FOREST COVER MAPPING

Introduction

Forests are indispensable, being the haven for dynamic functions of an ideal ecosystem. But man's indiscriminate exploitation of the preci9us asset is leading devastating ecological imbalance threatening his own existence.

The abounding forests of SilQrim exhibit a bewildering variety and diversity of plants and animals ranging from tropical screw pines to alpine Primulas. Within a vertical strip of rugged mountainous terrain of roughly 40 to 60 miles broad and 100 miles deep, Sikkim presents a spectacle of exquisite Rhododendrons and Orchids of every hue, shape, size and family. Sikkim is also justly proud of its Himalayan fauna, avi-fauna, snow-capped peaks, glaciers, lakes and cascading streams and rivers. The myraid life forms of both plant and animal that characterise these biogeographical regions is unique and unparallel, perhaps in the whole world. Ranging from streaming hot foothills to ice cold alpine meadows, Sikkim encompasses within its narrow belt a luxuriant floristic composition encountered nowhere else in a similar situation. Its loftiest peaks, transverse narrow valleys, wide alpine meadows and tropical foothills all provide a mosaic of habitat where floral and faunal diversity and richness is incredibly high.

Highland topography of Sikkim particularly, the plateau region, is dotted with a number of perennial lakes fed either by the melting snows or ground springs. Against the backdrop of a glittering range of snowy peaks, the lakes and glaciers add unmatched beauty, serenity and grandeur to the vast rugged Himalayan landscape. These lakes are the habitat of an umpteen number of resident and migratory waterfowls and for the Brahminy ducks, principally they are the permanent breeding habitats. There are about 180 big and small lakes spread over the vast expanse of its folds and faults. In short, within such a small size and land area of 7096 sq. km. biodiversity in Sikkim can undoubtedly be one of the immense interests to the ecologists and environmentalists, earth scientists and nature lovers, botanists and biologists in equal measure. However, the forest resources could not be scientifically managed due to inaccessible terrain and strategic locations. Proper management of such areas is of paramount importance to evolve plan for ecological balance because depletion of. forest cover in the river catchment is unwarranted threat for divesting floods and large scale erosion.

Sikkim is renowned for its Rhododendrons and Orchids as also of high altitude Primulas, Meconopsis and Blue puppies. These are special niches and constitute the ecological heritage endowed by nature to this tiny Himalayan region. Sri J. D. Hooker, the famous botanist in 1848- 1850, described as many as 34 new Rhododendron species in his monumental monograph entitled "Rhododendron of Sikkim Himalaya". To date 36 species have been recorded from Sikkim itself. In addition to Rhododendron species, Orchids constitute the glory of Sikkim. Of the 1100 odd Orchid species found in the country, Sikkim has as much as 400 species.

Sikkim is veritable storehouse of multitude of medicinal and economical plants. The climate, topography and terrain provide a congenial environment for the growth of rich and luxuriant vegetation in which many plants of medicinal value are found to grow. From the majestic YEW *(Taxus becata)*, a tree recently recognised as possessing cancer healing properties to herbs such as Aconite, Ephedra, Rhem, Podophyllum, Kuth, Majhita, Chirata to Lycopodium, the list is endless and amazing. In fact, there is immense potential for local pharmaceuticals to go in for small scale ayurvedic and Tibetan medicine manufacturing units in Sikkim.

The National Forest Policy 1952 proposes that the total area under forests in the country be increased steadily to cover at least one third of the total land area, the proportion aimed at being 60 percent in hilly areas and 20 percent in the plains. However, the recent estimates of National Remote Sensing Agency, Hyderabad (based on visual interpretation of Landsat MSS 1:1 million scale data of 1972-75 and 198082) and Forest Survey of India, Ministry of Environment and Forests, Dehra Dun (based on visual interpretation of Landsat TM 1:250,000 scale for the year 1985-87) shows that forest cover of India is 19.49 per cent with closed forests (crown density >40%) accounting to 11.73 per cent, open forests (crown density between 10% and 40%) to 7.63 per cent and mangroves 0.13 per cent (Table-I).

Status of Remote Sensing technology

The remote sensing in the form of aerial photography has already been accepted as an important utility tool in forestry since the last half century. The forest cover and land use mapping in India has hitherto been conducted using aerial photography and satellite data by different organizations such as Forest Survey of India (FSI), Dept of Space (DOS), National Atlas and Thematic Mapping Organization (NATMO), State Remote Sensing Centres and also State Forest Departments. The satellite remote sensing applications for land resource mapping was initiated with the launching of Earth Resources Technology, satellite I by National Aeronautic Space Administration (NASA) USA, in 1972, which was later named as Landsat 1. So far Landsat I, II and III have provided the data of the earth's natural resources through sensors on board with Return Beam Videocon camera (RBVC) and multi spectral scanner (MSS). The Landsat IV replaces the RBVC with Thematic Mapper in addition to the regular MSS.

Indian Remote Sensing-IA (lRS-IA)-was launched on 17 March 1988, it had two types of payloads employing Linear Imaging Self Scanning (LISS) technique, a sensor LISS I with a geometric resolution of 72.5 m, with four spectral bands (0.450.52,0.52-0.59,0.62-0.68 and 0.77-0.86 micrometer) and a swath of 148.48 km. The second sensor LISS II has two cameras A and B with a spatial resolution of 36.25 m having same spectral bands as that of LISS I and provides a combined swath of 145.45 km. Allowing 3 km. Overlap between them.

The IRS-IB identical to IRS-IA has been launched on 29 August 1991 to provide continuity of service to the users. The second generation IRS-1C and IRS-1D satellites are expected to be launched during 1995-96 and 1998-99 respectively with better spectral, spatial, more frequent revisit, stereo viewing and on-board capabilities. The IRS-IC will carry three sensors: an improved sensor LISS III with four spectral bands; in visible bands (0.520.59, 0.62-0.68 micrometers), infra-red band (0.77-0.86 micrometers) with a spatial resolution of about 23 m and middle infrared band (1.55-1.75 micrometers) with a ground resolution of 70 m; Panchromatic Camera (PAN) with a better than 10m ground resolution in one band (0.50-0. 75micrometer) with a swath of 70.5 km. a coarse resolution Wide Field Sensor (WIFS) in visible (0.62-0.68 micrometers and infrared (0.77-0.86 micrometers) with spatial resolution of 188 m and swath of 774 km. These sensors with different spatial resolution would be of immense help for generating various thematic maps on district, state to regional basis.

Till recently, the forest cover mapping of a major portion of India was being carried out with 80 m spatial resolution of Landsat MSS. Now with the advent of high resolution sensors in the orbiting satellites viz. Landsat TM (30 m), SPOT (20 m and 10 m) and IRS-1A LISS 1 of 72.5 m and LISS II of 36.25 m, the precision in the forest classification is expected to improve substantially, The Linear Imaging Self Scanning Sensor I & II (LISS I & II) with Charge Couple Devices (CCD) and the push-broom scanning mode of IRS-lA & IE are definitely the improvements over Landsat. This technology has brought about an improvement in achieving better geometric accuracy and also improved radiometry due to relatively longer dwell time. In addition, the equatorial crossing time of(10.25 am in descending mode) IRS1A being slightly later than the other satellites orbiting the earth, reduce the shadow effect in the hilly terrain conditions. Altogether, these improvements help forest cover mapping in reducing the locational errors, shadow effect and in delineating the subtle differences in forest cover due to improved radiometry.

Different earth resource satellites and their capabilities in monitoring the Earth's natural resources are given in the Table-2 A & B.

Objective of the manual

Forest density mapping on 1:1 million through standard visual interpretation techniques has been done by Food and Agricultural Organization (FAO), Rome, National Remote Sensing Agency (NRSA), Hyderabad and Forest Survey of India (FSI), Dehra Dun by both on 1:1 million" and 1:250,000 scale. In addition various State Remote Sensing Centres and State Departments are being actively using remote sensing data for survey and mapping of forests.

The present remote sensing system offers various image types. In spite of many new advances in satellite data analysis and development of various interpretation strategies during the last decade, there is no proper agreement on the selection of material or adoption of a particular' methodology. However, the selection of data to be used depends upon the information extracted from spatial, spectral, radiometry and temporal aspects of the satellite data. The visual and digital analysis have their own advantages' and disadvantages depending on the area under study, expertise, cost involved and the theme.

Space Application Centre, Dept. of Space, Ahamedabad has developed methodologies for mapping forest density, forest types, forest stock, forest encroachment and blank area monitoring using standard visual interpretation techniques (SAC, 1990). However, no attempt has been made to bring a reference manual on the digital processing techniques for forest cover mapping with special reference to hill terrain areas. Therefore, it was felt necessary to prepare a comprehensive interpretation manual to be used as reference for mapping forest type and forest density taking hilly terrain area of the State of Sikkim as an example.

The objective of the manual is to emphasize the significance of the digital image processing for generation of forest dens}ty and forest type map and to elaborate various techniques that have been adopted in the present study in association with State Forest Department, Sikkim.

INTERPRETATION TECHNIQUES

Introduction

An image is a general form for any pictorial representation of a scene recorded by a remote sensing system and it is commonly restricted to representations acquired by non-photographic methods like optical, electro spectral, mechanical or electric means. The variations in the electromagnetic radiation from different earth features are shown as variations in brightness on black and white images. But different sensors on board provide several images of the same scene in different wave length bands and remotely sensed images are produced by both photographic and non-photographic sensors.

Generally human-being receives and analyses visual information, it is called as sight, perception or understanding of the image whereas computer processes the same image, it is called as Computer Image Processing or Machine Processing or Remotely Sensed data or Computer Vision.

Forms of images

The image forms are of two types. They are photographic film form and digital form. The photographic sensor produces images in the photographic film form whereas digital images are produced by electro optical sensors like Multi-spectral Scanner (MSS) or push-broom scanners like Linear Image Self Scanner (LISS). Digital image is an array of numbers according to the brightness values and the data can be displayed, recorded or stored in binary notation. Each brightness value or element is called "pixel or pel" -a short name for Picture Element. Digital images, unlike photographic films do not deteriorate with age and preserve high radiometric quality. Both forms have advantages and disadvantages in various thematic applications.

Different image processing techniques

The following three types of techniques are being used for manipulating the images.

1. Photographic techniques
2. Optical techniques
3. Digital techniques

The photographic techniques mainly utilizes photo processing concepts for operations such as contrast improvements whereas the optical techniques are used to remove some degradation from images. The digital techniques due to their flexibility are applied on digital images for noise removal, geometric, radiometric corrections, image display, recording, manipulations, various enhancements to improve the visibility of the earth features and information extraction using different classification algorithms.

Activities of image interpretation

Interpretation is ,a process in which a person extracts "information" from an image or photo based on different techniques. It depends on the detection and identification of objects, measurement of objects and their significance in analysis and use of the above in classification.

The detection is a process of picking an object through interpretation techniques like a plantation area by its pattern/shape whereas identification is a process of distinguishing an object by its characteristic nature like forest from non forest areas. The measurement of object and their significance in analysis is a method of resolving or separating a set of features having similar set of characteristics like natural vegetation from man-made plantations.

The ultimate process in the interpretation is the classification of various earth features into different groups and it is the assigning individual pixels of a multispectral image to discrete categories.

Elements of image interpretation

There are certain fundamental photo/image characteristics which help in interpretation. They are tone, texture, pattern, size, shape, shadow coupled with site and association.

Tone

Tone can be defined as each distinguishable shades of grey from white to black of an image. In fact different objects reflect, emit and transmit different amount of radiation in different wavelength bands of a satellite. These are recorded as tonal, colour or density variations. In black and white images distinction between hues are lost and objects appear in tones of grey which fails to satisfy the interpreter's perception of familiar objects whereas false colour photography/colour enhanced photography increases interpretability. They are generated by both optical and electronic devices.

Texture

Texture is the visual impression of roughness or smoothness and it is formed due to the frequent changes and arrangement of tones in the image. It depends on the scale, as the scale of the photograph or image is reduced, texture becomes progressively finer and ultimately disappear.

Pattern

It relates to spatial arrangement of objects or repetition and it can be defined as the regularity and characteristic placement of tones or texture. The pattern is characteristic of many man-made objects and some natural features. Cultural features and man-made plantations are conspicuous due to straight lines or regular configurations and they can be recognized due to high contrast from the associated features.

Size

Size of an object must be considered in the context of the scale. A few measurements together with other factors help in interpretation. e.g. small storage shed may be misinterpreted as a barren land if size is not considered.

Shape

Shape or form is sometimes very distinctive. Imagery in a plane view/top view is different from profile or oblique view e.g. Volcanic cone from its conical shape.

Shadow

Shadows can help or hinder interpretation and they depend upon size/shape of object, viewing angle of the sensor and sun angle.

In fact the outline of a shadow affords a profile view of the objects and it is very helpful if the objects are very small or lack tonal contrasts. Sharp boundaries and shape of shadows enable identification of objects that are just at the threshold of recognition.

Site

The location/site of an object in relation to other features is helpful in interpretation. e.g. Certain trees would be expected to grow in uplands, near streams and well drained areas whereas other tree species are expected to occur in low lands and poorly drained areas.

Association

Some objects/tree species are so commonly associated with other objects/tree species that one tends to confirm a feature on the basis of its association with other features. Therefore, association s an important clue for man-made installations and species composition. Most of these image characteristics depend on the spectral, spatial, temporal and radiometric resolution of the sensor and the ability of an imaging system to record finer details in 8; distinguishable manner. Resolution depends on many parameters, but it places a practical limit in interpretation. In fact some objects are too small or even large but lack sufficient contrast with background.

The classification through digital techniques generally takes care of only "tone" without having any consideration for other variables like texture, shape, size, pattern, association and location. Therefore, the similar spectral responses from different objects and dissimilar spectral responses from similar objects cause spectral confusion leading to misinterpretation. In view of this spectral confusion in delineating various earth features, it is necessary to implement suitable hybrid approach in digital classification strategy to achieve mapping accuracy. In case of Sikkim most of the area is of rugged terrain condition, hence, the features like built-up area, lakes etc. are invisible due to the shadow factor. To achieve considerable accuracy it is pertinent to use both visual as well as digital techniques. Though these two techniques are complementary to each other they have some advantages/ disadvantages. (Table-3).

The local acquisition time of the satellite image plays an important role in casting shadow. The Landsat, IRS and SPOT has local acquisition time of 0930, 1025 and 1130 hrs respectively. It is expected that SPOT has got minimum shadow than the other two, however, due to non-availability of SPOT data at the time of the processing, next best available IRS satellite data has been selected. The present approach of classifying problem areas separately helped in controlling the signature extension and also shadow effect becomes localized. In view of different brightness intensity values of same category with the deep shadow, partial shadow and non-shadow, in the rugged terrain conditions of East district, Sikkim, the classification of different categories through digital techniques pose problems. However, the image ratios do enhance and suppress the effect of shadow (Holben and Justice 1981) and some researchers used multidimensional analysis using digital topographic data as added dimensions and physical models which estimate the reflection of solar radiation from slopes (Leprieur et.al. 1988). However some of the land use/cover classes of lakes, rock outcrops, built-up areas are obscured on the image due to the influence of deep shadow. Therefore, such categories are located and marked on the Survey of India topographical maps and digitized these classes. They were precisely superimposed on to the image to improve the mapping accuracy.

The forest of the district can broadly be demarcated as Sal forests under Tropical moist deciduous/semi evergreen forest and Subtropical mixed broad-leaved forests, Temperate forest and Alpine forests. The differentiation of Tropical to Subtropical is not distinct due to mixed composition of the species. However the Sal the dominant species occupying extensive areas in the lower reaches is quite distinct because of their unique spectral signatures. In Forest management, the density of the canopy cover plays a major role in deciding health regeneration capacity of the crop. Therefore, the assessment of canopy cover , could properly be done only in the season where leaf is matured and fully grown on the canopy. During November season, the effect of shadow among the tall trees can very" well be utilized in mapping dense forests more precisely and also height/age class with the aid of field samples coupled with intensive ground verification. In view of the shadow effect on different tree heights, the digital numbers in the near infrared band shows less compared to the other canopy structures in the non-shadow areas. In case of open forests, the intermediate gaps between tree canopies have an overall effect of the background along with tree canopy, making the digital number higher than the dense forest. In case of degraded forest, the back ground effect is quite high than that of open, the digital number value is also equally higher. Even the delineation of Sa I coppice is quite possible due to uniformity in canopy cover without any shadow effect since they are of medium size trees/bushes and their digital number values are quite high compared to any type of vegetation. The shrubs with less than 10 per cent tree cover are distinct in view of discrete nature and their digital number values are moderately high; which generally fall in between degraded and sal coppice range. However, in the present study different linear contrast stretching parameter were given to red, green and blue filters to IRS band 4, 3 and 2 respectively to extract useful information before identifying the features belonging to forest and non-forest categories. Though the stretching is scene specific, it has helped to identify various forest as well as landuse/cover classes precisely than any other enhancement techniques including ratios, principal component analysis.

FOREST TYPE MAPPING

Definition

Forest type is defined as a unit of vegetation which possess board characteristics in physiognomy and Structure sufficiently pronounced to permit of its differentiation from other such units (Champion and Seth 1968). The major groups are further divided into sub-types on geographic basis because these forest types vary with locality owing to difference in floristic composition, minor variations in climate and environment.

The State Forest Departments have also been following the classification of Champion and Seth (1968) for determining the forest types as it is more authentic based on climate, edaphic and past treatment of the forests.

Judicious forest management of any area requires identification of different vegetation types because the impact of deforestation has got a strong bearing on the status of the forest. The appropriate prescriptions for improving the forest stock basically depends on the existing forest type. Therefore, forest type along with their crown density classes in a map form is necessary for scientific forest management.

Vegetation and flora

The vegetation with its quantitative structural characters is closely related to climate conditions, whereas the flora which enumerates the different types of plant species within a limited boundaries of an
area forms a matter of quality and is closely dependent on the physiological aspects of individual species concerned.

Factors determining the vegetation types

The type of vegetation within a given locality depends on (i) climate (ii) Soil and (iii) Past treatment; so that study of these factors are important for better understanding the vegetation of the area under study.

Climate

Temperature is the most obvious factor of climate. It can broadly be related to the latitude giving a rough differentiation into the following eight vegetational zones on either side of the equator with broad climatic characteristics as follows:

1. Equatorial zone: being 15° on either side of the equator
2. Tropical zone: extending from15°-23° 5'
3. Sub tropical zone: from 23° 5' - 34°
4. Warm temperature zone : from 34°-45°
5. Cold temperature zones: 45°-58°
6. Sub-arctic zone : from 58°-66° 5'
7. Arctic zones: 66° 5' - 72°
8. Polar zones: from 70° to the poles

General characteristics of climate and temperature in India in the four major zones are given in Table-4. The effect of altitude and rain fall has already been noticed in vegetational changes. It is generally noted that for every 270 m increase in altitude a fall of 1°C temperature up to 1500 m, above which the temperature fall is more rapid. The temperature fall is also pronounced in the lee side (sheltered from the wind) of the hill than on the windward side. The rain fall and duration have highest influence on the growth and development of various plants. The slope gradient and its location with reference to direction of monsoon have a significant effect on the type of flora. Generally South-East aspect facing monsoon winds has a much higher and better distribution of species than the opposite North-East aspect which is considered to be rain shadow. Regarding the temperature, Southern aspects receive more solar radiations than Northern in proportion to their latitude and gradient. Soil moisture mostly depending up on the soil thickness and has more explicit impact on vegetation. The shallow soil on steep slopes easily dries up and hence can harbour only dried type of vegetation like
Dry deciduous to thorny-scrub type of forests.

Soil

Soil substructure being the nutrient medium supplying essential nutrients and water, studies on the soil chemistry and monitoring its changes on time sequential mode are indispensable in vegetation investigations.

Most of the important forest species grow in black, red and lateritic soils. Black soils developed from ballistic rocks, crack widely and deeply in dry seasons and they are neutral to alkaline, poor in Nitrogen and Phosphorus, good in lime and potash. The dark colour is due to mineral constituents and humus. The major constituent of forest species favoring this type soil is Teak plants *(Tectona grandis).* Red soils associated with granites, gneisses and ferralitic in nature; they are typically coarse, often with ferric concentrations, neutral to acidic with poor organic/mineral nutrients. They tend to carry most of the evergreen and deciduous forest with Sal *(Shore robusta)* as a dominant species. Lateritic soil are characteristic of the tropics with monsoon rainfall and tend to cap the hill in most part of peninsula. The soils are developed from basic rocks and they are acidic with poor mineral and low silica/oxide ratio. *Xylia xylocarpa* is the characteristic species growing in such soils, often found Sal but not Teak. *Tectona grandis* (Teak) is ecologically characteristic and economically important species of Southern India forest and *Shorea robusta* (Sal) is predominantly in northern India while *Terminalia* species forms the most noticeable association in both.

Past treatment

Human interaction with the forest environment has got its own influence in changing the vegetation type. e.g. fast changing of dry deciduous forests to thorny scrub forest due to illicit cutting and over grazing by cattle. But at the same time, the developmental activities through Social Forestry schemes also alters/influences the vegetation cover.

After realising the importance of vegetation for ecological balance and other useful functions, extensive plantations of fast growing species like Eucalyptus, timber yielding species like Teak, Sal etc. have been taken up by various State Forest Departments. These measures coupled with controlling illicit cutting of forest has regenerated various low grade forest to good canopy forest areas in recent times.

Vegetation types of India

The most acceptable classification of Indian forests with immense diversity in their floristic composition is that of Champion and Seth (1968). This classification primarily a climatic classification with ecological information and floristic composition. They have classified Indian forests into 16 major forest types (Table-5).

State-of-the-art

Application of remotely sensed data for delineating different vegetation types have been carried out by various workers. Use of aerial photographs for forestry applications has already been well established (Sheda 1983, Tiwari 1978). In recent times both visual and digital techniques have been tried under various projects to segregate various vegetation types and their density classes (Madhavanunni 1983, 1990, 1992, Roy et.al., 1990, Kachwha 1983, Sudhakar et.al., 1986, 1991, 1992).

FOREST DENSITY MAPPING

Definition

The term "Forest density" denotes nu merical strength of forest stock and it may be ground density (number of trees per unit area) or crown density (per cent canopy cover with respect to the ground area exposed).

Forest Division/District is an administrative unit and the State Forest departments prepare working plan map (forest stock maps) to depict on forest density, forest type, encroachments and regeneration status for every 10-12 years of interval on 1:15,840 (4"=1 mile) scale through conventional ground survey methods.

In most of these working plan maps the crown density has been divided into the following categories.

1. Dense/closed forests> 40 %
1. Open forests 10 %-40 %
2. Degraded forests < 10 %

Depending on the objective of the project and prescription to be applied to improve the forest stock through afforestation methods, these density classes can further be separated.

State-of-the-art

Remote sensing provides a means for obtaining a synoptic view of the status of forests and condition on real time basis. So far, forests density mapping has been carried out on the basis of tonal variations within a given scene and it has been attained operational status on 1:1 million and 1:250,000,scale using standard visual interpretation techniques. However, the digital processing involves pattern recognition techniques which classifies the image data into different crown density classes on the basis of radiance information. The difference in the reflectance of different forest crown cover classes basically depends on spatial, spectral and temporal resolution. But the difference in spectral radiance of each forest category becomes the basis of the identification and differentiation on a satellite image. Therefore, the information on such forest crown cover categories as "ground truth samples" are necessary and from these observable radiance measurements of the digital image, the condition, status and composition in the form of forest density classes are inferred.

The efforts involved to prepare such large scale maps based on ground survey methods involve lot of time and have got its limitations like ocular judgment in deciding the forest stock and approximate boundary delineation/locational errors.

Aerial photographs have been successfully used for forest management in India and elsewhere (Sheda, 1979, Tiwari, 1978). However the utilization of aerial photographs could not be made operational for the purpose of forest monitoring due to non-availability of real time data, time consuming and lack of adequate trained personnel coupled with high cost involved in generating the forest resource maps. In turn, the satellite remote sensing has now been successfully implemented on operational basis for forest management in India through standard visual interpretation techniques (FSI, 1991). Satellite remote sensing has now been used on routine basis in India for mapping different forest types and density classes with reliable accuracy through visual as well as digital techniques (Madhavanunni et.al., 1991, Rao, 1990, Roy et.al., 1990, Sudhakar et.al., 1992, Tiwari, 1992, Vasudeva Rao, 1987, RRSSCIKGP, 1993).

FOREST COVER MAPPING OF SIKKIM

Study area

Sikkim, the tiny Himalayan State situated between the latitude 27° N to 28° N and longitude 87° E to 89° E approximately has a total geographical area of 7096 sq. kms. Sikkim bounds between the Kingdom of Bhutan in the East and Nepal in the West, and Chinese Tibet in the North and the State of West Bengal in the South. The State has four districts namely East, West, North and South with geographical areas of 954 sq. km, 1166 sq.km, 4226 sq. km, 750 sq. Kms respectively. But sizeable areas under the North, East and West districts are under perpetual snow cover. The State abounds in a number of high altitude perennial lakes, a large number of perennial and seasonal streams and mountain springs. Teesta and Rangeet are the major rivers of Sikkim which originate from the glaciers (Fig. 1 A, B, C, D).

Physiographic ally Sikkim can be said to have its feet in the Ocean and its head in the sky. The altitudes vary from 300 meters to 8500 meters. Climatically, Sikkim experiences variable temperatures with burning summer at the foothills to freezing chills in winter on high mountains. The State receives an average annual rainfall of 500 cm, which is the highest in the Eastern Himalayas.

The entire State is a young mountain system with highly folded and faulted rock strata at many places. The major rock types consists of phyllites and schists and therefore, the slopes are highly susceptible to weathering and prone to erosion and landslides. The high intensity of rainfall causes extensive soil erosion and the steep slopes succumb to a number of landslides during the monsoon.

Forest is the main land use in the State and nearly 40 per cent of the total geographical area is under varying densities of forest cover. The available agricultural land is approximately 12 per cent of the total geographical area and is confined to the altitude less than 2000 meters. Terraced cultivated fields with interspersed nullahs with the bamboo clumps and tree groves are the traditional habitations along the hill slopes of Sikkim. The major agricultural crops are rice, maize and millet and the major cash crops are large cardamom, ginger, orange and potatoes.

Vegetation and flora of Sikkim

The flora of Sikkim Himalaya has partly been studied by the famous Taxonomist Shri J. D. Hooker as early as 1948 as a part of Flora of British India published in 1872 -1897. Since then, the Botanical Survey of India has been exploring the approachable pockets in parts of Sikkim from Botanical point of view (Rolla S. Rao, 1968). However, no comprehensive vegetation type map of the entire Sikkim could be generated due to inaccessibility probably a great constraint for ground survey.

In the present study, six broad vegetation types have been demarcated in Sikkim based on Champion and Seth (1986). They are:

1. "Tropical Semi-evergreen Forests;
2. Sub-tropical Broad-leaved Hill Forests;
3. Himalayan Wet Temperate Forests;
4. Sub-alpine Forests
5. Moist Alpine Forests and
6. Dry Alpine Forests.

A. Tropical Semi-evergreen forest (300m-900m)

The Tropical semi-evergreen Forests with Sal as a dominant species along with a few deciduous components, is the climax type of vegetation in the foot hills of the district. These forests have been influenced by physiographic, edaphic and biotic factors of the region.

B. Sub-tropical mixed broad-leaved hill forests (900m-1800m)

As altitude increases from 900-1800m, the forests also gradually change from Tropical to Sub-tropical forests comprising tree species of *Macaranga, Schima, Eugenia, Sapium, Castanopsis* and these are generally mixed with shrubby species of *Baliospermum, Clerodendrum* and *Emblica.*

Generally it is not possible to identify these two vegetation types as separate classes in satellite imagery since the signatures of these mixed composition of species are not distinct, hence classified as Mixed broad leaved hill/Mixed forests.

C. Himalayan wet temperate forests (1800m-2700m):

The vegetation gradually changes from sub tropical to sub-temperate in the altitudinal range of 1800-2400m and beyond that the vegetation becomes that of distinct Temperate forest.

In the region between 1800 m to 2400 m, the dominant species are Suaga (Hemlock), *Acer, Michelia, Juglans, Rhododendron, Ilex* associated with *Rosa, Rubus, Berberis and Viburnum.* The typical temperate forests *Quercus* (Oak), *Acer, Populus, Larix* and *Abies densa* predominate the region between 2400 m and 2700m.

The Himalayan wet temperate forests comprise of coniferous species with needle shaped leaves easily differentiable from broad leaved species due to their distinct spectral signatures.

D. Sub-alpine forests (2700m3700m)

The vegetation from typical temperate type gradually changes to sub-alpine type at higher elevations. The tree species of *Rhododendron* are found predominantly mixed with a ariety of species like *Gaultheria, Euonymus, Vibrunum, Juniperous* and *Rubus.*

Under this zone, the extensive *Rhododendron* patches were delineated but further stratification into different density classes could not be done due to their uniform canopy cover.

E. Moist Alpine forests (3700m4000m) :

The vegetation in this zone mainly comprises of typical alpine meadows where tree growth is completely arrested. Quite a few stunted bushy growth species of *Rhododendron* mixed with tough clumps of *Juniperous*, *Salix*, *Berberis*, *Rosa* and *Lonicera* are common.

F. Dry Alpine forests (above 4000 m)

The vegetation is practically of scattered scrubs, often barren. Most of the species are of stunted thorny scrubs nature. Some of the common species are *Berberis, Juniperous* and *Salix.*

In the present investigation, the alpine zone has been delineated into three categories as alpine barren with no vegetative cover, alpine scrub with scattered bushy vegetation and alpine meadows/pastures with predominantly of grasses.

The diagrammatic representation of different forest types and the capability of remote sensing techniques in segregating various forest types are shown in Figure-2.

Digital image processing for vegetation mapping

Selection of data

Champion and Seth (1968) has classified India forest to 16 major forest types but it is rather difficult to identify a type in any single season because of wide diversity in the vegetation and floral composition coupled with different phenological stages. Therefore, the identification of different forest types basically depends on the canopy condition which in turn is based on the phenological condition of the constituent species. Different seasons that are suitable for identifying various vegetation types are given in Table-6.

Data acquisition

The NRSA, Hyderabad normally supplies the remotely sensed satellite data and data products. The collateral data or ancillary data is nothing but the secondary data pertaining to the area of interest other than satellite data.

Remotely sensed data

The following types of satellite data products are available with NRSA, Hyderabad.

1. Black and White individual band transparencies and photocopies.
2. Transparencies of False Colour Composites (FCC) on 1:1 million scale.
3. Paper prints of FCC on 1:250,000 or 1:50,000 scale.
4. Computer Compatible Tapes (CCT).

The Computer Compatible Tapes are the data products used for digital analysis and each satellite has got the indexing o~ the basis of its orbiting the earth through path and row system. Other data products are for visual interpretation only. There are four categories of data products available from Indian Remote sensing satellite as follows:

1. Quick look Product
2. Browse Product
3. Standard Product
4. Precision Product
5. Special Product

All the above mentioned products are available with NRSA and they supply on the users request. The details of their format, radiometric, geometric corrections and location accuracy are given in the Table-7.

Collateral data

The Survey of India topographical maps on 1:50,000 or 1:25,000 scale can be procured from Survey of India Regional Offices. The aerial photographs, if available can also be used as secondary data. The earlier working plan maps or any other related maps can suitability be used/consulted during the course of the work.

Spectral reflectance of vegetation

The spectral reflectance of vegetation is very distinct/unique and is influenced by leaf structure, water content, pigments and air spaces within the leaf. These factors mainly influence the visible, near infra-red and middle infra-red region of the electromagnetic spectrum (EMS) incident on the leaf.

The low reflectance observed in blue and red regions corresponds to two chlorophyll absorption bands centred around 0.45 um and 0.65 um respectively. A relatively lack of absorption and more of reflectance in the green part of the EMS allows normal vegetation to look green. But in the near infra-red region, there is high reflectance, transmittance of similar magnitude and very low absorption. These three reflectance characters of vegetation depends on the internal structure of leaves whereas younger plantation or new emerging leafy trees show markedly high reflectance values in near infra-red; as leaves grow, inter-cellular space becomes less due to more transportation of photosynthetic materials thereby the reflectance decreases markedly immature plantations or old leaves on a tree canopy. When the vegetation becomes stressed due to drought or excess of mineral content as in mining areas or senescent period, the amount of chlorophyll pigment decreases thereby the reflectance ion green band decreases considerably and at the same time red reflectance increases. In view of decrease in intercellular spaces reflectance values in the near infra-red will also decrease. These unique reflectance curves help in identifying the disease plant efficiently and also to assess the total biomass of the vegetation under study.

In view of this relation, the ratio of the reflectance in near infra-red and red or any derived indices of vegetation data are sensitive indicators of vegetation growth! vigour. In the middle IR reflectance peaks occurs at 1.6 & 2.2 um. It has been shown that total incident solar radiation absorbed in the region is directly proportionate to the leaf water content. With this background, it is pertinent to know the spectral reflectance curves of various forest/land use classes in multi-spectral images for better understanding before subjecting the raw data for classification. The spectral reflectance curves of different forest classes during the course of study on Sikkim forest cover mapping are given in Figure-3.

Forest type and density mapping

Realizing the importance of forest cover in the ecological conservation and economic development, the National Forest Policy proposed that the total area under forests in the country be increased steadily to cover at least one third of the total land area, the proportion be distributed 60 percent in hilly areas and 20 per cent in the plains. Thus the forest area and quality are significant aspects for sustainable development of nation and are being monitored using remote sensing techniques ever since the launch of the first satellite of Landsat series in 1972. Recently, Forest Survey of India, Dehra Dun has reported the total forest cover of Sikkim as 3124 sq. km. (42.80 per cent) to the total geographical area of 7300 sq.km. based on visual interpretation techniques using Landsat TM on 1:250,000 scale but district wise analysis has not been given (FSI, 1989). An attempt has also been made to utilize digital classification techniques to delineate different forest classes on South district, Sikkim but due to non availability of satellite data for some portion of south-eastern part, the entire district could not be covered (Jadav et.al,1993).

The utilization of remote sensing techniques in forest resource mapping has been proved to be cost effective and reliable on real time basis. The non availability of cloud free data for different seasons, rugged terrain which generally casts shadow and subsequent loss of information are some of the problems faced with the Sikkim area. Since the classification of forest types are mainly decided on the dominant association of vegetation, structure and phenological behavior, particular season or two seasons data (pre and post monsoon) could generally be of help in delineating one type of forest from the other. In addition, the variation in floristic composition with respect to altitude also effects the overall spectral response of vegetation.

In view of different brightness intensity values of same category within the deep shadow, partial shadow and non-shadow, in the rugged terrain conditions of West district, Sikkim, the classification of different categories through digital techniques pose problems. However, the image ratios do enhance and suppress the effect of shadow (Holben and Justice 1981) and some researchers used multidimensional analysis using digital topographic data as added dimensions and physical models which estimate the reflection of solar radiation from slopes (Lepreur et.al. 1988) However, in the present study different linear contrast stretching parameters were given to red, green and blue filters to IRS band 4, 3 and 2 respectively to extract useful information before identifying the features belonging to forest and non-forest categories. Though the stretching is scene specific, it has helped to identify various forest as well as landuse/ cover classes more precisely than any other enhancement technique including ratios, principal component analysis.

The local acquisition time of the satellite image plays an important role in casting shadow. The Landsat, IRS and SPOT have local acquisition time of 0930, 1025 and 1130 hrs. Respectively. Knowing SPOT has got minimum shadow, however, due to nonavailability of SPOT data at the time of the processing the data, next best available IRS satellite data has been selected. The present approach of classifying problem areas separately helped in controlling the signature extension and also shadow effect becomes localized. However some of the landuse/cover classes of lakes, rock outcrops, built-up areas are obscured on the image due to the influence of deep shadow. Therefore, such categories are located and marked on the survey of India topographical maps and digitized these classes. They were precisely superimposed on to the image to improve the mapping accuracy.

Forest type is defined as a unit of vegetation which possesses broad characteristics in physiognomy and structure sufficiently pronounced to permit its differentiation from other such units.

Forest density gives the numerical strength of the forest area under study and it has got two components:

1. Ground density which denotes number of trees per unit area.
2. Crown density which represents the per cent canopy cover with respect to ground area exposed.

In case of Sikkim forest cover mapping, the following forest crown cover density classes in each of the vegetation type have been segregated based on tonal variations.

1. More than 40% represents crown cover density of the forest as dense/closed canopy.
2. 200/0-40% shows crown cover density of the forest as open canopy.
3. 10%-20% crown cover density of the forest gives the degraded area.
4. Less than 10% crown cover density of the forest comes under the total degraded with scrubs.

The various steps involved in the study on Forest Cover Mapping of Sikkim is given in Flow-Chart-l.