiling district is the northernmost and the only hill district of the state of West Bengal with a geographical extent of 26° 27' 05" and 27° 13' 10" N latitude and 87° 59' 30" and 88° 53' E longitude has a total area of 3077.71 km^2. The Darjiling hills with its geographical expanse of 2228.13 km^2 covers 3 administrative sub-divisions *viz.* Darjiling Sadar, Kurseong and Kalimpong. The entire hill region, starting with an elevation above 180 m amsl has been considered in the present study. The hills, which are a part of the Singalila Range of Eastern Himalaya is well known for its rich biodiversity, numerous endemic and rare species. The district lies is the Himalayan hotspots of biodiversity. The district apart from being recognised for its biodiversity also has many other implications, in terms of scientific, environmental, and cultural aspect. Darjiling district is basically mountainous with highly variable topography and extremely difficult terrains with large portion of the hills being inaccessible. Irregular hill ridges, deep valleys and highly diverse drainage pattern with wide variation in climate and soil have resulted in varied ecological diversity. Physical features are treacherous, with extremely difficult topography but different locations are well connected by motorable roads. A large number of metalled and unmetalled roads have come up in recent years connecting the once inaccessible remote parts of hills with the mainstream. There is only one rail line that traverses the hills and connects Darjiling town with Siliguri in the plains.

The Darjiling Himalaya shows climatic peculiarities caused by its geographical relief and wide altitudinal variations. The climate of the hills varies greatly corresponding to variation in altitude, aspect. It exhibits a typical monsoon climate, with wet summer, cold

and dry winter. Maximum precipitation is brought about by south-west monsoon flowing from the Bay of Bengal during June to September. The average annual rainfall varies from 2,004 mm to 4,400 mm. The south facing lower hill receives the highest rainfall compared to north facing places and high altitude. Wide altitudinal variation within the hills has dramatic fluctuation in temperature regime; with warm and hot plains, cool weather in the higher altitudes yet extreme cold in the upper reaches, where temperature remains below zero for 2 – 3 months during winters.

Physiographically, Darjiling Himalaya is wedged between Central (Nepal) Himalaya and the Bhutan Himalaya and consists of unaltered sedimentary rocks. It consists of the Sub-Himalayan *Siwalik* deposits of Tertiary age, coal-bearing *Damudas* coinciding with the Main Boundary Fault, *Dalings* and the *Darjiling gneiss*. The soil of Darjiling-Sikkim Himalaya is represented with 5 orders *ultisols, alfisols, mollisols, entisols* and *inceptols*. Almost everywhere the soils are derived from weathering of underlying rocks. The depth of the soil varies in different regions, with texture varying from fine sand, loam to coarse sand. The pH of the soil of the region is generally acidic. The soils in the hills are covered under thick forest litters rich in humus that releases good amount of available nitrogen. The greater portion of the area is lying under *Darjiling Gneiss* which commonly decomposes to stiff reddish loam and stiff red clay and pure sand, a condition favourable for the cultivation of tea.

Darjiling hills, with a total population of 5,90,293 supports 36.76% of total district population of 16,05,900. The population density of the hills is high with 267.75 km^2 distributed in 342 villages and 3 municipal towns. The hill populace is largely rural and agrarian in profession. Large number of people depends on agriculture; Tea is another sector where large sections of the population are employed. Tourism, though seasonal, is also one of the main sources of income. Extension of land for tea cultivation and agriculture are having negative impact on the forest cover and survival of the biodiversity especially in the mid-elevation zone.

The hills of Darjiling with its four protected areas (Singalila National Park, Neora Valley National Park, Senchal Wild Life Sanctuary and Mahananda Wild Life Sanctuary) and a large number of reserve forests, and plantation forests in different ecological zones

provides an ideal home for diverse flora, fauna and microbes and forms a core part of Himalayan Hotspots. Because of extremely variable habitat, micro-climatic condition, the region supports flora and fauna of diverse affinities. Due to the ongoing degradational activities such as illegal collection of timber and non-timber forest products, grazing, extension of tea cultivation and extension of agricultural land, various developmental programmes such as construction of roads, dams etc, resulting the fragmentation of the once prestine landscape of Darjiling Himalaya.

Four scenes of IRS-1D LISS III data have been used to assess land use/ land cover for Darjiling hills, which was digitally mapped at 1:50,000 scale. The satellite data of optimal season have been used to delineate different vegetation types on 1:250,000 scale. The satellite data were geometrically and radiometrically corrected and mosaiced. Intensive reconnaissance was carried out prior to classification. Nested quadrat sampling approach was adopted for sampling various strata of the vegetation. Various vegetation types were mapped using visual interpretation techniques. Phytosociological analysis was done for each stratum separately. Importance value index (IVI) was computed based on Relative Density, Relative Frequency and Relative Dominance. Total Basal area, stand density and distribution of tree species in different girth classes of individual tree species in these forests have been analysed to understand the structure, density and over all health of forests. The ground truth data was analysed for deriving various diversity indices like, *Shannon-Weiner index, Simpson's index, Menhinick's index* and *Margalef's index.* Similarities, co-efficient between different forest types were also analysed. The field data was also analysed for their economic values, endemic status, medicinal values and degree of threat.

The digitally classified map was subjected to landscape analysis to assess fragmentation level, patchiness, porosity, interspersion and juxtaposition. These landscape parameters along with biotic zonation were then used as an imput for disturbance regime modelling. Weightages were assigned for each of these parameters according to importance. Finally, biological richness map was generated for the Darjiling hills based on spatial and field data. Biological richness information was determined based on parameters like ecosystem uniqueness, species diversity, biodiversity value, terrain complexity and disturbance index.

Mapping of biodiversity has been done only for Darjiling hills, which covers 2228.13 km^2 of the total 3077.710 km^2 area for the district. Forest holding for the hills is assessed at 49.14 % (excluding area covered by cloud and shadow). A total of 23 land-use/ land cover could be identified from Darjiling Hills. 17 forest classes and 6 non-forest classes including cloud and shadow were mapped. Eight dominant phenological types, along with degraded, plantations (mainly of Teak and *Cryptomeria*) and general edaphic and seral types could be delineated. Intensive sampling was done and 172 sample plots were laid in 16 vegetation types. Tropical Semi-evergreen Forests, which occupy small area (18.50 km^2) constituting 0.60 % of the hill district. Himalayan Sal Forests occupies 74.14 km^2 (2.41 %), Moist Mixed Deciduous Forests with 222.28 km^2 (7.22 %) Riverine Forests 9.33 km^2, (0.30 %), Sub-tropical Broad Leaved Hill Forests 225.33 km^2, (7.32 %), Wet Temperate Forests 282.47 km^2 (9.18%), Temperate Broad Leaved Forests 70.31 km^2 (2.28%), *Alnus* Forests with mere 1.95 km^2, Conifer Forests 21.50 km^2 (0.70 %), Sub-alpine Scrubs 12.93 km^2 (0.42 %), Bamboo Brakes 6.33 km^2 (0.21 %), *Rhododendron* Forests with mere 1.64 km^2, Open Scrubs 21.85 km^2, (0.71 %), Teak Plantations with 6.33 km^2, *Cryptomeria* Plantations 34.09 km^2, (1.11 %), Degraded Forests 48.28 km^2, (1.57 %), *Cinchona* Plantations 37.75 km^2, (1.23 %), Agriculture 682.24 km^2, (22.17 %), Tea Gardens 346.95 km^2, (11.27 %), Barren Lands 8.01 km^2, (0.26 %), River beds/ Water bodies 39.90 km^2, (1.30 %), Settlements 19.28 km^2, (0.87 %), Cloud and shadow 36.75 km^2, (0.63 %),

In Darjiling hills maximum species diversity was observed for Sub-tropical Broad Leaved Hill Forests followed by Himalayan Sal and Tropical Semi-evergreen Forests. Temperate vegetation viz. Conifer Forests, *Cryptomeria* Forests and *Rhododendron* Forests shows highest stand density. Similarly, total basal area (m^2/ha) was highest for Conifer Forest followed by Temperate Broad Leaved Forests, *Rhododendron* Forests and Wet Temperate Forests. The temperate zone also exhibited maximum similarity. Wet Temperate Forests and Temperate Broad Leaved Forests recorded a high percentage of individuals in the highest girth class compared to other forest types in the same category. Temperate Broad Leaved and Wet Temperate Forests were found to have maximum number of endemic species (40 each).

The land use/ land cover map derived from satellite image was used for landscape ecological analysis. The spatial extent of the patch size, its distribution, porosity, interspersion, juxtaposition and fragmentation over a landscape were studied. These landscape parameters were subjected to mask size sensitivity and optimum size was determined and considered for analysis. Darjiling hills are found to have significant level of fragmentation with 47.42% of the district area coming under non-forest category. Further, this is corroborated by the findings that 396.35 km^2 of the forest constituting 17.79% of the total hill area are under medium to high level of fragmentation. It accounts to 36.20% of the total forests cover and therefore is significantly fragmented. Eastern part of Singalila National Park, Kurseong-Mahaldiram, Singbulli and Tindharia areas in the Kurseong sub-division; Suruk-Samtar, Lolaygoan, Pala, Singi and Samalbong areas in Kalimpong sub-division; Gokh and Sukhia Pokhria in Darjiling sub-division are under high level of fragmentation. Sub-tropical Broad Leaved Hill Forests are highly fragmented. The forests in Darjiling shows 10.76 km^2 (0.48%) under high level of patchiness and 130.86 km^2 (5.87%) under moderate level otherwise it is largely homogeneous Singalila National Park, Senchal Wildlife Sanctuary and reserve forests along the river Teesta shows maximum number of patches. Major phenological types like Moist Mixed Deciduous Forests, Sub-tropical Broad Leaved Hill Forests and Wet Temperate Forests constituting 730.08 km^2 (66.67%) have been considered for porosity assessment. Sub-tropical Broad Leaved Hill Forests shows highest porosity level. There was no interspersion for 821.01 km^2 of the forested area. Juxtaposition for the forest was good with 266.96 km^2 constituting 11.98% falling under high category.

Various human induced factors such as extension of human settlement, clear felling for cultivation, construction of roads through forest, the influx of tourists and natural factors including dispersal ability, have considerably altered the natural ecosystem. It was found that 430.69 km^2 (19.40%) of the hills are under high level of disturbance. High levels of disturbances are observed along the fringes near human habitation, along roads and near dry river beds which acted as trails/ paths. The sub-tropical zone is highly disturbed. Natural conservatories too are affected to varying level of disturbance. Senchal Wildlife Sanctuary is one of the most badly affected conservatories. Others protected areas were affected to varying degrees. The Moist Mixed Deciduous Forests in the reserve forest category along the southern side shows intact homogeneous forest cover with low disturbance. This tract of forest land too can be brought in the ambit of protected area

network before they are lost. The Sub-tropical Broad Leaved Hill Forests shows high level of disturbance, as this forest is located near to human habitation.

Mapping of biologically rich sites for Darjiling hills was based on ecosystem uniqueness, species diversity, economical values, terrain complexity and the disturbance regime. The richness map was characterized at four levels. The temperate zone has been found to be biologically richer. Wet Temperate Forests with highly complex terrain and high number of endemic species has been found to be biologically richest, followed by Temperate Broad Leaved and Himalayan Sal Forests. The Moist Mixed Deciduous, Temperate Broad Leaved and Conifer Forests were also observed to possess high biological richness. Sub-tropical Broad Leaved Hill Forests show moderate richness. Plantation forests (mainly of Teak and *Cryptomeria japonica*), Riverine Forests, *Alnus* Forests and Bamboo Brakes show low richness values. After all, the Open scrubs show the least richness value.

Remote sensing and GIS have greatly helped in developing spatial data bases in the form of vegetation maps, landscape map and biological richness map for Darjiling hills. The classified vegetation map may be helpful in understanding the spatial extent of different vegetations. Conjunctive studies of spatial and the field data have been effective in characterizing the vegetation types with valuable information on the study of floral diversity. Landscape maps, Disturbance index map and the Biological richness map generated is expected to be helpful in formulating conservation strategy, demarcating broad corridors between different conservatories within the hills and host of other forestry related activities. Interplay of different disturbance factors contributing to degradation of natural habitats may give a valuable insight for planners and wildlife managers. Highly stressed vegetations such as Sub-tropical Broad Leaved Hill Forests can be taken on priority basis in controlling from further degradation. Aforestation programs can be implemented in areas having degraded forests and open scrubs.

Main observations

- Remote Sensing and GIS have tremendous potential in studying forest cover over a large area and their assessment over a short period of time with greater accuracy. The technique can be an effective tool to recognize biodiversity hotspots within a landscape.
- Anthropogenic disturbance is a major concern against the existence of forested vegetation. High disturbances are more visible along the human settlements and roads where human related activities are taking place.
- Forests in temperate zones are more homogeneous and are in their natural condition with good species diversity, high degree of endemism and hence are biologically richer.
- Sub-tropical Broad Leaved Hill Forest shows high species diversity and is highly disturbed and vulnerable to degradation and needs immediate attention.