**MONITORING CHANGE IN FOREST COVER IN KARNATAKA, INDIA USING
LANDSAT DATA**

By

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ABSTRACT

This research evaluates the potential for forest change monitoring in the state of Karnataka, India using Landsat data. Landsat imagery from 1986 and 2003 was analyzed using two different change detection techniques: image differencing applied to the Principal components of the data, the Normalized Difference Vegetation Index (NDVI), and Kauth-Thomas transformed data, and post-classification comparison of binary change/no-change maps. The study demonstrates how data acquired from Landsat provide an invaluable resource for monitoring forest cover dynamics using these change analysis methods. The NDVI image differencing method was slightly better in detecting vegetation loss than PC 2 and KT-G; however, post classification comparison performed better in detecting changes as compared to NDVI differencing. Analysis of vegetation change maps revealed links of deforestation and reforestation to land use and cultural practices in the Karnataka region. The most significant causes of deforestation were submergence of forests by reservoirs in the construction of hydroelectric dams and organized smuggling of valuable timber such as sandalwood, whereas reforestation was mainly due to ongoing forest plantation projects.

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List of Acronyms

AVHRR	Advanced Very High Resolution Radiometer
APAR	Absorbed Photosynthetically Active Radar
CIR	Colour infrared
CSE	Centre for Science and Environment
DN	Digital number
ETM+	Enhanced Thematic Mapper
FSI	Forest Survey of India
GCP	Ground control point
GIS	Geographic Information System
GS	Gramm-Schmidt
IRS	Indian Remote Sensing
JFM	Joint Forest Management
KT	Kauth-Thomas Tasselled Cap Transformation
KT-G	Kauth-Thomas greenness index
LAI	Leaf Area Index
LULC	Land use/ land cover change
MIR	Mid infrared
ML	Maximum Likelihood
MOEF	Ministry of Environment and Forests
MSS	Multi-Spectral Scanner

NCA	National commission on Agriculture
NDVI	Normalized Difference Vegetation Index
NIR	Near infrared
NN	Nearest Neighbour
NRSA	National Remote Sensing Agency
PCA	Principal component analysis
RMS	Root Mean Square
SAR	Synthetic Aperture Radar
SFD	State Forest Department
SPOT	Satellite Probatoire d'observation de La Terre
TIR	Thermal infrared
TM	Thematic Mapper
UNFAO	United Nations Food and Agriculture Organisation
USGS	United States Geological Survey
VFC	Village Forest Committee

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Chapter 1

INTRODUCTION

1.1 Introduction

“Although some societies may have lived, and perhaps some still live, in ecological harmony with their surroundings, depending solely on local resources and using these sustainably, this seems to have been a rare occurrence.”

-Poore, D. 2003

Forests are a vital and important global resource that human populations depend on for wood, air quality, recreation and many other uses. They also serve as habitats for millions of plants and animal species. Tropical forests range in variety due to climate, soils, physiography and other factors. For instance, rain forests generally found in the wetter equatorial and tropical regions, on poor soils, are very rich in species. Therefore, the clearing of these types of forests, which is mainly due to agricultural expansion, illegal cutting or fire, will have a significant impact on bio-diversity (Poore 2003). As the climate varies spatially, leading to variation in rainfall, rainforests give way to semi-deciduous forests, and then to deciduous types. These forests are also extensively modified by agricultural practices, such as shifting cultivation, grazing, harvesting for fuel wood etc.

Monitoring of the forest resources of a country plays an important role, especially in the formation of sustainable management policies and conservation of these prized resources. With the advent of satellite remote sensing,

monitoring of vegetation dynamics over large regions has become feasible. For example, in 1970 Apollo/Gemini photographs, with a resolution of 5 nautical miles were reported as good enough to monitor the moisture/vegetation conditions in the Mississippi and Niger valleys (Rabchevsky (1970) cited in Unni 1975).

Since the launch of the Landsat satellite system in 1972, remote sensing has been considered to be an important tool for monitoring the regeneration as well as the rate and extent of deforestation at regional to national scales. Thus, it is a practical alternative to expensive and time-consuming field methods, which were traditionally used to gather information about forests. Satellite remote sensing provides a synoptic view of forests and their condition on a real time basis (Lillesand and Kiefer 1999). It is being used for monitoring change in land cover / land use (Giri *et al.* 1998; Chen *et al.* 2003) and in a variety of forestry applications such as forest cover type mapping (Unni 1975; Anderson 1977; Hoekman and Quinones 2000; Jain and Chaudhary 2002), forest fire analysis and mapping, terrain analysis, and deforestation (Jha *et al.* 2000; Alves 2002; Guild *et al.* 2004). Deforestation is considered to be one of the most important issues in the world, especially in the tropics, during the last century. The basic premise for using remote sensing data for the detection of deforestation is that changes that occur in the forest cover over a period of time will result in changes in surface radiance values, which can be separated from changes due to other factors, such as differences in atmospheric conditions, illumination and viewing angle, soil moisture etc. (Phua *et al.* 2002).

For change detection analyses, multi-temporal datasets are used to detect changes in land cover between dates of imagery (Lillesand and Kiefer 2000). For example, Cohen et al. (1998) mapped cutovers between 1972 and 1993 using Landsat satellite images in the Central Oregon Cascade Range. Thus, in countries where cutting is controlled, remote sensing is used as a tool to monitor whether the companies are following management plans and regulations.

The greatest advantage of remote sensing is that it helps monitor inaccessible and remote areas, where otherwise illegal cutting or damage would go unnoticed, for a long period of time. For example, in tropical areas, where field observations necessary for investigating forest changes may be lacking, monitoring with satellite data can play an important role.

In India, the causes of deforestation and forest degradation are numerous and vary regionally and temporally. Hence, it is very difficult to carry out an evaluation of the forest resources for the whole of India using conventional field survey methods, especially if time, labour and cost are limited, and because many areas are difficult to access. Further, existing estimates of rates of forest change in India are conflicting and questionable for reasons described later in this thesis. It is therefore crucial to monitor change on a timely basis, to aid in design of effective management and conservation policies at the state and forest block level.

1.2 Objectives

This research had two primary objectives. The first was to conduct a historical review of change in forest cover in India, focussing mostly on the period of 1986 to 2003, the causes of it, and changes in forest policies. The second was to evaluate the potential for monitoring forest change at the state level using Landsat data and two change analysis techniques. The state of Karnataka was used as the study area. The methods of change analysis were: image differencing of raw data and data transforms, and post-classification comparison.

To accomplish the above-mentioned objectives, literature was analyzed to evaluate the status of forest management in India and causes of forest change. This was integrated with an analysis of remote sensing data to monitor the change in forest cover in the study area.

1.3 Organization of the thesis

The thesis is organized into seven chapters. CHAPTER 1 is a brief introduction to the research topic and the objectives of the research. CHAPTER 2 describes the forests and forest resource use in India, and attempts to situate the problem of forest cover change, particularly deforestation, in a historical context. Also, it reviews the forest policies and the role of the Joint Forest Management (JFM) program in India. Further, problems in the assessment of forest cover in India are presented. In CHAPTER 3, the role of remote sensing in monitoring change in forest cover in India is presented, followed by an overview of different change detection analysis methods. CHAPTER 4 describes the study area, Karnataka, briefly touching on the main reasons for deforestation in this

state and the role of JFM. It also presents the data acquisition; pre-processing and analysis used to evaluate the potential for remote sensing based monitoring of forest change in Karnataka. This is followed by the results in CHAPTER 5. Discussion of the significant findings of the research, limitations and recommendations for further work are given in CHAPTER 6. The final chapter, CHAPTER 7, gives the conclusions of the thesis.

Chapter 2

FORESTS AND FOREST RESOURCE USE IN INDIA

"So far as I am able to judge, nothing has been left undone, either by man or nature, to make India the most extraordinary country that the sun visits on his rounds. Nothing seems to have been forgotten, nothing overlooked."

-Mark Twain, from Following the Equator.

2.1 Introduction

India is the seventh largest country in the world (Kumar et al. 2000) covering an area of 328.72×10^6 ha (India: State of Environment 2001). It is bounded by the Himalayas in the north and extends past the Tropic of Cancer in the south, tapering off in the Indian Ocean between the Bay of Bengal on the east and the Arabian Sea on the west. The mainland extends from $8^{\circ}4'N$ to $37^{\circ}6' N$ and $68^{\circ}7'E$ to $97^{\circ}25' E$. The climate is mainly tropical monsoon with four seasons: winter (January - February), hot summer (March - May), rainy southwestern monsoon (June - September), and post-monsoon (also known as north-east monsoon in the southern peninsula) (October - December).

India has large and diverse forest resources (Figure 2.1), which are the result of its highly varied climate, topography, and soils. The forest types are diverse and include tropical rainforest in northeastern India, desert and thorn forests in the west (for example in Gujarat and Rajasthan states), mangrove forests in West Bengal, Orissa and other coastal areas, and the alpine pastures of Ladakh in the

north. Champion and Seth (1968) classified Indian forests into 16 broad types, namely:

1. Tropical wet evergreen, which are generally found in the Western Ghats, upper Assam area and on Andaman Island.
2. Tropical semi-evergreen forests typically along the western coast and in Assam state, the eastern Himalayans, Orissa and the Andamans.
3. Tropical moist deciduous forests found in the Andamans and much of Peninsular India covering Uttar Pradesh, Madhya Pradesh, Gujarat, Maharashtra, Mysore (in Karnataka) and Kerala. The natural vegetation is mostly deciduous or semi-deciduous; commonly known as monsoon forest. *Tectona grandis* (Teak forests) in peninsular India and *shorea robusta* (Sal forests) in eastern India and the Ganges valley are of great economic value.
4. Littoral and Swamp forests. Littoral forests are found along the coast, while swamp forests cover the deltas of larger rivers.
5. Tropical dry deciduous forests at the foot of the Himalayas extending up to Cape Comorin except in Rajasthan, the Western Ghats and Bengal. The vegetation is mainly stunted formations with woody species such as *Manilkara hexandra* and *Chloroxylon swietenia*.
6. Tropical thorn forests in a large strip of Southern Punjab, Rajasthan, the upper Gangetic Plains, the Deccan Plateau and lower peninsular India.

-
- The map illustrates the geographical distribution of forest types in India. It shows the following features:
- Neighboring Countries:** China, Pakistan, Nepal, Tibet, Bangladesh, Myanmar.
 - Major Cities:** Srinagar, Chandigarh, Delhi, Jaipur, Lucknow, Patna, Guwahati, Calcutta, Bhubaneswar, Mumbai, Hyderabad, Bangalore, Chennai, Thiruvananthapuram.
 - Water Bodies:** Arabian Sea, Bay of Bengal, Indian Ocean.
 - Legend:**
 - Dense forest (represented by a dark, dense pattern)
 - Open forest (represented by a lighter, less dense pattern)
 - Mangrove (represented by a wavy line pattern)
 - Scrub (represented by a stippled pattern)
 - Water - Bodies (represented by a solid dark area)

Figure 2.1 Forest map of India

9. Sub-tropical pine forests in the Himalayan region between 1,000 and 1,800 m elevation.
10. Subtropical dry evergreen forests in the Shiwalik and the western Himalayas up to about 1,000m
11. Montane wet temperate forests mostly in Madras (Tamil Nadu), Kerala, the eastern Himalayas, Bengal, Assam and Northeast India.
12. Himalayan moist temperate forests between 1,400 and 3,300 m in Kashmir, Himachal Pradesh, Punjab, Uttar Pradesh, Darjeeling and Sikkim.
13. Himalayan dry temperate forests in the Ladakh area, the Lahol and Chamba areas of Himachal Pradesh.
14. Sub alpine forests at the upper limit of trees in the Himalayas.
15. Moist alpine scrub along the entire length of the Himalayas above 3,000m.
16. Dry alpine scrub at the uppermost limit (3,500m) in the Himalayas.

Hence, it can be seen that India's existing forests are primarily concentrated in three main regions: the Himalayan region to the north; the central forest belt covering Chottanagpur Plateau of Orissa, Bihar and Madhya Pradesh; and the north-south belt of the Western Ghats (Poffenberger and McGean 1996) (Figure 2.1).

Out of 328.72×10^6 ha of its geographical area, approximately 264.5×10^6 ha are used for agriculture, forestry, pasture and other biomass production (State of the Environment 2001). Although it is the seventh largest country in the world, it currently has only 1.8 % of the world's forest cover¹ (Kumar et al. 2000; Forest survey of India (FSI) 2000). Further, India supports approximately 16 % of the world's human population and 20 % of the world's livestock population on merely 2.5 % of the world's geographical area. Thus, rapidly growing human and livestock populations combined with widespread poverty and economic and trade liberalization are putting immense pressure on the country's limited land resources (State of the Environment 2001). The pressure is exacerbated by competing uses of land for forestry, agriculture, human settlements and industry and thus can be correlated with the lack of implementation of well-defined land-use policies and non-sustainable and unscientific land management, resulting in the current phase of general land degradation (State of the environment 2001).

2.2 Indian forest policies and the Joint Forest Management (JFM) program

In general, the concerns in forestry are mainly focused on resource degradation, and declines in bio-diversity, and how they impact climate change at global and regional levels. In contrast, the impact of deforestation on local people is not given much importance at the national level because the forest dwellers have no political voice (Saxena 2001).

¹ Forest cover means all lands with a tree canopy density of more than 10%, though they may not be statutorily notified as forests (FSI 1999)

There are two diametrically opposite viewpoints on the causes of deforestation in India (Wietze Lise 2000). The official viewpoint, which will be discussed in detail later in Section 2.3 contends that an increased demand for fuel wood, timber, land for agricultural expansion and other infrastructural requirements leads to forest depletion. Growth in the population and livestock, in combination with poverty and forest dependence, are the main causes of deforestation. Further, it is viewed that free rights given to the people to access the forests have led to depletion, as these people do not contribute towards the maintenance and regeneration of forests. The opposing view, which better represents popular perception (Joshi 1983; Chakraborty 1994), does not give credence to the above factors as the main causes of deforestation. It contends that the primary cause of forest depletion is the failure of the forestry bureaucracy to secure people's participation. The forestry bureaucracy, which is perceived as the exploiter of natural resources is characterized by centralized efforts, predetermined outcomes and is particularly revenue oriented (Chakraborty 1994).

This explains the discriminatory pricing of forest products, which is generally in favour of large industries producing plywood, pulp etc. and against the needs of small artisans. According to Chakraborty (1994), the distorted price of the bamboo supplied by the Forest department is one of the examples explaining the discrimination of prices of forest products. Where paper and pulp manufacturers paid only Rs 12 per tonne of bamboo, the rural artisans had to pay Rs 1200 per tonne (Chakraborty 1994). This discrepancy in prices can also

be correlated to the high levels of illegal encroachment in forests by these poor artisans to get bamboo for their livelihoods.

In a developing country such as India, where much of the rural population depends on the forests for livelihood, it seems illogical to restrict forests to state use only with the sole purpose of revenue generation. Therefore, for sustainable management of forests, participation of local communities is essential. This participation of local communities is only possible if these local communities are provided with better job opportunities and benefits to reduce their dependence on illegal use of forest resources. India's New Forest policy, developed in 1988, was designed to address this issue by combining resource development and poverty alleviation through involvement of local communities in forest management.

India has a very uneven distribution of inhabitable forests because of its diverse climate and topography. Most of the forests are concentrated in the poorer regions with low agricultural productivity and poor soils, where India's indigenous communities live (Saxena 2001). A significant proportion of these people were brought to these regions by the forest departments during the colonial period for labour purposes. Hence, forests are an important source of their livelihoods, in terms of fuel wood, fodder, etc.

Forest policies and management strategies are significant in terms of state ownership and control of forest resources, and are determined mainly by foresters and industrialists. Until 1988, management strategies were mainly

decided by the foresters, and thus, were more inclined towards commercial and industrial exploitation of the resources for revenue generation, rather than for sustainable use of the resources. Due to the intensification of the debate on forest management, both locally and at the national level, certain changes have been made in forest policies that have led to better management of the resources by involving local communities.

2.2.1 Indian forest policy from 1878-1987

Indian forest usage was, and still is, partly influenced by British colonialism during the late nineteenth century. The Indian forests mainly served the commercial interests of the British, thus limiting Indian private property rights only to continuously cultivated lands, as per the Indian Forest Act in 1878, in which the state was recognized as sole proprietor of classified forestlands.

Hence, uncultivated lands, which were uninhabited, were declared as forests by the government and managed under the New Forest regulations of Indian Forest Act of 1927 for timber production (Saxena 2001). This continued even after independence in 1947, whereby the Government of India made no changes in the above stated administrative structure and its monopoly holding rights over forests (Vira 1995), and the state governments had the power to divert forestland to other uses (Kumar et al. 2000).

Although 1952 policy criticized the clause in the 1927 Forest Act of giving power to state governments to divert forestland to other uses, the laws remained unchanged. Hence, in the National Forest Policy of 1952 it was declared,

"Village communities should in no event be permitted to use forests at the cost of 'national interest', which was identified with defence, communications and vital industries." Therefore, it was a formal reinforcement of the rights of the state with regard to the management and control of forest resources. The main aim of the 1952 Forest Policy was to 'increase' the area under forest cover to one-third of the country's geographical area (Vira 1995). However, this policy mainly supported a commercial approach, which was directed towards the supply of cheap timber and non-timber products for state sponsored industrialization and modernization.

In 1976, following the 42nd amendment to the constitution of India, the forests were made a concurrent subject (Kumar et al. 2000), thereby giving control to both the central government and States over forest matters. Further, the National Commission on Agriculture (NCA) report also approved the commercial approach of the 1952 policy, thereby leading to the second round of major changes in the next forest policy, (NCA (1976) cited in both Saxena 2001 and Kant 2001) which stated that,

"Production of industrial wood would have to be the *raison d'être* for the existence of forests. There should be a changeover from the conservation-oriented forestry to a more dynamic programme of production forestry. The future production programme should concentrate on clear felling of valuable mixed forests, mixed quality forest and inaccessible hardwood forests and planting these areas with suitable fast growing species yielding higher returns per unit area"(Saxena 2001).

From the above statement it is clear that the new policy emphasized more the cost and returns from the production of industrial wood from these fast growing plantations, which did not seemed very environment friendly policy. The NCA also continued as per the British presumption that if free access were given to local people, it would lead to the destruction of the forests. Therefore, keeping this in view, it was recommended by NCA that a National Forestry Programme for the establishment of plantations on a large-scale should be implemented so that the needs of local people related to fodder and fuel wood could be met (Kant 2001). This resulted in the era of industrial forestry, where most of the money in state forest departments was spent on monoculture plantation projects. The National Forestry programme was supposed to benefit the poor and marginalized people by providing them accessibility to fodder and fuel wood, but instead the foresters lacked the initiative and means to transform it into a more people-oriented program. Hence, more priority was given to the industries and large-scale farmers than to the people living in and around the forestlands, to generate more revenue. Therefore, the basic needs of the forest dwellers, mostly tribal, were ignored simply by converting a natural forest into genetically modified plantations, in the name of 'scientific forestry'. Such conventional forestry, based on clear felling, disrupts the annual cycling of nutrients and increases soil erosion (Saxena 2001). Also, these monoculture plantations are more prone to pest attack and diseases. For example, in Kerala, eucalyptus plantations raised after clear felling of dense green deciduous forests were devastated by fungal disease. This decreased the productivity to much lower levels, thus defeating the

very purpose of the establishment of these plantations in the state (Nair 1985 as cited in Saxena 2001).

Thus, after independence, forestry in India was mainly inclined towards the production of uniform industrial cropping. There were three factors that affected these policies. The foremost factor was the development of the nation, which heavily impacted the decisions made by planners regarding forest policies. As a result, the output from forestlands was heavily subsidized, so that it could be used as raw material to build and maintain various industries. Hence, the impacts of these policies on the environment, natural forests and forest dwellers were not considered to be serious. The second factor was that the tribes and the forest dwellers had little or no political voice so they were not considered while making decisions. Thirdly, the foresters were trained only to grow and manage trees for timber production, as other non-wood forest products were considered of insignificant value (Saxena 2001). The combination of these factors led to long-term continuation of this timber and revenue-oriented policy to meet the goals of the nation.

Growing awareness of development of the impacts of this policy led to greater criticism and movements related to access to forests and more defined property rights, especially for the people depending on forests for livelihood. In the 1976 policy, NCA acknowledged that non-forestlands should be used to meet the requirements of local people thereby reducing pressures on forests. Thus, the concept of social forestry, a term used by the NCA in 1976 to denote tree-raising programs on village and private lands to supply fuel wood, fodder, small

timber and minor forest produce to rural populations, was introduced (Centre for Science and Environment (CSE) 1985). The main aim of this concept was to plant trees on private lands, named as farm forestry and afforestation of village lands. Though farm forestry was a huge success in a few states, such as Gujarat, Karnataka etc., there were problems associated with it (Saxena 2001). The main problems were that it was mainly confined to the more prosperous agricultural regions, and it mainly supported eucalyptus plantations. Though eucalyptus covers 0.5×10^6 ha in India, it is not popular with environmentalists (CSE 1985). It does not allow other plants to grow due to its large water requirement and it depletes soil nutrients. In Karnataka, protests over its use included uprooting of trees in several places while farmers dug trenches to keep the roots of eucalyptus away from their crops (CSE 1985). Another problem was the lack of involvement of local people, who had no role in decision-making or choice of species to be planted on these private lands. Further, there was no management, control or defined rights of these planted village lands. As a result, there were organized 'mass loots' of these plantations by the villagers due to conflicts with the forest departments regarding property rights and sharing of forest products. In addition to this, forest departments generally planted market-oriented species, thereby neglecting fodder trees, which did little to solve the problems of fodder and fuel wood. This led to increased pressure on forestlands. State funds were soon depleted and commitment to these projects decreased. Many of the forestlands entered a period of negligence in management that resulted in a reduction of the timber supply and thus led to the escalation of

prices. All these factors affected the forest dwellers and tribes, resulting in increased illegal cutting and smuggling of timber from forestlands.

2.2.2. Indian forest policy from 1988 to present

In the Indian forestry sector, the distribution of responsibility was conceptually weak, as forestlands were used generally to meet commercial needs, while the farmlands were used to meet the requirements of fuel wood and fodder. This weakness was considered as one of the main reasons for the failure of the above-mentioned industrial forestry programs of the 1950s-1970s, and the social forestry program of the 1980s (Saxena 2001).

The inputs and the pressures from the people and environmentalists finally led to changes in the 1988 National Forest Policy of Independent India. This policy, envisages people's involvement in the development and protection of forests. It also gives more rights to poor people, specifically tribal and scheduled caste (lower caste) compare to the industrial sector. It emphasizes that the requirements of the people living in and around the forests for fuel wood, fodder and small timber, should be given first priority and forest communities should be motivated to identify themselves with the protection and the development of the forests from which they derive benefits (Kant 2001). Hence, this policy gives high priority to environment stability, by giving preference to mixed forests over monoculture plantations, rather than just using forests as a means of revenue generation.

Despite all the policies enacted, depletion of forest resources continued and it was realized that the active and willing participation of local communities is necessary for any forest regeneration program to succeed. Therefore, following up on the 1988 National Forest Policy, the government of India issued guidelines to all state governments in June 1990 regarding the formulation of forest management programs in collaboration with local people. These guidelines were known as Joint Forest Management (JFM) (Kant 2001).

JFM seeks to foster partnerships between state forest departments (SFD's) and local institutions of forest dependent people on the basis of mutual trust, shared benefits and forest management responsibilities (Singh *et al.* 2001). However, this is mainly related to the management of the degraded forests.

In 1994, the Ministry of Environment and Forests prepared a draft of the new bill called the Conservation of Forest and Natural Ecosystems Bill to replace the Indian Forest Act of 1927. The draft generated a lot of debate from voluntary organizations that prepared an alternate draft and submitted it to the MOEF. Unfortunately, the bill was not presented in Parliament due to many disagreements between the organizations and the MOEF. Hence, the old Indian Forest Act of 1927, with subsequent amendments is still in operation.

Further according to the 73rd amendment in the constitution, the village Panchayats (defined as a village council which collects taxes and maintains revenue records of a particular village) have been provided with power of control

over the natural resources including land and forest produce, which is still an issue in most of the states in India.

2.3 Deforestation: causes and effects

2.3.1 Historical context of Indian deforestation

India, like many other parts of the world, has seen increasing pressures on its natural forest resources over the past two centuries. Deforestation, which is a type of land degradation, and considered to be one of the main causes for other kinds of degradation such as soil erosion, has accelerated at a much faster rate during the last three decades (Poffenberger and McGean 1996; State of the Environment 2001). Data gathered from remote sensing on Indian forest cover revealed that between 1980 and 1987 the deforestation rate was about 1.48×10^6 ha/yr, which was far more than previously believed (Poffenberger and McGean 1996). The types of activities leading to loss of vegetation are: over-grazing and conversion of forest land to non-forestry uses such as infrastructural development (energy, roadways etc.), shifting cultivation (practised mainly in north-eastern India), unsustainable extraction of fuel and fodder from forests, forest fires, over-cutting beyond permitted limits, unsustainable forest management practices, uncontrolled logging and illegal felling, and illegal encroachment into forestland due to land shortages, short-term, or insecure land tenure. For example, approximately 1.5×10^6 ha of forestland is estimated to be occupied illegally for agriculture and other uses (MOEF 1999). Currently, about 90 % of India's 64×10^6 ha of forests are under state ownership; the rest are community and private forests. However, state control over forestlands is weak,

which is one of the reasons for the considerable encroachment by individuals and communities.

Large-scale destruction of forests began in the times of British rule. Forests were generally cut down for timber² and agricultural purposes to expand the British Empire in order to create a vast railway network throughout the country (Sekhsaria 1999) and for revenue generation (Kant 2001). The main aim was fast, cheap and efficient transportation of inexpensive raw materials to the ports from the hinterlands of the country, for export to British industries. It is estimated that between 1869 and 1885, more than 6,500,000 deodar (*Cedrus Deodara*) sleepers³ were extracted from the Yamuna Valley forests in the Himalayas because of the exhaustion of the supply of teak and Sal (*Shorea Obusta*) from Peninsular India (Gadgil and Guha 1992, cited in Sekhsaria 1999).

The other major cause of deforestation immediately after independence was agricultural expansion. For example, most of the rich moist deciduous forests of the humid Terai region in northern Uttar Pradesh were cleared to provide land to immigrants from the newly created Pakistan (Sekhsaria 1999).

² The shortage of timber in Britain and the isolation of Britain from the Baltic supply lines during the years of the French Revolution and the Napoleonic wars, between 1793 and 1815, forced the Empire to look to alternative sources of wood for shipbuilding. In the late 18th and early 19th centuries, Indian forests were mainly used by the British to meet the requirements of the Royal Navy (Smythies 1925; Kant 2001)

³ The wooden or, more commonly these days, concrete cross pieces on which the rail rests. In North America these are known as 'ties'.

The pressure on India's forests is extremely high from the rapidly growing human and livestock populations⁴ living in and around them. This is due to the decline of per capita availability of cultivated land for the existing population. For instance, cultivated land declined from 1.42 ha per person in 1800 (Sharma 1975) to 0.39 ha per person in 1991 (North Eastern Development Finance Corporation Ltd. 2002⁵). Also, under different welfare schemes for poorer regions, forestlands are often converted to farming lands (Reddy *et al.* 1990). Forestland is an important source of grazing and fodder, especially in the absence of adequate pastureland and a viable policy on fodder development. Though India has a large livestock population, it does not have enough fodder resources for feed (Ghose 1986; cited in Reddy *et al.* 1990). This has made forestland more vulnerable to grazing. For instance, it is estimated that over half of the livestock population (some 270 million) grazes in the forests (MOEF, India 1999.Vol.1). These include traditional ethnic sedentary village livestock and migratory animals herded by ethnic grazers. Additionally, these grazers collect an estimated 175 to 200 million tons of green fodder annually (MOEF 2001). This results in overgrazing and over extraction of green fodder from the forestland, hence further leading to forest degradation through damage to regenerating vegetation and soil compaction. This accelerates the process of soil erosion, and results in the formation of wastelands (Reddy *et al.* 1990). A survey done by FSI (1999) estimated that grazing impacted 78% of the country's

⁴ Human pop. ~ 1 billion and Livestock pop. ~450 million (Kumar *et al.* 2000) In some states like Uttaranchal the high density of population is responsible for deforestation in order to meet their daily requirements.

⁵ Accessed online http://databank.nedfi.com/content.php?menu=1016&page_id=377 (NER Databank)

forests. Out of this, 18 % of forests were highly impacted and 31 % had medium impact. Grazing practice has also impacted protected areas. About 67% of the national parks and 83% of the wildlife sanctuaries surveyed reported grazing incidences (MOEF 2001).

Schmidt *et al.* (1999) consider poverty as one of the major causes for land degradation and deforestation. In India, a large number of people are living below the poverty line⁶. They depend directly or indirectly on forest resources such as fuel wood for cooking, cattle grazing, and agriculture, and thus are considered as one of the contributors to forest degradation. Consumption of wood (timber and fuel wood) is 4 to 5 times higher than what can sustainably be removed from the forests. For example, in India, although the annual demand for fuel wood is estimated to be $240 \times 10^6 \text{ m}^3$, the sustainable production level of fuel wood is estimated to be only $41 \times 10^6 \text{ m}^3$ (Schmidt *et al.* 1999). Hence, to meet this demand, forests are cut illegally. In 1990, the estimated removal of fuel wood was about $250 \times 10^6 \text{ m}^3$, and was estimated to increase to $310 \times 10^6 \text{ m}^3$ by 2000 (MOEF 1999). According to Reddy *et al.* (1990), about $175 \times 10^6 \text{ ha}$ of Indian land is degraded, including non-forest, and this wasteland is further subjected to soil erosion. Soil erosion in wasteland leads to a scarcity of fuel wood and this in turn exacerbates the pressure on forestlands. Also, there is illegal encroachment into forestlands where there is a lack of economic opportunity, unequal distribution of land ownership rights and growing class

⁶ In India, people who earn less than \$ 2 US per day are stated as living below the poverty line. Source: http://databank.nedfi.com/content.php?menu=1016&page_id=377 (NER Databank)

differentiation (Rangan 1996). This is because in the absence of ownership rights or secure tenure, communities and individuals have no incentive to care for the land or sustain the forests (Salim and Ullsten 2000), and thus encroachment is seen as a means of gaining a livelihood.

Another important factor in the rapid decline of Indian forests is that the demand for industrial wood products, such as timber, is much greater and is increasing at a rate much higher than the production level. For example, most of the forests of the northeastern states bordering China and Myanmar and the remote islands of Andaman and Nicobar, have been cut to fulfill the demands of plywood mills (Sekhsaria 1999). Eventually this leads to conversion of forestland into wasteland.

Land use practices such as shifting cultivation contribute to deforestation, especially in the northeastern part of India (Unni 1978; Kushwaha et al. 1993). Shifting cultivation (known as 'Jhum' in north-eastern India) refers to a farming system in which a short but variable cultivation phase (on slash-and-burn land) alternates with a long and equally variable fallow period. In the past, fallow periods ranged from 20-30 years. However, recently, this fallow time period has decreased to less than 5 years due to a large increase in population (Kushwaha et al. 1993). As a result, this practice of farming, which was once in equilibrium with nature, has become unbalanced, reducing the potential for effective regeneration of forests. Frequent cutting and burning encourages weed species, such as *Imperata*, that compete with the crops as well as the regenerating forests, thereby reducing the fertility of soil (Kushwaha et al. 1993). Further,

when forest cover is reduced, the ground surface becomes more exposed to erosion from rainfall (Singh 1999). Thus, a decrease in the Jhum cycle accelerates the rate of soil erosion. An assessment by the FSI indicated that 1.73×10^6 ha of land have been affected by shifting cultivation in the northeastern part of India during the period 1987-1997 (FSI 2000).

Despite such pressure on forests, there has been an increase in forest cover in the states of Arunachal Pradesh, Himachal Pradesh, Jammu and Kashmir, Tripura, Uttar Pradesh and West Bengal according to an assessment for the period of 1997 to 1999 (FSI 2000). However, this increase does not reveal the extent of pressure on these resources, particularly in states such as Himachal Pradesh and Jammu and Kashmir, where forests occupy a relatively small proportion of the total area. Forest areas in proximity to population centres and villages are reported to be degrading faster due to the collection of fuel wood and cattle grazing, as compared to forests away from population centres and in inaccessible areas (FSI 2000). At the same time, a decline has been witnessed in the northeastern states of Assam, Meghalaya, Mizoram, Nagaland and Sikkim (FSI 2000).

The rate of degradation of Indian forests varies from state to state, due to varying intensities of the factors discussed above and of reforestation activities (MOEF 2002). According to Reddy et al. (2001), though, recent years have shown an improvement in the area under forests, but contradictions still exist among different data sets. This slowing down of deforestation can be related to the immense national investment in fast growing tree plantations such as

monoculture eucalyptus, acacia etc., which do not possess the biological and ecological characteristics of the natural forests. For example, between 1952 and 1980 over 3×10^6 ha of plantations were established in India, most to fulfill industrial needs (Saxena 2001). Thus, these plantations are not generally grown for environmental reasons and are usually felled within a decade of establishment.

In summary, deforestation is caused by a variety of factors and has diverse environmental, social and economic impacts such as loss of ecological stability, loss of biodiversity, soil erosion resulting in the silting of reservoirs, reduction in carbon retention and its associated effects on climate, and above all, reduction in food availability and livelihood security of people dependent on forests (MOEF 2001).

Thus, despite the 42nd Amendment to the Constitution on forest conservation (making forests a subject of parallel jurisdiction of central and state governments) (MOEF 2002), and despite the development of various forest management policies, and reforestation projects, deforestation, shifting cultivation, unsustainable fuel wood, fodder and timber extraction are still persistent problems.

2.4 Problems related to the assessment and mapping of Indian forests

Although India has a well-articulated forest policy that has evolved over time, forest laws have lagged in translating policy into a strategy that can be well implemented. As a result, the strategy has not met the diverse demands for

forest products and services. Though it is stated in the National Forest Policy (NFP) (1988) that periodic collection and publication of reliable data on relevant aspects of forest management at the national level needs to be improved, the lack of availability of reliable and precise data for the forestry sector (Prasad et al. 2000), as well as consistent estimates of deforestation rates (Menon and Bawa 1998) are a large concern. There is no long-term time series data on the actual forest cover of the country (Chakraborty 1994), which is one of the major drawbacks in the analysis of temporal change of forest cover. The literature on Indian forest cover generally includes indicators such as the ratio of good⁷ forest cover to the total land surface, or the percentage of closed forestland to all forestland, which are generally not well defined or consistently evaluated. Another problem is that the data on forest cover are not published regularly and are inconsistent among different government organizations (Prasad et al. 2000). The reason for this is that generally the information is scattered amongst many organizations and there is not a standardized set of procedures for gathering information or for exchange between organizations. The World Bank found that the data provided by different institutions on forest cover, its rate of change, and the demand and supply of forest products were inconsistent and unreliable (Kumar *et al.* 2000). The reason may be that the FSI includes plantations on farms and degraded lands (whatever can be observed by satellites), while the FAO calculates the rate of deforestation only on natural forests and reports plantations separately (based on government data provided by countries).

⁷ Good forest cover means dense natural forest with crown density 40 % and over (Chakraborty 1994)

An example of the disparity in deforestation estimates of India is from the studies conducted by the FAO (1993) and the National Remote Sensing Agency (NRSA) (Ravindranath and Hall 1994) for the 1981 – 1990 period (Table 2.1). It can be clearly seen that the FAO study estimated the annual deforestation rate in India as 0.6% between 1981 and 1990 while the NRSA study estimated that India's total forest area (which includes both plantations and natural forests) declined by only 0.04% annually for the same time period. The main source of the disparity is the definitions of forest and plantation adopted by the FAO and NRSA (Menon and Bawa 1998). The FAO defined forests as "ecosystems with a minimum of 10% crown cover of trees and/or bamboos, generally associated with wild flora, fauna and natural soil conditions, and not subject to agricultural practices" and therefore excludes plantations (FAO 1993; as cited in Menon and Bawa 1998). The NRSA defined forests as areas under natural forest as well as tree plantations with > 10% crown cover contiguous over 25 ha. It is difficult to obtain an idea of natural forest cover of the country as it was not known what proportion of tree plantations were included as forests. Also, for the purposes of its coarse scale remote sensing based mapping, forests smaller than 25 ha were excluded from the NRSA estimate. For afforestation, the FAO study reported an annual rate of 1.44×10^6 ha between 1981 and 1990, which is almost 3 times greater than the estimated annual deforestation rate. This might be due to the usage of data from different sources such as satellite imagery for estimation of forest cover and gross country reports for plantations.

Table 2.1 Comparison of FAO and NRSA deforestation estimates

	FAO Estimate	NRSA Estimate
Reference	FAO 1993	Ravindranath and Hall, 1994
Time period	1981-1990	1982-1990
Data sources	Forest cover: Satellite imagery (Landsat MSS and TM, IRS) at sample locations and extrapolation by modeling. Plantation: Country reports (tabular data)	Forest cover and plantations: Satellite imagery (Landsat MSS and TM)
Scale of maps produced	Not known	1:1 million (1981-83) 1:250,000 (1985-87, 1987-89, 1989-91)
Validation	Yes at selected sample locations	Yes
Forest definition	Natural forest with >10 % crown cover	Natural forest + tree plantation with >10 % crown cover and contiguous over 25 ha
Plantation definition	Artificial stands for production or wood, fuel wood, and non-wood products	Tree plantations with > 10 % crown cover and contiguous over 25 ha
Caveats	Imagery evaluated only at sample locations then extrapolated	Proportion of tree plantation included as forests is unknown
Total Forest area (1981)	56.5 x 10 ⁶ ha	64.2 x 10 ⁶ ha
Total forest area (1990)	51.7 x 10 ⁶ ha 70.6 x 10 ⁶ ha (forest + plantations)	64.0 x 10 ⁶ ha
Annual deforestation estimate	333,000 ha (0.6 %)	23,750 ha (0.04 %)
Annual afforestation reported (plantation)	1981 – 1990: 1.44 x 10 ⁶ ha	Not reported

(Source: Menon & Bawa 1998)

Although there has been an improvement in total Indian forest cover in recent years, data sets provided by different organizations such as the Agricultural Department, the Ministry of Environment and Forests etc., as well as the UN FAO (Table 2.2) have produced inconsistent estimates regarding the actual forest cover of the country (Reddy *et al.* 2001; Kumar *et al.* 2000). The problem is not between estimates for a single time, but when temporal change is analyzed, the difference in numbers may impact the estimation of actual forest cover of a country. If deforestation is < 0.5 million ha per year, then it cannot be distinguished from the method used to calculate it i.e., the precision is not high enough to say there has been real change. Thus, depending on which figure one

adopts, the rate of past (and also future) changes will vary and may affect forest policy (MOEF, India 1999. Vol. 1).

Table 2.2 Comparison of data published by different Indian institutions and the FAO

Year	Forest cover (million ha)	Agency	Source
1989-1990	67.41	Agricultural Dept.	Ministry of Agriculture 1996
1989	63.88	FSI / MOEF, India	MOEF, India 1999
1991	63.94	FSI, India	FSI 1999
1990	64.96	FAO	FAO 1990

(Source: World Bank Report, Kumar et al. 2000)

In the states of Arunachal Pradesh, Jammu and Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and the Union Territory of Andaman & Nicobar Islands, the forest cover is more than the recorded forest area⁸. Thus, it is possible that even in states where the forest cover is less than the recorded forest area, some part of the forest cover lies outside the recorded forest area. Hence, methods of monitoring forest change must be consistent among different organizations. Remote sensing offers the most potential to provide maps over large areas using consistent methods and provide more spatial information than traditional forest surveys.

According to Prasad et al. (2000) there are no systematic and periodic checks to verify the quality and authenticity of forestry information generated by different organizations. Also, lack of computer connectivity between forestry organizations leads to a lack of systematic computerization of information. As a result, there is poor communication between different users and producers of

⁸ Recorded forest area is defined as all lands statutorily notified as forest though they may not necessarily bear tree cover (FSI 1999).

forestry information, which is mostly due to the absence of a single point forestry data access facility.

2.5 Conclusion

India has large and diverse forests due to varied climate, soil and topography. Despite of amendments made in the forest policies to conserve and manage these prized resources, Indian forests are still undergoing changes. The causes for the depletion of forests are many and vary according to the regions. Further, forestry information is inconsistent and scattered among different organizations, such as FSI, MOEF and NGO's.

Chapter 3

REMOTE SENSING OF VEGETATION CHANGE

3.1 Role of remote sensing in monitoring change in forest cover: Literature review

Tropical forests occupy only 7 % of the world's area, but they are rich in biodiversity of both plants and animal species (Tucker and Townshend 2000). They are decreasing in extent at an alarming rate due to various anthropogenic activities, which are responsible for the extinction of species as well as adverse effects on biological diversity due to habitat destruction. At the same time, tropical forests are of interest because of their greenhouse gas reduction potential. Hence, the associated factors and impacts of the loss of these prized resources on the global environment are of great concern. For sustainable and wise use of these natural resources, information on existing land use/land cover and capability for monitoring of change in these resources on a timely basis are critical. Information regarding changes in the Earth's resources also improves our understanding of the relationships and interactions between humans and their environment, thereby aiding decision making in terms of environment law and policy.

Conventional ground methods for mapping land use/land cover are labour intensive and time consuming, particularly for areas not easily accessible due to varied topography. Consequently, land use cover inventories using field methods are done relatively infrequently. Also, the maps produced soon become

outdated, due to rapid change in the environment. Hence, it is not economically viable, especially for a developing country, to use conventional field methods to monitor the type, extent and change in forest resources over large areas.

Remote sensing data with different resolutions, such as the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+), the Advanced Very High Resolution Radiometer (AVHRR), the Satellite Probatoire d'Observation de la Terre (SPOT), Indian Remote Sensing (IRS), radar sensors and aerial photographs etc. have been used for detection and analysis of land-use / land cover (LULC) change (Giri *et al.* 1998), forest or vegetation change, deforestation (Di Maio Mantovani *et al.* 1997), environmental change, urban change etc. Remote sensing offers a potential means to map and monitor a country's natural resources because of its synoptic view and repetitive coverage.

To produce the estimates of tropical deforestation, two types of satellite data are most commonly used: 1. AVHRR, despite having a large pixel sample size of 1.1 km at nadir, has daily coverage of continental sized areas and very low image acquisition and processing costs (Di Maio Mantovani *et al.* 1997; Lu *et al.* 2003; and Maxwell *et al.* 2002), and 2. Landsat data has better spatial resolution (80 m pixels, Multi-Spectral Scanner (MSS) or 30 m pixels, Thematic Mapper (TM)) (Alves *et al.* 2002), and several spectral bands in the visible (400-700 nm), near infrared (NIR, 700-1100 nm), mid infrared or short wave infrared (MIR or SWIR, 1100–2500 nm) and thermal infrared (TIR, 8-12 μ m). Landsat is more expensive to acquire and images cover a much smaller area (185 km x 185 km) than AVHRR images (2400 x 2400 km), but its cost (\$900/scene) is not

prohibitive for regional and national scale studies. Other privately operated sensors such as SPOT and Radarsat, as well as some government operated sensors (e.g., IRS sensors) are 4-10 times more expensive for the same image coverage and thus are not commonly acquired for large areas by most governments.

Though satellite imaging radar has been studied for mapping tropical forest extent, type, classification (Hoekman and Quinones 2000; Oliver *et al.* 2000) and deforestation, its use has been limited because of the multiple polarizations and acquisitions required to achieve accuracies similar to those achievable with Landsat. Also the data are costly and pre-processing of the data is time consuming. Its primary advantage for tropical areas is a capability to image through cloud, which can be persistent over long periods.

In India, the Forest Survey of India (FSI) is an associated institution of the Ministry of Environment and Forests, which is responsible for preparing the state of the forest reports and the national vegetation map of India every two years, since 1987 using remote sensing data. It also prepares forest inventories and carries out growing stock and volume assessments. Hence, it is a key organization in India, for the generation of primary forest cover and the resources data. The first FSI report was published in 1987 using Landsat MSS data and the 1989 report was based on Landsat TM data, using visual interpretation of false colour images. Since 1995, IRS data have been used for the assessment of forest cover.

To conduct change analysis for local areas, moderate resolution data such as TM, Satellite Probatoire d'Observation de la Terre (SPOT), Synthetic Aperture Radar (SAR) are quite often used (Grover *et al.* 1999; Hoekman and Quinones 2000; and Oliver *et al.* 2000), whereas for continental or global level change analysis, coarse resolution data such as AVHRR are more suitable.

The spectral and spatial resolution of Landsat data as well as its cost makes it suitable for multi-temporal change detection studies. Numerous studies have been conducted using Landsat data for temporal analysis of change in vegetation and classification of forests in tropical regions (May *et al.* 1997; Oliver *et al.* 2000; Wang *et al.* 2004; Asner *et al.* 2002; Alves 2002). Klankamsorn (1987) reported that Landsat data can be used to identify current forest areas and therefore are good for monitoring changes caused by human activities or natural disturbances by comparing images of two different time periods. Alves (2002) used the deforestation maps derived from Landsat MSS and TM imagery to analyze the spatial patterns of deforestation in the 1970s and from 1991 to 1997 in Brazilian Amazonia. A spatial auto-correlation indicator was used to determine auto-correlated deforestation. It was found that 90% of the deforestation had occurred within 100 km of the major roads established under federal development programmes. Further, results indicated that deforestation was more intensely concentrated over some regions, thereby leading to the enlargement of forest clearings and contributing to aggravate deforestation impacts in such areas.

For this research Landsat TM (1982-present) and ETM+ (introduced in 1999) were used. They have the same pixel size, i.e., 30 x 30 m (excluding the thermal band), and it was possible to obtain cloud-free data for the Karnataka region. As the main objective of the research was to analyze change over as long a period as possible using satellite imagery, and Landsat had the longest archived acquisition period of any moderate resolution sensor, it was selected for this research. High spatial resolution satellite data (e.g. Ikonos, Quickbird) were not used because of their small scene coverage, high cost per hectare, and lack of temporal archives.

3.2 Change detection methods

Change detection is defined as the process in which temporal differences in the state of an object or phenomenon are identified (Singh 1989). During past 20 years, it has become a major application of remotely sensed data because of increasingly consistent image quality and repetitive coverage at short intervals (Mas 1999). Different change detection techniques have been developed that can be grouped into seven categories, based on the level of complexity: 1) algebraic, such as image differencing, ratios, and change vector analysis; 2) transformations of temporal data (from greater than one date), including principal component analysis (PCA), Kauth-Thomas (KT), Gramm-Schmidt (GS), and Chi-Square transformations; 3) classification of multi-date data, or comparison of maps classified from individual dates; 4) temporal analysis using advanced models (e.g., spectral mixture models, optical-physical reflectance models such as the Li-Strahler model); 5) Geographic information system (GIS) approach,

which includes the integrated GIS and remote sensing methods and the pure GIS method, 6) visual analysis of multi-date imagery, and 7) other approaches (Lu et al. 2003). Most of these can be applied using raw spectral data or data transforms such as those listed under 2) above. For temporal comparison of images, the images should be calibrated so that detected differences are due to land cover change and not due to atmospheric or sensor differences. Two types of calibration may be conducted: absolute calibration using atmospheric corrections and sensor drift calibration, or relative calibration where one scene's image brightness distribution is matched to the other. The latter was used in thesis as described in Section 4.4.3. The following subsections describe the data transforms applied in this research followed by the change detection methods employed.

3.2.1 Data transformations

Spectral image data can be transformed in a variety of ways to produce new images that enhance physical gradients such as vegetation, wetness, etc. The following provides descriptions of the transformations that were applied in this research.

3.2.1.1 Vegetation indices

Vegetation indices are defined as "dimensionless, radiometric measures that function as indicators of relative abundance and activity of green vegetation, often including leaf-area-index (LAI), percentage green cover, chlorophyll content, green biomass, and absorbed photosynthetically active radiation (APAR)" (Jensen 2000). Over forty different vegetation indices (Bannari *et al.*

1995) have been in use in the field of remote sensing applications, to qualitatively and quantitatively evaluate the percent vegetation ground cover.

The Normalized Difference Vegetation Index (NDVI), Equation 1, developed by Rouse *et al.* (1974) is the most common in use, as it compensates for varying view-angle-illumination across a scene and topographic brightness variations in comparison to a simple vegetation index of NIR/R (Lillesand and Kiefer 2000). Further, it is easy to calculate and interpret using various types of satellite data. NDVI is able to separate green vegetation from other surfaces because the chlorophyll of green vegetation absorbs red light for photosynthesis and reflects the NIR wavelengths due to the scattering caused by the internal leaf structure (Wilson and Sader 2002). As vegetation increases, NIR reflectance increases while red reflectance decreases, producing an enhanced difference in the numerator of the index. NDVI is highly correlated with vegetation parameters such as green leaf biomass and green leaf area (Tucker *et al.* 1981; Justice *et al.* 1985; Roy 1993).

$$NDVI = (NIR - R) / (NIR + R) \quad (1)$$

where, NIR is the reflectance or brightness in the near infrared band and R is the reflectance or brightness in the red band.

Of the many other indices in the literature, for research purposes, the other that was selected incorporates visible, mid IR and thermal IR image information. As Boyd *et al.* (1996) suggested “the relationship between forest biophysical properties and mid and thermal infrared radiance may be stronger

than that between forest biophysical properties and visible and near-infrared radiance” (cited in Southworth 2004). The thermal index is calculated as:

$$TM\ 6 / (TM\ 3 + TM\ 5) \quad (2)$$

where TM 6 is the Landsat thermal band, TM 3 is the red band and TM 5 is the first mid-infrared band.

Use of the thermal infrared in vegetation change analysis has been successfully conducted in some studies. For example, Di Maio Mantovani (1997) used AVHRR channel 3 (3.5 - 3.7 μm) images to detect new deforestation in Mato Grosso, Brazilian Legal Amazon region. The images were compared with 30 m Landsat Thematic Mapper reference data. The percentages of correct location of newly deforested sites for September 1989 – 1990 and July 1990 – September 1990 were as follows: 49.1% and 56.5% for 200 deforestation sites of assorted sizes, respectively and 82.5 and 90% for sites larger than 3.1 km².

3.2.1.2 Principal Component Analysis (PCA)

Principal component analysis, also known as PCA or Karhunen-Loeve analysis, has been widely used and proven to be of significant value in temporal analysis of remotely sensed digital data (Jensen 2000). It is a statistically based transformation that can reduce redundancy within the image data caused by correlations between spectral bands (Lillesand and Kiefer 2000). It is based on the idea that multi-spectral or multi-temporal data are highly correlated and a set of orthogonal axes can be identified that better represent the data variance. The principal component transformation rotates the data axes into new axes that

maximize the amount of data variance in each component. In general, the first principal component (PC 1) contains most of the total variance, while the succeeding components contain decreasing proportions of the variance (Lunetta and Elvidge 1999). PCA can be applied either to data from two dates individually followed by image differencing, ratios or other change detection techniques, or it can be applied to a temporal data set consisting of data from more than one date. As an example of the latter, Byrne *et al.* (1980) studied the effectiveness of temporal PCA to identify changes in land cover between two dates and found that PC 1 and PC 2 tend to represent information regarding unchanged land cover, while PC 3 and other components contain changed land cover information. In this thesis, PCA was applied to individual dates to identify which components represented vegetation. These components were then used in image differencing to detect and map vegetation change.

3.2.1.3 Kauth-Thomas Tasseled Cap Transformation

The Kauth-Thomas Tasseled Cap Transformation was developed by Kauth and Thomas (1976) originally for Landsat MSS (Lillesand and Kiefer 2000). It is a linear transformation similar to PCA whereby the new three or four-dimensional index bands or features are created by using the Gram-Schmidt orthogonalization process on the original four (Landsat MSS) or six bands (Landsat TM), excluding the thermal band. It is called the Tasseled Cap Transformation due to the shape of typical data distributions when plotted in the visible and near infrared. "This "Tasseled Cap" transformation rotates the data so that majority of the information is contained in two (MSS) or three (TM)

components or features that are directly related to the physical scene characteristics” (Lillesand and Kiefer 2000). In the case of TM imagery, the new bands produced typically represent overall brightness, greenness, and moistness. The brightness image is often linked to soil and urban brightness, and the green vegetation cover or biomass above ground is represented by the greenness index. The third wetness or moistness axis relates to canopy and soil moisture while the fourth is often data variance related to haze and data noise. The following are the equations for the first three indices as used in IDRISI and based on Mather (1989):

$$\text{TM Bright} = 0.3037 \text{ TM } 1 + 0.2793 \text{ TM } 2 + 0.4343 \text{ TM } 3 + 0.5585 \text{ TM } 4 + 0.5082 \text{ TM } 5 + 0.1863 \text{ TM } 7 \quad (3)$$

$$\text{TM Green} = -0.2848 \text{ TM } 1 - 0.2435 \text{ TM } 2 - 0.5436 \text{ TM } 3 + 0.7243 \text{ TM } 4 + 0.0840 \text{ TM } 5 - 0.1800 \text{ TM } 7 \quad (4)$$

$$\text{TM Moist} = 0.1509 \text{ TM } 1 + 0.1793 \text{ TM } 2 + 0.3299 \text{ TM } 3 + 0.3406 \text{ TM } 4 - 0.7112 \text{ TM } 5 - 0.4572 \text{ TM } 7 \quad (5)$$

Brightness is defined as the weighted sum of all the bands (TM band 1-5 and 7), in the direction of the principal variation in soil reflectance (Lillesand and Kiefer 2000). The greenness feature is a contrast between the visible and near infrared bands and is approximately orthogonal to the brightness feature. The moistness feature is sensitive to shadowing and leaf water content and has been found useful for forest applications. Franklin *et al.* (2000) found the moistness

component to be an important feature in detecting changes due to partial harvesting in eastern Canada (as cited in Wilson and Sader 2002).

Roy *et al.* (1991) used Landsat TM data and aerial photographs of the Baratang forest division of the Andaman group of islands for tropical forest type mapping and monitoring. Different digital enhancement techniques were evaluated for discriminating forest types and for the analysis of land-use practices to assess human impact. The Kauth-Thomas (K-T) transformation was found to contain the most useful information on forest types, but discrimination was improved when the K-T brightness and greenness indices were combined with PC 2.

According to Lu *et al.* (2003), the advantage of using the K-T transformation over PCA is that the coefficients of KT transform are less scene dependent than PCA coefficients, meaning they depend less on the land cover types present in a scene.

3.2.2 Change detection techniques

Change detection techniques selected for this research are presented in this section. They include image differencing of relatively calibrated data and data transforms (NDVI, PCA, KT), as well as post-classification map comparison. Classification or PCA of multi-date data are more complex. The former requires from-to training data, and the latter produces up to 12 PCs for Landsat TM data that are difficult to analyze for change information.

3.2.2.1 *Image differencing*

In image differencing the spatially registered images of time t_1 and t_2 are subtracted, pixel-by-pixel, resulting in a difference image representing change (Singh 1989). The difference image will consist of a distribution of change values with mean near zero, as the number of changed pixels is generally small in relation to the number of unchanged pixels in a given Landsat scene. The change distribution is usually 'thresholded' to distinguish significant change mostly results from major changes in land cover reflectance from natural image data variability, which is generally smaller given that the atmospheric, illumination and sensor conditions are closely matched. Changed land cover pixels lie towards the tails of the distribution. Defining a threshold is often subjective, requiring iterative visual analysis of various thresholds. The difference image can then be re-classified into classes of positive change, negative change, and no change or natural variability.

Image differencing is perhaps the most common change detection technique and has been used in a variety of geographical environments. For example, Singh (1984, 1986) used this technique for monitoring change due to shifting cultivation in a tropical forest environment. In 1998, Prakash and Gupta used differences and ratios of the spectral bands and NDVI to detect change in land use in the Jharia coalfield of India, and found that all the methods were equally good in detecting the changes in the study area. Young and Wang (2001) analyzed differences of NDVI to analyze ground cover change in China from 1982-1992 using AVHRR Pathfinder Landcover (PAL) data. NDVI

differencing indicated a decline in productivity in forest regions and an increase in agricultural regions.

3.2.2.2 Post-classification comparison

The objective of classification is to transform continuous data into categorical information classes describing the landscape that are meaningful in decision-making regarding the effective management of natural resources (Krishnan 2002). In post classification comparison, registered scenes from the two dates are classified independently. Then, the pixels with a change in classification are determined. Statistics and change maps can be compiled to express the specific nature of the changes between the dates of imagery (Lillesand and Kiefer 2000). This is one of the most common image change detection procedures. It can work better than image-based methods, especially if there are significant phenological differences between the two dates (Lunetta and Elvidge 1999). However, precise classification usually requires supervised methods where the quality and quantity of training sample data plays a crucial role (Lu et al. 2003). For historical image data classification, it is often difficult to select high-quality and sufficient training data for image classification.

Mas (1999) used Landsat Multi-Spectral Scanner (MSS) images for detecting areas of change in Terminos Lagoon, Mexico. Different change detection techniques such as raw image differencing, vegetation index differencing, post-classification comparison etc. were compared. It was found that the post-classification comparison produced the best accuracy and had an advantage in indicating the nature of change (from-to classes identified). Guild *et*

al. (2004) used multi-date Landsat TM data between 1984 and 1992 for the detection of deforestation and land conversion in Rondonia, Brazil. Maximum likelihood classification of multi-date KT, PC and KT difference images found that multi-date KT classification produced the highest accuracy of 0.78 (Kappa coefficient (Lillesand and Kiefer 2000)), and also discriminated pasture from cultivated areas.

Chapter 4

METHODOLOGY

4.1 Introduction

An important initial stage of this research was to identify a suitable study area that may exhibit significant vegetation change during the period of Landsat TM data availability (1986-2003) for the study area as a result of some of the factors discussed in Chapter 2. Other considerations included the area under forest cover, types of forests, data accessibility for the defined time period, season, minimum cloud cover, problems related to the rate of conversion of forests for different land uses, and above all the importance of the region in terms of bio-diversity.

Karnataka state, in the Western Ghats region was selected based on these criteria. An additional reason was that it is one of the bio-diversity hot-spot regions of the world (Menon and Bawa 1997; Shi 2003) where biodiversity is high and threatened and not much research has been done using different change detection techniques to monitor the rate of change of land cover in the area. Other regions such as NE India were also considered, but suitable data were not available.

4.2 Study area: Karnataka

4.2.1 Physical geography of Karnataka

Karnataka extends roughly between 11.5°–18.5° N and 74.0°–78.5° E (Figure 4.1). The state is bounded by Maharashtra and Goa states in the north

and northwest respectively; the Arabian Sea in the west; Kerala and Tamil Nadu in the south and Andhra Pradesh in the East. It extends approximately 760 km from North to South and about 420 km from West to East, and, covers an area of 191,791 km².

Figure 4.1 Location of Karnataka in India
(Note: Map is not to scale due to government controlled access to information)

Physiographically, the state is divided into three distinct regions of varied topography, namely: the Deccan plateau, hill ranges and coastal plains (Badrinath *et al.* 2002). Soil varies from clayey black in the northern part; red

sandy in the central and southern parts; red loamy, laterite and mountain soil in the Western Ghats, to mixed red and black soil in the Central parts of the state.

There are three main types of climates prevalent in the state. A tropical monsoon climate covers the entire coastal belt (Uttara Kannada and Dakshina Kannada) and adjoining areas. The northern part of the state has a hot, semi-arid, tropical steppe type of climate, whereas the southern part of the state is hot, with a seasonally dry tropical savanna climate. Further, the weather of the state also varies with seasons, as follows: winter (January-February), summer (March-May) with April and May as the hottest and driest months, southwest monsoon (June-September), and northeast monsoon (October-December). The state receives about 80% of its rainfall during the southwest monsoon period. The rainfall ranges from 562 to 4119 mm with an average rainfall of 3930 mm in the coastal region. The temperatures are more or less uniform for both day and night in the state ranging from 16°C to 45°C, except in the coastal region and high-elevation plateau. Thus, the variability in climate, soils and topography results in a wide variety of natural vegetation types in the state and they are primary factors affecting land use. Agricultural production is principally for local consumption, and culture and customs drive food types. Forestry products are for both local use and export.

The study area mainly consists of the Western Ghats mountain region extending from 13°30' to 15°23' N and 73°25' to 75°30' E, thus covering most of the Uttara Kannada district, and parts of Dharwad, Shimoga, and Dakshina Kannada (Figure 4.2 and 4.3). The Western Ghats is an ecologically sensitive

and biologically rich region and has been identified as a world bio-diversity hot spot (Menon and Bawa 1997; Shi et al. 2003).

4.2.2 Forests of Karnataka

Out of 191,791 km² of geographical area, the state forest department controls an area of 38,724 km² (20 %). These forests are classified as reserved (28,611 km²; 73.88%), protected (3,932 km²; 10.16 %), unclassified (5,748 km²; 15.96%), village (124 km²) and private (309 km²) (FSI 1999).

Figure 4.2 Forest cover map of Karnataka, 1999
(Source: Forest survey report (FSI), 1999)

Forest cover is very critical for Karnataka, especially from an environmental point of view, as 13,000 km² of the State spread over ten districts falls within the environmentally sensitive Western Ghats. The composition of the flora in the state changes with the level of precipitation. It comprises tropical wet evergreen, tropical semi-evergreen (15.15%), tropical moist deciduous (15.10%), tropical dry deciduous (18.99%), dry scrub and thorny forests (21.79%), and unwooded (28.97%) areas, with most forests situated in a belt running from north to south from Belgaum to Mysore in the western part of the state (FSI 1999; Forests of Karnataka 1999) (Figure 4.2).

Some of the most important tree species found in the evergreen forests are gurjun (*Dipterocarpus*), karimara (*Hopea Parviflora*), dhoopa (*Vateria indica*) (Reddy 1988), bamboo (*Bambusa arundinacia*) and canes. Semi-evergreen forests typically consist of a mixture of both wet evergreen and moist deciduous trees.

In moist deciduous forests the vegetation is mainly influenced by the southwestern monsoon, and corresponds to Champion and Seth's (1968) southern Indian Moist Deciduous Forest type, consisting of moist, teak-bearing forests, moist mixed deciduous forest without teak, and secondary moist mixed deciduous forests. Sal and teak, along with mango, bamboo and rosewood generally dominate the moist deciduous forests. The dry deciduous forests mainly comprise species of sal, varieties of acacia and bamboo. Further, due to reforestation projects, the state also has many plantation forests. The

plantations generally comprise fast growing species like eucalyptus, teak, acacia, etc.

4.2.3 Protected areas

A total of 0.64×10^6 ha constituting 3.34% of the geographic area of the state is protected. In addition, Karnataka has five national parks, namely: Bandipur, Aanshi, Kudremukh, Bannerghatta, and Nagarhole (Rajiv Gandhi national park) spreading over an area of 0.25×10^6 ha and 20 wildlife sanctuaries covering 0.39×10^6 ha (FSI 1999).

The study area of this research includes two of the protected areas in the state: Dandeli wildlife sanctuary and Aanshi national park, both located in Uttara Kannada. The Dandeli wildlife sanctuary covers an area of 834.16 km^2 . It is rich in both flora, especially bamboo, and fauna and consists of mainly moist deciduous and semi-evergreen forests. The Aanshi national park lies in an eco-sensitive part of the Western Ghats to the south of the Dandeli wildlife sanctuary and it covers 250 km^2 of area. The Aanshi National Park mainly consists of semi-evergreen and evergreen forests and is rich in rare species of flora and fauna.

4.2.4 Deforestation / degradation of forests in Karnataka: causes and impacts

The FSI publishes statistics on forest cover of the whole country every two years, but regional estimation for more recent periods is sparse. This is partly because of a lack of funds and the use of traditional methods, such as field

surveys at the state level, which require intensive labour and time. Further, there are various problems related to data availability for the forestry sector at both the regional and national levels, which have been already mentioned in Chapter 3, Section 3. 2.

Not much study has been done regarding estimation of change in forest cover for all of Karnataka State, but extensive research has been conducted on the assessment of bio-diversity and land use change in the Western Ghats region using remote sensing (Jha *et al.* 2000; Chattopadhyay 1985; Caratini *et al.* 1991; Gadgil 1996; Ramesh *et al.* 1997; Menon and Bawa 1997). Jha *et al.* (2000), to analyze deforestation and land use change in the Western Ghats region, compared satellite data from Landsat MSS (1973 image) and IRS 1B LISS-I (1995 image). They used supervised Maximum Likelihood (ML) classification along with an accuracy assessment of change classes undertaken by estimating errors of omission and commission. In their estimation of change in forest cover in the southern part of the Western Ghats between 1973 and 1995, they found a loss of 25.6% of forest cover. This estimation was considered to be the highest reported so far in this region using remote sensing data.

Chattopadhyay (1985) analyzed deforestation, its causes and related environmental problems from 1905 to 1973 in the southern sector of the Western Ghats (Kerala) using Landsat images and topographical maps. It was found that despite the reserved forest status, 29% of the legal forest area under government control was lost. The methodology used to analyze deforestation was not discussed in the paper other than reference to field survey and visual analysis.

Deforestation is quite prevalent in Karnataka, particularly on the seaward slopes of the Western Ghats. There are many causes of forest degradation in this region. The foremost is replacement of natural forest with monoculture plantations most commonly of acacia, teak and eucalyptus to fulfill commercial timber needs, as well as with tea, coffee and cardamon plantations. For instance, initially Mysore paper mills in Karnataka used bamboos and hardwood as a raw material. After depleting the forests nearby, the paper mills shifted to eucalyptus grown on farmlands. Finally, they took over the large areas of protected forests, marked to meet the biomass needs of the village population, for raising their own plantations to supply the raw material (Gadgil 1989; Reddy 1988), thereby leading to conflicts between village people and mill management. The other causes include organized smuggling of valuable timbers such as teak, rosewood, and sandalwood, forest fires, and collection of fuel-wood (Gadgil 1989; Reddy 1988) and fodder. Submergence of forests by reservoirs in the construction of hydroelectric dams is also a contributing factor (Reddy 1988). Forests are lost to direct flooding and as a result of secondary activities associated with dam construction such as road building, settlements, etc. that increase access and encroachment into formerly intact forests. For example, the major hydro projects, namely the Silent Valley Hydroelectric Project, and the Linganamakki project resulted in the loss of large tracts of forests. Mining is also one of the contributors to deforestation in the area. For example, extraction of iron in the Kudremukh national park in the Western Ghats has resulted in the loss of many fish species due to pollution, and a decline in the agricultural productivity

downstream because of the deposition of mine tailings (Drillbits and Tailings 2000). Further, isolated degraded forest patches are mostly cleared for cashew and rubber plantations (Reddy 1988).

Deforestation results in soil erosion, which is significant in the Western Ghats region due to heavy rainfall. Soil particles flow down the slopes in moving sheets of water, resulting in sheet erosion. This forms small gullies, which then grow, and result in the silting of reservoirs and rivers. Deforestation also leads to habitat destruction of some of the endangered species in the region, such as the tiger (*Panthera tigris*) and lion-tailed macaque (*Macaca silenus*).

To summarize, it can be seen that deforestation is caused by a combination of the above-mentioned factors, and one factor cannot be solely linked to this problem. The combined influence of pressures from increasing human and livestock populations, the development of the state and industry, along with government policies, has resulted in the present situation.

4.2.5 Reforestation and conservation practices

4.2.5.1 Joint Forest Management (JFM) and Karnataka

In general, reforestation and conservation practices have not involved local communities in the development and protection of forest resources. Hence, the state government introduced the Joint Forest Management (JFM) scheme in 1993 based on the National Forest Policy (1988) (which envisages people's involvement in the development and protection of forests) so that the local people can be actively involved in conservation, planning and protection of degraded

forests. Further, it was envisaged that the communities who would participate in the conservation practices would share the benefits, defined as a certain share of the timber harvest along with non-timber forest products, as specified by the State Forest Department (SFD) (FSI 1999). JFM generally covers degraded forestland where the canopy cover is 25 % and less, and non-forest government wastelands that are under the control of the Revenue department (Forest department, Government of Karnataka 1993).

Under the JFM scheme, local institutions such as Village Forest Committees (VFC's) have been developed, to involve people from rural areas in the protection of degraded forests, and to decrease the encroachment in forest lands for collecting fodder and fuel wood. According to the FSI (1999), presently 1,212 VFC's are managing a total area of 12,800 ha in the state.

4.3 Data acquisition

From previous studies on deforestation, it was found that Landsat could provide the best temporal data on forest cover due to its broad spatial coverage, pixel size of 30 m, frequent acquisition throughout the year (every 16 days), a long data archive, and high quality spectral information in seven bands (Tole 2000). Hence, Landsat data were used for this research instead of slightly higher resolution Indian Remote Sensing System (IRS) or SPOT data, which were much more costly.

The initial step of the change detection process is data acquisition followed by a number of pre-processing steps prior to data analysis. The main

goal in data acquisition is to minimize cloud and haze cover and maximize area coverage of high quality data. For image acquisition, less than 10 % cloud cover was used as a selection criterion. A Landsat 5 Thematic Mapper scene (01/04/1986) acquired from the National Remote Sensing Agency (NRSA), India and a Landsat 7 Enhanced Thematic Mapper scene (19/02/2003) acquired from the USGS (United States Geologic Survey) EROS Data Centre were used as the principal sources of data for change detection analyses. Both scenes were obtained as geometrically and radiometrically (i.e., systematically) corrected data products (i.e., still level-1 data) in GeoTIFF format. GeoTIFF⁹ is a format that enables referencing of a raster image to a known geodetic model or map projection. Also, by using this format, both metadata and image data can be encoded into the same file. Each spectral band of Landsat data in the GeoTIFF format is a greyscale of uncompressed, 8-bit unsigned integers. A level-1G (i.e., still level-1 data) product is a geometrically rectified product that is free from distortions especially related to the satellite platform (e.g., attitude deviations from normal), the sensor (e.g., jitter, view-angle effects), and global Earth characteristics (e.g., rotation, curvature). But distortions due to the Earth's terrain are still present, despite of geometric corrections (USGS 2000). On level-1G product, Radiometric correction is performed either by using gains computed on the fly by the internal calibrator or by using gains available in the calibrator parameter file (USGS 2000).

⁹ for more information on GeoTIFF, please refer to the World Wide Web:
<http://www.remotesensing.org/geotiff/geotiff.html>)

The 2003 scene was cloud free, while the 1986 scene had cloud cover in the upper left corner, with two major line losses. Due to the extremely limited availability of a cloud-free Landsat 5 scene for the specified time period (1980-1986) of the first scene, this scene with two line losses was accepted for use in the research. Further, the requirement of <10% cloud cover resulted in the two scenes being 1.5 months apart.

The time period from January – April was determined to be best for this study (Jain and Chaudhary 2002) because these months are more cloud-free than the monsoon season of June – December and vegetation is in full vigor. The period of April - July was not considered because it is very dry and results in drought stress, particularly in deciduous tree types.

The exact coverage of the scene is from 15.39° to 13.50° North latitude and 73.43° to 75.50° East longitude. Figure 4.3 shows the geographical extent of the Landsat coverage of the study area (Source: Atlas of Forest resources of India, 1976). These bounding coordinates result in images that are 6920P by 5680L (1986 image) and 7423P by 6966L (2003 image) given a pixel size of 30 x 30 m. Here, P refers to pixel and L to line. In all subsequent analysis, the 2003 scene was used as the reference.

All seven bands namely, Blue, Green, Red, near infrared (NIR), mid infrared 1 (MIR 1), thermal infrared (TIR), and mid infrared 2 (MIR 2), in .tiff format for both dates, were imported into PCI Geomatica format. All bands were

used in change detection analyses; they are described in Table 4.1 and are displayed in Appendix A and B.

Maps of 1:1,000,000 scale from the years 1988 and 1991, and published information about the land use/land cover in the study area (Karnataka) were used as secondary data sources.

Table 4.1 Landsat sensor system characteristics (TM and ETM+)

	Band	Wavelength (µm)	Nominal spectral location (µm)	Pixel size (m)	Principal applications
TM	1	0.45-0.52	Blue	30	Mapping of coastal water, discrimination of soil / vegetation, forest type mapping
ETM+		0.45-0.515			
TM	2	0.52-0.60	Green	30	Measure green reflectance peak of vegetation, cultural feature identification
ETM+		0.525-0.605			
TM	3	0.63-0.69	Red	30	Chlorophyll absorption band used for plant species differentiation
ETM+		0.63-0.69			
TM	4	0.76-0.90	NIR	30	Vegetation types, vigour and biomass content, for delineating water bodies, soil moisture discrimination
ETM+		0.75-0.90			
TM	5	1.55-1.75	mid-IR	30	Vegetation moisture content and soil moisture, differentiation of snow from clouds
ETM+		1.55-1.75			
TM	6	10.4-12.5	Thermal IR	120	Vegetation stress analysis, soil moisture discrimination and thermal mapping applications
ETM+		10.40-12.50		60	
TM	7	2.08-2.35	mid-IR	30	Discrimination of mineral and rock types, also sensitive to moisture content
ETM+		2.09-2.35			
ETM+	8	0.52-0.90	Pan	15	Black and white panchromatic image

(Source: Lillesand and Kiefer, 2000, p. 396)

4.4 Data pre-processing

The main objective of data pre-processing was to transform the acquired image data into a format from which accurate information related to the land cover could be extracted, by using different change detection analysis techniques.

Figure 4.3 Geographical extent of the Landsat coverage of Karnataka

(Source: Water Resources Development Atlas of India, 1996, National Atlas & Thematic Mapping Organisation, Plate 30, Karnataka)

NOTE: In the above Figure, 1 = Dandeli national park, 2 = Yellapur district.

In Figure 4.3 shades of green represent forest types varying from evergreen to deciduous and the red checkerboard symbol represents degraded forests.

4.4.1 Image-to-image registration

For change detection analysis using multi-temporal data, accurate geometric fidelity and alignment of data from each date are particularly important. As analysis is generally performed on a pixel-by-pixel basis, any misregistration greater than one pixel will lead to an anomaly in the temporal analysis result for that pixel (Lunetta and Elvidge 1999). Thus, to overcome this problem, the root mean square (RMS) error of image alignment should not exceed 0.5 pixels (Lunetta and Elvidge 1999).

To align the 1986 scene to the 2003 scene, the first step was to collect ground control points (GCPs) common to both scenes. It has been found from different studies that GCPs that are distributed evenly across the scene are able to correct non-systematic errors, which result from altitude and attitude variations of the sensor platform (Lillesand and Kiefer 2000). Image-to-image registration was done using PCI Inc. GCP Works software. Eleven GCPs were located at well defined and easy to recognize points, such as road intersections, bridges, etc. on both the reference (2003) and unaligned data (1986). Table 4.2 lists the coordinates of the GCPs. A second-order polynomial transformation was performed requiring a minimum of six GCPs. Mathematically the polynomial transformation describes how the uncorrected scene will be warped so that it can fit over the georeferenced scene (PCI 2000). Nearest-neighbour (NN)

resampling was used to determine the appropriate grey level in the new aligned 1986 image from the closest pixel to the specified coordinates.

Table 4.2 Location of ground control points and errors in image-to-image registration

ID #	Residual (pixels)		2003 (UTM 43P E012)		1986 Uncorrected	
GCP	X	Y	X (Eastings)	Y (Northings)	X Column	Y Line
1	0.01	-0.01	464310.000	1686510.000	4614.50	5625.50
2	0.01	-0.02	476458.125	1623466.875	4701.56	3518.06
3	0.03	-0.05	517726.875	1574255.625	5819.81	1717.06
4	-0.04	0.07	491366.250	1578071.250	4967.88	1970.38
5	0.01	-0.02	501999.375	1663231.875	5743.31	4684.69
6	0.02	-0.03	458041.875	1577390.625	3864.44	2111.69
7	-0.00	0.00	428786.250	1521281.250	2620.38	432.88
8	0.00	-0.01	525918.750	1523021.250	5835.63	13.88
9	-0.02	0.04	495146.250	1668281.250	5541.63	4882.13
10	-0.01	0.02	444116.250	1645511.250	3743.75	4392.25
11	-0.01	0.02	538067.813	1553948.438	6391.81	959.06

The overall root mean square (RMS) error of the control point transformation was less than ½ a pixel, i.e., RMS of 0.23 and 0.32 pixels for the 'x' and 'y' directions, respectively.

4.4.2 Generation of a subset image

A subset for the study area was created from the original scene coverage, that covered the northern part of Karnataka, including the Western Ghats region comprising mainly Uttara Kannada, parts of Dharwad, Shimoga and Dakshina Kannada districts. This was done primarily to decrease file sizes which totaled 118 Mbytes for each date. Also, during later image analysis, it was found that background values, including black areas surrounding each image, were being processed by the analysis algorithms and had a significant impact on the results. The subset image covered approximately 102 km x 157 km.

4.4.3 Image Calibration

Of the various requirements of pre-processing for change detection, radiometric and atmospheric corrections along with image-to-image registration play an important part (Lu et al. 2003). For quantitative analysis of multi-temporal images, the data distributions of one scene must be matched to the other scene to avoid false detection of change due to overall brightness differences between scenes. Calibration can be absolute, where each image is individually converted to reflectance using first a sensor calibration function to derive at-sensor radiance, followed by an atmospheric correction combined with measured or modelled solar irradiance on the surface to derive surface reflectance. Simpler methods of relative calibration attempt to match the data distribution of each spectral band in one date to that of the corresponding spectral band of the other date (Lu et al. 2003).

For this research, a relative calibration method was conducted using the CALIBRATE module in IDRISI. Each spectral band for 1986 (x) was regressed on the corresponding spectral band for 2003 (y, selected as the reference data because of its superior image quality over TM data). The whole scene was used as it was difficult to visually identify invariant bright and dark targets. Use of the whole scene assumes that temporal land cover change is small with respect to overall brightness change due to atmosphere and sensor differences. Following regression, the 1986 image was adjusted to match the reference image by applying the resulting regression equation to each of the 1986 pixel values. The output 1986 bands typically had means and standard deviations very similar to

their corresponding 2003 bands. In subsequent change analysis, these relatively calibrated transformed 1986 data were used with the reference data (2003).

4.5 Change detection methods used in the research

Methods summarized in Chapter-3, such as image differencing, and post-classification comparison of raw and transformed data have been the most commonly applied in studies related to forest change cover analysis. Hence, they were adopted in this research using the Landsat data for analysis of forest change in the Karnataka region of India.

4.5.1 Temporal analysis using transformed data

The selected change analysis techniques were implemented using relatively calibrated and transformed spectral data. The most common image transformations applied for temporal analysis of vegetation are 'vegetation indices'. They are mathematical combinations of spectral bands that enhance vegetation versus other land cover types. Two types of vegetation gradient images were created, NDVI, KT vegetation indices, as described in Chapter 3, and PCA. For all transformations representing vegetation gradients, the term 'vegetation index' is applied hereafter. Below are specific details related to each method.

4.5.1.1 NDVI vegetation index

The calibrated 1986 data and the 2003 data were used to create NDVI images using their respective red and near infrared (NIR) bands. The 1986 NDVI image was then subtracted from the 2003 NDVI image to create an NDVI

difference image. From the distribution of values in the NDVI difference image, z-scores were calculated and classified into six categories: < -2 std. dev., -2 to -1 std. dev., -1 std. dev. to mean, mean to $+1$ std. dev., $+1$ to $+2$ std. dev., and $> +2$ std. dev. Here, < -2 std. dev. indicated a significant change in the negative direction (vegetation loss) and $> +2$ std. dev. indicated significant change in the positive direction (vegetation gain). Data beyond these thresholds represented 5% of all the NDVI difference pixels. Between the two thresholds, pixels were assumed to have not changed significantly. Use of 2 standard deviations as a threshold for significant change in a difference image was determined based on visual analysis of images created from tests of several thresholds. Rogan et al. (2002) used 1.5 standard deviations as a threshold in difference images, whereas Young and Wang (2001) used 2-3 standard deviation as moderate change and > 3 standard deviations as extreme change for NDVI difference images to analyze land cover change in China from 1982-1992. Here it was found that -2 , $+2$ standard deviations provided the best distinction between slight-moderate vegetation changes and moderate-extreme changes.

The resulting classified colour image was analyzed visually in comparison to the raw images to identify the changes in land cover that resulted in vegetation loss or gain. Further, to show the direction and the magnitude of the changed pixels only, two binary threshold images were created showing only areas of < -2 std. dev and $> +2$ std. dev. During the above processes, it became apparent that the NDVI difference images detected changes in vegetation that were more subtle than those in the extreme tails of the distribution.

From the NDVI difference analysis, vegetation change was detected but it was not possible to distinguish forest change from other vegetation change. To produce deforestation and reforestation maps the following procedure was carried out. Binary maps were produced for forest and non-forest for each date from the classification methods described in Section 4.4.1.4. They were overlaid using a logical AND operation with the NDVI vegetation loss and gain binary maps to produce deforestation and reforestation maps. For deforestation, the binary map from 1986 showing forest was overlaid with the NDVI vegetation loss map. Areas that were classified as forest in 1986 AND that exhibited vegetation loss were taken to be 'deforested' during the 1986-2003 period. For reforestation, the binary map showing forest from 2003 was overlaid with the NDVI vegetation gain map. Areas that were forest in 2003 AND that exhibited vegetation gain over the 17-year period were taken to be 'reforested'.

4.5.1.2 Principal component analysis (PCA)

PCA can be done using either unstandardized or standardized data to create the components. In an unstandardized PCA, the variance-covariance matrix is used and the bands with higher variability contribute more to the new principal component images. In a standardized PCA, the correlation matrix is used and all the bands have equal weight in creating the new components (Singh and Harrison 1985). For analysis of land cover change using multi-temporal datasets, standardized PCA generally produces more useful components than the unstandardized option (Young and Wang 2001). Hence, this method was used in this study.

Principal component analysis was conducted on each Landsat scene using IDRISI software. Each scene contained six spectral bands (blue, green, red, NIR, and two mid Infrared) and therefore six components, or eigenchannels, of 16-bit were extracted. PCA was also conducted using the thermal band with the other six bands. The two PCA's were then compared and it was found that the results were very similar, as there was not much difference between the variance of components. Therefore, PCA without the thermal band was used in all subsequent analyses.

Each principal component was displayed individually as a greyscale image. Various colour composites were generated using the original bands and principal components to highlight land cover features. In addition, a matrix of factor loadings was constructed, using the correlation coefficients between the six new components and the original six bands for both scenes. The combination of visual and factor loading analysis was used to interpret the gradient represented by each component from each date.

The components that exhibited vegetation gradients were used in image difference change analysis using the same methods described above for NDVI difference images. Results from the PCA and NDVI analyses were compared to determine which is better in detecting vegetation loss and gain in the study area.

4.5.1.3 Kauth-Thomas Tasselled Cap transformation

The Kauth-Thomas Tasselled Cap transformation was applied to the Landsat data from both dates using IDRISI software to produce the brightness,

greenness and moistness images. Image differencing was performed using each of these indices. Different visual enhancement techniques were also tested on these images for analysis of land cover types and changes.

4.5.1.4 Post classification comparison

In this research, a comparison of supervised Maximum Likelihood (ML) classification maps for the 1986 and 2003 Landsat scenes was conducted. Different combinations of spectral bands and transformations were tested as inputs to the classification to see if accuracy varied. First, all the spectral bands were used as input and a second classification was done using NDVI, PC 2 and the K-T greenness index as input. Other arbitrary combinations of bands and transformed data were also tested. Training data were selected to produce three classes: water; forest representing all natural forests and plantations; and non-forest including bare soil, urban and agriculture. Training polygons were delineated for each class based on visual interpretation. Examples are shown in Figure 4.4 and Figure 4.5, where the image is displayed using MIR, NIR and red bands, i.e, 5, 4, 3 combination (False colour composite) as RGB.

Figure 4.4 Example training polygons at full resolution for all classes (1986)

Figure 4.5 Example training polygons at full resolution for all classes (2003)

Note that topographic variations in image brightness are evident in Figure 4.5 for the forest class. Slopes facing away from the sun were darker than slopes facing towards the sun for this and the non-forest class. Training data had to be selected to represent the range of brightness for each class, as correction for these topographic effects was not conducted. Different standard deviation threshold values for the training data distributions were tested ranging from 1.00 to 3.00 to see the impact on accuracy. Finally, the best two resultant thematic maps for each date were produced. These maps were cross-tabulated with one another in IDRISI, to analyze the changes that occurred over the seventeen year time period, with respect to the forest and non-forest classes.

4.6 Temporal change validation

Due to the lack of field data, validation was conducted by visually identifying areas of known forest change or no-change in magnified displays of the CIR composites. The change detection results were compared for these areas to determine which method performed best at detecting vegetation gain and loss and which methods were susceptible to identification of vegetation change when none had occurred. In this way, for the change class, errors of omission (detection of no-change when change had occurred) and errors of commission (detection of change when no change had occurred) were identified and compared between methods. The 1:1,000,000 map accessed from the water resource development atlas (Water Resources development Atlas of India, 1996) aided this process.

Chapter 5

RESULTS

5.1 Introduction

This study deals with the digital interpretation of Landsat TM and ETM+ images from two different years, 1986 and 2003, to analyze the forest change that occurred within the study area during the seventeen year time period. Two change detection techniques, image differencing using raw and transformed data and post-classification comparison, were performed on the subset area of the scene. Binary change/no-change maps were created using NDVI (found to be the best images differencing method as shown in 5.2) and maximum likelihood thematic maps were prepared for each date using three classes, water, forest and non-forest. Cross tabulation of the thematic maps was conducted to inventory the area that had changed from forest to non-forest and vice versa. Finally, deforestation and reforestation maps were produced using an overlay operation applied to the classified maps and the NDVI vegetation loss and gain maps. The NDVI difference maps and the post-classification binary maps were compared to see which method is better in identifying the change.

5.2 Visual analysis of Imagery

Colour infrared (CIR) and natural colour composites were created using different spectral bands (Figures 5.1 and 5.2). A colour infrared composite assigns the NIR, R and G bands to the R, G, and B display colours, respectively. The study area has natural forests, plantations, urban and rural settlements, agricultural fields, bare soil, rivers and reservoirs, etc. Moderate vegetation

cover dominates the eastern portion of the study area while coastal hills are heavily vegetated. In Figures 5.1 a,b deep red generally corresponds to reserved forests (Source: Water Resources Development Atlas of India, 1996, National Atlas & Thematic Mapping Organisation, Plate 30, Karnataka). Gross changes in vegetation can be seen when comparing the two dates, as shown for example in rectangles, 1 and 2).

a) 1986

b) 2003

Figure 5.1 Colour infrared (CIR) composite

a) 1986

b) 2003

Figure 5.2 Natural colour composite

The mean and standard deviations of each of the six raw spectral bands for both Landsat images, 1986 (calibrated) and 2003, were calculated (Table 5.1).

Table 5.1 Mean and standard deviations of six Landsat bands.

Band	Mean (DN)			Std. dev. (DN)		
	1986 (original)	1986 (calibrated)	2003	1986 (original)	1986(calibrated)	2003
Blue	83.69	74.25	74.26	8.63	4.56	6.72
Green	37.69	54.44	54.44	8.0	7.24	8.63
Red	41.56	48.72	48.77	17.22	15.04	17.2
NIR	59.01	47.4	47.36	29.74	22.08	23.34
Mid-infrared 1	80.09	64.2	64.23	54.32	39.14	42.64
Mid-infrared 2	37.54	39.48	39.51	29.66	26.41	29.4

As evident in Table 5.1 the relative calibration procedure matched the overall band means well, while the standard deviations of the 1986 data were slightly lower than those for the 2003 data. The means represent mixtures of the primary land covers: water, vegetation, and bare soil. The Blue band in 1986 and 2003 had a noticeably higher mean brightness, i.e., 74 DN as compared to the other bands, which may be due to the proximity of the study area to the Arabian Sea, the presence of other water bodies, such as rivers, reservoirs etc., and atmospheric haze.

5.3 Image difference analysis

Image differencing of calibrated spectral bands, NDVI, the first two principal components, and the Kauth-Thomas Tasseled Cap greenness and moistness indices were conducted to analyze vegetation change from 1986 to 2003. The following subsections present: 1. Results for each method for the

whole subset scene, 2. zoomed in examples comparing methods to determine which is best for change detection band differencing

5.3.1 Calibrated spectral band differencing

The image differencing was performed on all the relatively calibrated spectral bands (see Appendix C). The difference images were analyzed visually to see the changes, but were not used to create binary maps.

5.3.2 NDVI differencing

NDVI images for each year are given in Appendix B. The NDVI difference image (see Appendix C) shows negative values indicating decreases in vegetation, i.e., darker tones, while positive values indicate increases in vegetation, as bright tones (see arrows in Figure 5.3).

Figure 5.3 NDVI difference image

The binary change / no-change images were produced for vegetation loss and gain in the study area using different thresholds. Figure 5.4 shows the change/no-change maps for a threshold of -2 and $+2$ standard deviations.

a) Vegetation gain

b) Vegetation loss

■ No change ■ Change

Figure 5.4 Binary change/no change NDVI map

5.3.3 Principal component analysis (PCA)

PCA results are given in Table 5.2 and Table 5.3. The resulting PC images were output in 16-bit format. From Table 5.2, it can be seen that together PC 1 and PC 2 contain almost all the data variance, 94.52 % (1986) and 94.99 % (2003). The third component (PC 3) accounted for only 3.83 % (1986) and 3.56 % (2003) of the variance. PCs 4-6 were mostly composed of noise, and hence were not considered for further analysis.

Table 5.2 Percent variance contributed by each eigenvector

PC	1986 % variance	2003 % variance
PC 1	76.15	67.71
PC 2	18.37	27.28
PC 3	3.83	3.56
PC 4	1.06	1.03
PC 5	0.41	0.28
PC 6	0.18	0.13

Figure 5.5 shows the first component in 2003 as an example. Full images for all PCs for each date are given in Appendix B. In PC 1, water appears black, with pixel brightness values in the 1986 image ranging from 74 DN, in the Arabian Sea, to 150 DN in the reservoirs, especially in the Linganamakki reservoir, and from 63 to 83 DN in 2003 image (the values in 2003 are pretty homogeneous both in the Sea and in the reservoirs). The forested areas in the study region appear dark grey with pixel values ranging from 93 to 121 DN in 1986 and 88 to 139 DN in 2003.

Figure 5.5 Image of PC 1, 2003

The non-forest areas, which include urban, agriculture and bare soil, appeared from light grey to white, ranging in brightness from 159 to 249 DN in the 1986 image and 191 to 301 DN in the 2003 image.

Table 5.3 Factor loadings derived from PCs and original spectral bands
a) 1986

		Components					
Spectral Bands		PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
	Blue	0.73	-0.64	-0.15	-0.16	-0.00	-0.00
	Green	0.94	-0.20	-0.18	0.15	-0.07	-0.00
	Red	0.98	-0.12	0.02	0.07	0.13	-0.00
	NIR	0.60	0.74	-0.26	-0.06	0.01	0.02
	Mid-IR 1	0.94	0.27	0.18	-0.04	-0.03	-0.02
	Mid-IR 2	0.96	0.07	0.25	-0.02	-0.03	0.02

b) 2003

		Components					
Spectral Bands		PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
	Blue	0.34	-0.92	-0.10	-0.15	0.01	-0.00
	Green	0.91	-0.28	-0.23	0.12	-0.06	0.00
	Red	0.97	-0.16	0.04	0.08	0.10	-0.01
	NIR	0.55	0.78	-0.27	-0.09	0.02	0.01
	Mid-IR 1	0.94	0.26	0.15	-0.06	-0.03	-0.05
	Mid-IR 2	0.97	0.05	0.21	-0.03	-0.02	0.06

Hence, it seems after visually analyzing the images that this component exhibits a brightness gradient related to the overall reflectance across the blue-mid-infrared spectrum of these cover types, with water having generally low reflectance, vegetation moderate reflectance (low in visible, high in NIR, MIR) and bare/urban with high reflectance over these wavelengths. This was confirmed from the factor loadings (Table 5.3 a,b), which generally show equal and high correlations of the spectral bands with PC 1. However, the NIR band and the blue band are less related to PC 1 in the 2003 scene.

The second component shows forest areas very bright compared to non-forest areas, while water is black. This can also be seen from the zoomed in view of forest and non-forest areas in PC2 (2003) as compared to a CIR image (Figure 5.6). The NIR band has high positive correlation, while the visible bands are negatively correlated with PC 2. These correlations follow standard vegetation reflectance gradients with brightness in the respective bands.

As vegetation increases, NIR and Mid IR reflectance increases while visible blue and red reflectance decreases, although the red correlation is low. Hence, this PC represents a vegetation gradient. PC 3 has some information, but represents little of the total data variance. There is a low to moderate correlation between PC 3 and some of the spectral bands. PC 3 increases as mid infrared brightness increases and as NIR and green brightness decrease. Therefore, it seems to be a moisture gradient, where dry areas are brighter compared to water bodies and wetter areas.

Figure 5.6 Zoomed in examples of vegetation and non-vegetation in CIR and PC 2 (2003)

PC 4 to PC 6 images mainly comprise noise with very little information related to the total data variance ($< 5\%$ of the total variance in each of these PCs). Therefore, only the first three components were used for further analysis.

Since the second component shows a strong vegetation gradient, it was used instead of the NIR band to form a colour infrared (CIR) composite image in order to clearly show the variation in brightness values of the vegetation across the image. Both CIR composites are presented side-by-side in Figure 5.7 showing examples of vegetation and non-vegetation areas from 2003 image.

PC 2 enhances vegetation gradients and for change detection analysis, it provided clear images of the spatial distribution of vegetation that can be used for difference analysis and classification.

Figure 5.7 Zoomed in example of CIR composites of vegetation and non-vegetation (2003)

PC 2 (vegetation gradient) was further used for image differencing, so that the resulting PC 2 difference image could be compared to NDVI and KT-G difference images to see which one is better in detecting change over a period of time. The PC 2 difference images were thresholded using $-2/+2$ std. dev. and binary maps showing the vegetation loss (Figure 5.14 b) and gain (Figure 5.15 e) were created.

5.3.4 Kauth-Thomas (K-T) image analysis

The Kauth-Thomas transformation was performed independently using images from both years. The combination of K-T greenness, brightness and moistness was used to create enhanced images for both 1986 and 2003. It can

be seen from Figure 5.8 that the areas undergoing vegetation loss around the reservoir were enhanced in blue.

Figure 5.8 Kauth-Thomas Tasseled Cap transformation enhancement

Further, image differencing was performed using KT greenness and moistness components (Appendix C). The images were thresholded using $-2/+2$ std. dev. and binary maps showing vegetation loss and gain were created (Figure 5.9 and 5.10).

Figure 5.9 KT greenness binary maps showing change / no change from 1986 to 2003

a) Gain **b) Loss**

No change **Change**

Figure 5.10 KT moistness binary maps showing change/no change from 1986 to 2003

5.3.5 Comparison of image difference methods for vegetation change detection

Comparison of K-T greenness to PC 2 and NDVI can be seen in Figure 5.11. It can be seen that the agricultural fields (see arrows in Figure 5.11) can be more clearly identified in PC 2 compared to NDVI and K-T greenness, in both the 1986 and 2003 images.

The KT moistness image was compared to PC 3 as presented in Figure 5.12 showing examples of different areas. From visual analysis, PC 3 is inversely related to KT moistness. As for KT greenness, KT moistness was able to enhance the boundaries of agricultural fields (see rectangles in Figure 5.12) more sharply than PC 3.

Figure 5.11 Comparison of K-T greenness to PC 2 and NDVI

Figure 5.12 Comparison of K-T wetness to PC 3

Further to analyze the changes in the study area NDVI, PC 2 and KT-G difference images were compared (Figure 5.13, 5.14 and 5.15). After conducting extensive tests on the images for areas of change, three examples of vegetation loss and gain were used to compare these change detection techniques (Figure 5.16 and 5.17).

INDEX FOR THE COLOUR MAPS OF NDVI, PC 2 AND KT-G

INDEX FOR THE BINARY MAPS

a) NDVI

b) PC 2

Figure 5.13 Comparison of NDVI, PC 2 and KT-G differences (2003-1986) using colour maps of 6 classes showing whole image

c) KT-G
Figure 5.13 (contd')

a) NDVI vegetation loss map

b) PC 2 vegetation loss map

Figure 5.14 Comparison of NDVI, PC 2 and KT-G using binary maps showing vegetation loss

c) KT-G vegetation loss map
Figure 5.14 (contd')

d) NDVI vegetation gain map

e) PC 2 vegetation gain map

Figure 5.15 Comparison of NDVI, PC 2 and KT-G using binary maps showing vegetation gain

f) KT-G vegetation gain map
Figure 5.15 (contd')

Figure 5.16 Zoomed in examples for vegetation loss showing the comparison of NDVI, PC 2 and KT-G using colour maps with six classes and binary maps

Figure 5.16 EXAMPLE 2 (contd')

Figure 5.16 EXAMPLE 3 (contd')

Figure 5.17 Zoomed in examples for vegetation gain showing the comparison of NDVI, PC 2 and KT-G using colour maps with 6 classes and binary maps.

Figure 5.17 EXAMPLE 2 (contd')

Figure 5.17 EXAMPLE 3 (contd')

From the examples showing vegetation loss and gain, it was found that all the techniques were equally good at detecting change but NDVI and KT-G differences were slightly better than PC 2 in detecting vegetation loss around reservoirs. KT-G detected the change in coastline (i.e., change from water to bare) as a change in greenness (see Example 1, Figure 5.16), which is an error of commission while NDVI and PC-2 were correct in not identifying this area as vegetation change. Also, for vegetation gain, the NDVI difference image faired slightly better than the KT-G difference image (see Example 2, Figure 5.17). Hence, the NDVI difference image was used for further analysis instead of the KT-G difference image.

5.3.6 Production of deforestation and reforestation maps from image difference vegetation change maps

To classify the detected vegetation changes as deforestation and reforestation, binary forest / non-forest maps created using classification as described in Section 5.4 were overlaid with the NDVI vegetation change maps showing changes beyond -2s (deforestation) or +2s (reforestation). Figure 5.18 a and b show these respective maps. The area of deforestation shown in Figure. 5.18a, is 23,157.63 ha, while the area of reforestation shown in Figure. 5.18b, is 53,412.3 ha.

Figure 5.18 Deforestation and reforestation maps from NDVI difference analysis

5.4 Post-classification comparison analysis

The second method of temporal analysis was post classification comparison where maps of forest and non-forest from each date were cross tabulated to show areas of forest gain and loss. The training pixel statistics (Table 5.4 a,b) showed higher mean NIR and lower red values for forest than for non-forest cover in the 1986 and 2003 images, respectively.

Table 5.4 Training pixel statistics

(a) 1986 image

Types	Bands	Mean	Standard deviation
Forest	Red	38.21	1.92
	NIR	70.65	9.17
Non-forest	Red	88.93	16.07
	NIR	67.29	13.50

(b) 2003 image

Types	Bands	Mean	Standard deviation
Forest	Red	36.76	2.36
	NIR	71.57	14.62
Non-forest	Red	84.51	21.59
	NIR	55.99	12.30

The two classifications: A) using spectral bands as input B) using NDVI, PC 2 and KT-G as input are compared using examples (Figure 5.19 to 5.22). It is clearly visible that the classification using NDVI, K-T greenness and PC 2 as inputs enhances the features more, for example the coastline in the upper left of the 1986 image (see a in Figure 5.20, Example 1). The agricultural areas were also more enhanced (see b, in Figure 5.20, Example 2) although linear features

like bridges (see d in Figure 5.22, Example 2) on the rivers were more clearly seen in the classification using spectral bands as input.

Figure 5.19 Comparison of supervised classification maps (1986): A. using all spectral bands; B. using KT greenness, PC2, and NDVI.

Figure 5.20 Zoomed in examples showing comparison of supervised classification (SC) maps (1986)

Figure 5.21 Comparison of supervised classification maps (2003): A2. using all spectral bands; B2. using K-T greenness, PC 2, and NDVI

Figure 5.22 Zoomed in examples showing comparison of supervised classification (SC) maps (2003)

The band means for the training data for the water, non-forest and forest classes were highly different. The accuracies for the training data were > 99.7% for both the 2003 and 1986 scenes. Training accuracies for simple and distinct classes such as these (forest, non-forest and water) are expected to be very high. In 2003 scene, out of 401,856 training pixels for 'water', 99.9% were classified water, while 0.09% were classified as forest and 0.01% as non-forest when the spectral bands were used as input. The reason for misclassifications may be mixed pixels especially near the coast, where paddy fields are in abundance, that were selected as training pixels for the water class. In the forest class, out of 8,136 pixels, 99.78% were classified as forest but 0.22% were classified into the non-forest class.

The forest class generally represents natural forests and plantations (monoculture and mixed), while the non-forest class includes agricultural areas such as bare soil (dry and moist), and urban settlements. Hence, many pixels were mixed and there might be a possibility of error while training the classes. As a result, some of the forest training pixels were classified into the non-forest class. Also, the reflectance of some agricultural fields and forest was quite similar, thereby increasing the chance of error.

For the classification using NDVI, K-T greenness and PC-2 as input the average accuracy went up slightly, i.e., 99.99% as compared to the first classification where average accuracy was 99.89%. Also based on examples used to show the comparison of two classifications i.e., a) using spectral bands as input and b) using NDVI, K-T greenness and PC 2 as input (Figures 5.19 to

5.22); the supervised classification using NDVI, PC 2, and KT-G was judged to have performed better.

Cross-tabulation of the thematic maps resulted in an assessment of amounts of change and no-change as shown in Table 5.5. In Table 5.5a, 198,866 pixels that were classified as forest in 1986 were classified as non-forest in 2003, thus accounting for 1.1% of the total image. On the other hand, 2,109,148 pixels that had been non-forest in 1986 were classified as forest in the 2003 image, accounting for roughly 11.8% of the total image. Approximately 87.1% of the image was unchanged, whereas results obtained from the classification using NDVI, K-T greenness, and PC 2 as input (Table 5.5b), indicate that 10.5% of non-forest changed into forest and 1.6% of forest changed to non-forest. Hence the results from two classifications indicate that there has been a gain in vegetation, which might be due to reforestation projects in the state. (Note: The water and non-forest classes were combined together and named as non-forest class for cross tabulation results.

Table 5.5 Cross tabulation results of the 2003 and 1986 thematic maps

(a) Classification using spectral bands

1986				
2003		Non-Forest (1)	Forest (2)	Total
	Non-Forest (1)	9979210	<u>198866</u>	10178076
	Forest (2)	<u>2109148</u>	5521976	7631124
	Total	12088358	5720842	17809200

(b) Classification using NDVI, PC 2 and KT-

1986				
2003		Non-Forest (1)	Forest (2)	Total
	Non-Forest (1)	9288976	<u>295604</u>	9584580
	Forest (2)	<u>1865703</u>	6358917	8224620
	Total	11154679	6654521	17809200

There is likely a possibility of exaggeration of gain in forest cover due to the inclusion of water pixels depicting the Arabian Sea. If this area were masked, the results would be more accurate in showing vegetation gain.

Further, the thematic maps were cross-tabulated using an IDRISI algorithm to produce maps showing changes between classes. The two classifications (Figure 5.24): A) cross tabulation of classification with spectral bands as inputs, B) cross-tabulation of classification using the NDVI, PC 2 and KT-G as inputs; were compared to see which one is better (Figure 5.25). In Example 1 (Figure 5.25), it can be noted that the classification using spectral bands was not able to completely identify the changes from 1986 to 2003 caused by the submergence of the forest area by the reservoir. In the second example (Figure 5.25), the classification using NDVI, PC 2 and KT-G as inputs was able to identify changes along and near the coastline more accurately, as compared to the classification using spectral bands as input. Therefore the results indicated that classification B (using NDVI, PC 2 and KT-G as input) was visually more representative of the two major land cover classes (forest and non-forest) , so it was used for further analyses.

a) 1986

b) 2003

Figure 5.23 Colour infrared image

Figure 5.24 Comparison of cross tabulation of 1986 and 2003 forest cover maps: (A) cross-tabulation of classification using spectral bands as input; (B) cross-tabulation of classification using the NDVI, PC 2 and KT-G as input.

Figure 5.25 Examples showing change from forest to non-forest using zoomed in areas from Figure 5.24 (A) and (B)

Figure 5.25 (contd') Example showing change from non-forest to forest

Finally image differencing was performed on the post-classification maps. In the post classification image differencing map, values of 1 (non forest in 2003 (2) – forest in 1986 (1)) represent deforestation, while values of –1 (1 (forest, 2003) – 2 (non forest, 1986)) represent reforestation. These are shown as binary maps in Figure 5.26.

b) Deforestation map

Change

No change

a) Reforestation map

Figure 5.26 Binary maps of post classification comparison

5.5 Comparison of deforestation and reforestation maps from NDVI difference and post-classification

NDVI deforestation and reforestation maps were compared with post-classification binary maps to see which one is better in detecting change (See Figure 5.27 and Figure 5.28). The NDVI deforestation map showed that 23,157.63 ha of area changed over a period of 17 years, as compared to area estimates by the post-classification deforestation map where 26,604.36 ha changed from forest to non-forest. The area of reforestation shown in the NDVI map was 53,412.3 ha, as compared to the post-classification map, which estimated a change of 167,913.27 ha from non-forest to forest. Further, from visual analysis (see rectangular area in Figure 5.27, Example 1) it was found that post-classification was better in identifying deforestation as compared to NDVI maps, which sometimes identified no change areas over a period of 17 years as deforestation (error of commission). In a second example (Figure 5.27) it can be noted that the NDVI differencing binary map is showing the agricultural changes over a period of 17 years as deforestation as compared to the post classification binary maps, which correctly showed no forest change in these areas. The remaining forest and non-forest areas of the image were extensively evaluated in a similar manner to compare the capabilities of the methods to detect reforestation. It was found that both methods performed equally well, although in some areas (see Example 2, Figure 5.28) post classification was able to capture reforestation on shaded slopes better than NDVI differencing.

EXAMPLE 1: (deforestation)

a) 1986 CIR image

b) 2003 CIR image

c) NDVI binary map

d) Post-classification binary map

EXAMPLE 2:

a) CIR 1986 image

b) CIR 2003 image

c) NDVI binary map

d) Post classification map

Figure 5.27 Comparison of deforestation maps from NDVI difference and post-classification

EXAMPLE 1: (reforestation)

Figure 5.28 Comparison of reforestation maps from NDVI difference and post-classification

EXAMPLE 2:

Figure 5.28 (contd')

Besides errors of omission and commission presented above, the KT-G difference method was also susceptible to errors of commission as shown previously for the coastline in Figure 5.16, Example 1. Hence it was deemed to not perform as well as either NDVI differencing or post-classification comparison. NDVI differencing, in turn, falsely identified some deforestation and reforestation changes that the post-classification method did not. (Figures 5.27 and 5.28). In Figure 5.27, Example 1 (see arrow), the NDVI deforestation map is showing errors of commission. The area near the river remains unchanged over a period of 17 years, whereas the NDVI difference method is identifying it as deforestation. Thus it was concluded that post-classification comparison performed better than NDVI differencing.

5.6 Conclusion

Two change detection techniques were used for the research: 1. image differencing of raw and transformed data (NDVI, PC 2, KT) and 2. post-classification comparison. For image differencing, the image was tested extensively using examples for forest loss and gain. As NDVI differencing performed better than PC 2 and KT-G differencing, it was used for further analysis to create deforestation and reforestation maps. The comparison of NDVI difference and post-classification deforestation and reforestation maps showed that post-classification was better in detecting change over a period of 17 year time period, so it was taken to be the best method of all those compared.

Chapter 6

DISCUSSION

6.1 Introduction

There were two objectives for this research. The first was to conduct a historical review of change in forest cover in India from 1986 to 2003, the causes of it, along with the change in forest policies and status of forest management. The second objective was to evaluate how useful are data acquired from the Landsat sensor(s) Enhanced Thematic Mapper (L-7 ETM+) and Thematic Mapper (L-5 TM) in monitoring the change in forest cover from 1986 to 2003 in Karnataka using different change detection techniques. This was conducted using visual interpretation, in the absence of field data or data from other sources.

6.2 Significant findings

All methods show varying amounts of vegetation loss and vegetation gain that are substantial and each has its own advantages. The NDVI differencing technique was slightly better in detecting change as compared to the PC 2 and KT-G differencing method, but post-classification comparison performed better in identifying change out of all the methods used. Mas (1999) also found out that post-classification comparison produced more accurate results for detecting areas of change in Terminos Lagoon, Mexico as compared to the raw image differencing, and vegetation index differencing. Other vegetation indices that have been developed to reduce atmospheric and soil colour effects (e.g. as reviewed in Bannari 1995), may provide improved performance over NDVI. The

study reveals some interesting aspects of the human role in altering the land cover in the past 17 years. It seems maximum human impact has occurred in the area between the Dandeli and Yellapur districts (Figure 4.3). As from the 1:1,000,000 map (Figure 4.3) accessed from the water resource development atlas (Water Resources development Atlas of India, 1996, National Atlas & Thematic Mapping Organisation, Plate 30, Karnataka), it was visually determined that the area that was under reserved forests was submerged under water in 2003 (Figure 5.1). The same impact can be seen around the Jog falls, between the Siddapur and Sharavati districts (Figure 5.1). Forest extraction for fuel wood and submergence of reserved forests by reservoirs for hydropower development are the main causes of forest loss. The gain in vegetation can be mainly associated with the efforts of the Joint Forest Management Program, and various ongoing forestry projects in the country.

Hence, the research conducted was significant in highlighting the change using a $-2/+2$ std dev threshold criterion for differences in image pixels between the two dates. Therefore, by providing a broad snapshot of the change in forest cover in seventeen years, it is hoped that in the future, research will be able to provide a basis for more detailed classification of forests in the study area. Also, it will be able to highlight the problems associated with forest cover, which can be considered an invaluable step in improving the existing forest policies related to the management of forest lands and is certainly an attempt to make people aware of the problems and importance of forest resources.

The research conducted in the study area reveals that though there are some significant changes occurring around the reservoirs and coastal areas in terms of vegetation loss, overall there has been an increase in vegetation. The FSI (1999) reports that despite a loss of 2289 sq. km of dense forest cover, especially in Shimoga, Dharwad, Dakshina Kannada and Uttara Kannada, overall there has been a net gain of 64 sq km area. The increase is mainly in the southern part of Karnataka, which is due to the plantation efforts by JFM, mainly comprising eucalyptus and acacia species.

For the 1999 forest cover report, FSI used IRS data based on Dec. 1995 and Jan. 1996 to assess the forest cover of the country. The NDVI technique was used along with field data. The classification was done using the following classes: dense forest (tree cover of canopy density of 40% and above), open forest (tree cover of canopy density between 10 – 40%), Mangrove, scrub and non-forest (any area not included in above classes).

For this research two change detection techniques were used: image differencing of NDVI, PC2, KT-G and post classification comparison. Examples showing loss and gain were used to compare the change detection techniques. Though broad classification of forest, non-forest and water was used, and there were no field data, it was still possible to detect changes in vegetation of the study area over the 17 year time period and the results were generally consistent amongst the methods. Patterns of detected forest loss and gain generally corresponded well with visual patterns that could be interpreted from the imagery. It is difficult to compare the results in terms of numbers with the FSI

report which is for one time; also in this study only a part of the Karnataka state was analyzed and the changes were for a longer time period. But in general, the results of this study are similar to the FSI report, i.e., the forest cover in Karnataka has increased by 10.4% from 1986 to 2003 due to plantation projects and JFM efforts.

6.3 Research limitations and recommendations

Following are the limitations and the recommendations associated with this research:

The most significant limitation of the research was the acquisition of satellite data for the desired period. The first reason for this is that there was not much choice regarding the earlier data to do the temporal analysis. Hence, Landsat TM data with two line losses and some cloud cover (in the upper quadrant) were acquired for the research. This was so because the archived data for the desired study area was not good and had tape-sticking problems. Also, this was the only Landsat (TM) scene available with NRSA for the 1986 year for the study area, so image day and month could not be well matched to the 2003 image. A Landsat MSS image from the period before 1986 when TM data were not available for the study area was not acquired because of its poorer spatial resolution and radiometric quality than TM imagery.

The other important limitation associated with the research was the lack of accurate reference data. Due to strategic reasons, data availability for the study area is extremely low. As per the security policy of the Ministry of Defence,

Government of India, all gridded (Lambert grid) maps, and the maps that cover the 50-mile belt along the coastline of the country and international borders, are placed under the restricted category (Rao 2000). Further, the non-governmental organizations (NGOs) and other private organizations also cannot access topographic maps and aerial photos due to the restriction policy for the supply of topographical maps at scales 1:250,000 or larger. Hence, the only map available was from the year 1988, at a scale of 1:100,000,000, and its accuracy is not known. Therefore, no quantitative statements can be made regarding the accuracy of the images derived from the different change detection techniques. However, the visual examples presented showing change in the imagery and types of errors produced demonstrate the relative capabilities of each of the techniques employed to classify forest change. Another problem is related to the reflectance (brightness) of young forest plantations or non-forest vegetation in each spectral band. Changes in reflectance of these cover types may not have been detected as significant change. For example, if a forest plantation were established 5-10 years before 2003, then in the 2003 imagery, it would appear as a small positive change in the vegetation indices but would not be enough to be distinguished from noise. A similar argument in the opposite sense can be made for partial cutting in mature forests. These methods were only able to detect changes in vegetation that were significant over the 17-year period. Inventory of forest vegetation change using these methods would therefore differ from an inventory conducted through ownership and management records, which (if ethically conducted) would also show young plantation and partial cutting

changes. These methods are better suited to inventory of gross land cover changes resulting in large reflectance differences between imaging dates.

Sometimes differences in brightness values for a given land cover type are caused by topography, shadows, or seasonal changes in the sun's illumination angle and intensity. These conditions may hamper the ability to correctly identify temporal change in land cover. In temporal analysis, if imagery can be obtained at similar sun angles for each date, then correction of topographic and illumination brightness effects is not needed. In this study, the dates were quite different and the time of day of acquisition differed by 41 days and 3 hours in a day. Ratio transformations such as NDVI can reduce the effects of such environmental conditions (Friedman 1980), but there were probably residual brightness variations due to topography and sun angle.

It is recommended that for the studies related to the monitoring of land use change on a temporal basis, an effort should be made to use images of the same season and month. There seemed to be differences in soil moisture and vegetation phenology between both dates, February and April, which might have resulted in variation of spectral responses. According to Mas (1999) there are important variations in rainfall from one year to another and soil moisture and vegetation can be significantly different at the same time of the year.

Lack of field data was one of the major limitations of the research, which would have provided a basis for accuracy assessment of change occurring in the study area in terms of vegetation loss and gain. Hence, for future work it is

recommended to have field data, so that forests could be classified into types and a separate class for plantations could be included in classification.

The combined use of Landsat and other high-resolution data would be an asset and more feasible due to its enhanced capability to provide much more accurate and reliable analysis of forest cover on a timely basis. A given surface cover may fall into different categories, because of location, illumination aspect, etc., hence, a thematic map produced from high-resolution satellite data, studied in conjunction with topographical maps, air-photos etc., would be an asset. This will help in the development of new programs in the forest management sector, especially in the forest inventories and better planning at the micro level, such as Joint Forest Management activities. Finally, the data gathered from mapping and monitoring forest resources of a country will also help in updating the timber inventory at regular intervals for taxation and revenue purposes.

Due to the dual objectives of this research to evaluate the nature and impacts of forest change and management in India and Karnataka, combined with a remote sensing based forest change analysis, the methods selected for change analysis were a simplified subset of those most commonly applied. More advanced change detection techniques like linear spectral mixture analysis; artificial neural networks or a combination of different change detection techniques using multi-source data could provide capability for detection of more subtle change.

Chapter 7 .

CONCLUSIONS

There were two objectives for this research. The first was to conduct a historical review of change in forest cover in India and its relations with forest policy and management. The second was to evaluate the usefulness of Landsat data in monitoring the change in forest cover in Karnataka using different change detection techniques.

The results of the research clearly showed that Landsat data is very useful in monitoring changes in forest cover over moderate time intervals (17 years in this study) at a broad level of classification: forest, non-forest and water for a regional area or state. Further, all the techniques evaluated, NDVI, principal components and Kauth-Thomas image differencing, as well as post-classification comparison were useful for detecting changes in forest cover quite well and each has its respective advantages. NDVI differences performed better than PC 2 difference and KT-G difference in detecting vegetation loss. Though KT-G was able to detect significant changes in the coastline from 1986 to 2003, it mixed these changes with vegetation changes, thus creating errors of commission. For vegetation gain, all the techniques show consistent results. From the comparison of deforestation and reforestation maps of NDVI differencing and post-classification comparison, it was found that post-classification was a better technique in detecting changes and was accurate in identifying deforestation as well as reforestation. It is also apparent from the analysis that a considerable amount of forest area has been lost due to the submergence by reservoirs for

development projects. Although there was an overall gain in forest cover between 1986 and 2003 by 10.4%, it was due primarily to increases in monoculture and mixed plantations that have been established on degraded lands due to the efforts of the state forest department and the Joint Forest Management program. There is still deforestation occurring at some places.

This research was conducted to assess methods of forest change detection and to develop understanding of the nature of, and reasons for, the changes that were observed. Reference data to rigorously assess the accuracy of each method were not available, but specific examples of change visually showed that the methods were sensitive to both deforestation and reforestation. From this analysis, the method with the most potential from amongst those tested is NDVI differencing, but from the results KT-G differencing looks promising too. Ideally, in establishing a forest change-monitoring program, validation methodology would be an integral component, including permanent sample areas and reference data collected at regular intervals in association with the remote sensing data.

From the analysis of causal factors of forest change, it can be concluded that the pressure on Indian forests in some areas has reached beyond their productive potential, due to increased human and livestock populations. Hence, the disturbance gradient in forests of close proximity to human habitation needs to be monitored regularly. As most of the rural population of India is dependent on forests for their livelihood, the forests are subject to degradation from uncontrolled logging, illegal cutting beyond silviculturally permissible limits, over-

grazing, extraction of fuel wood and unsustainable forest management policies that exclude local communities. Therefore, for eco-development planning of forest use information regarding these impacts is essential. On the other hand, plantation projects and efforts of JFM are able to slow down the change occurring from forest to non-forest in some areas and have contributed to the forest increase.

REFERENCES

- ALVES, D.S., 2002, "Space-time dynamics of deforestation in Brazilian Amazonia," *International Journal of Remote Sensing*, Vol. 23, pp. 2903-2908.
- ANDERSON, J. R., 1977, "Land use and land cover changes—A framework for monitoring" *Journal Research U.S. Geological Survey*, vol. 5, no. 2, pp. 143-153.
- ASNER, G.P., KELLER, M., PEREIRA, R., and ZWEEDE, J.C., 2002, "Remote sensing of selective logging in Amazonia – assessing limitations based on detailed field observations, Landsat ETM+, and texture analysis," *Remote sensing of Environment*, vol. 80, pp. 483-496.
- Atlas of forest resources of India, 1976, edited by S.P. Das Gupta (Director), National Atlas Organisation, Dept. of Science & Technology, Govt. of India, Calcutta.
- BADRINATH, M.S., CHIKKARAMAPPA, T. and JAYAPRAKASH, S.M., 2002, "Karnataka Soil Reference Information Centre (KARSIC): a novel center for soil science education in India," presented at 17th WCSS, 14-21 August 2002, Thailand. Retrieved on 19/01/04 from the World Wide Web: http://www.sfst.org/Proceedings/17WCSS_CD/papers/0028.pdf
- BANNARI, A., MORIN, D., BONN, F., and HUETE, A. R., 1995, "A Review of Vegetation Indices," *Remote Sensing Reviews*, vol. 13, pp. 95-120.
- BANNER, A. V., and LYNHAM, T., 1982, "Multitemporal analysis of Landsat data for forest cutover mapping: A trial of two procedures" *Presented at 7th Canadian Symposium on Remote Sensing*, Winnipeg, Manitoba, Sept. 8-11, 1981, pp. 233-240.
- BOYD, D.S., FOODY, G.M., CURRAN, P.J., LUCAS, R.M., and HONZAK, M., 1996, "An assessment of radiance in Landsat TM middle and thermal infrared wavebands for the detection of tropical forest regeneration," *International Journal of Remote Sensing*, vol. 17 pp. 249-261.
- BYRNE, G.F., CRAPPER, P.F., and MAYO, K.K., 1980, "Monitoring land-cover change by principal component analysis of multitemporal Landsat data," *Remote Sensing Environment*, no. 10, pp. 175-184.
- CARATINI, C., FONTUGNE, M., PASCAL, J. P., TISSOT, C., and BENTALEB, I., 1991, "A major change at ca. 3500 years BP in the vegetation of the Western Ghats in North Kanara, Karnataka," *Current Science*, vol. 61, nos. 9&10, pp. 669-672.

- CENTER FOR STATE AND ENVIRONMENT (CSE), 1985, *The state of India's Environment 1984-85: the Second Citizen's Report*, pp. 49-58.
- CHAKRABORTY, M., 1994, "An analysis of the causes of deforestation in India" in Brown, K. and Pearce, D.W. (Eds.) *The causes of Tropical Deforestation, The economic and statistical analysis of factors giving rise to the loss of the tropical forests*, UBC Press, Vancouver, pg. 226-242.
- CHAMPION, H.G., Sir, and SETH, S.K., 1968, "A revised survey of the forest types of India." Delhi: Manager of Publications, 404p.
- CHATTOPADHYAY, S., 1985, "Deforestation in Parts of Western Ghats Region (Kerala), India," *Journal of Environmental Management*, vol. 20, pp. 219-230.
- CHEN, J., GONG, P., HE, C., PU, C., and SHI, P., 2003, "Land-Use/Land-Cover Change Detection Using Improved Change-Vector Analysis," *Photogrammetric Engineering & Remote Sensing*, vol. 69, no. 4, pp. 369-379.
- COHEN, W.B., FIORELLA, M., GRAY, J., HELMER, E., and ANDERSON, K., 1998, "An efficient and accurate method for mapping forest clear cuts in the Pacific Northwest using Landsat imagery," *Photogrammetric Engineering and Remote Sensing*, vol. 64, pp. 293-300.
- COLWELL, J. E., and WEBER, F. P., 1981, "Forest change detection," *Proceedings of the 15th international symposium on remote sensing of environment*: 11-15 May 1981, Ann Arbor, Michigan, pp. 65-99.
- COPPIN, P. R., and BAUER, M. E., 1996, "Digital change detection in Forest Ecosystems with Remote Sensing Imagery," *Remote Sensing Reviews*, vol. 13, pp. 207-234.
- DEERING, D.W., ROUSE, J.W., HAAS, R.H., and SCHELL, J.A., 1975, "Measuring Forage production of Grazing Units from Landsat MSS Data" *Proceedings, Tenth International Symposium on Remote Sensing of Environment*, Ann Arbor: ERIM, 2, pp. 1169-1178.
- DI MAIO MANTOVANI, A.C., and SETZER, A.W., 1997, "Deforestation detection in the Amazon with an AVHRR-based system," *International Journal of Remote Sensing*, vol. 18, no. 2, pp. 273-286.
- DRILLBITS & TAILINGS, 2000, "India: Mining and plantations put National Park at risk," *Article based on information from: Drillbits & Tailings; 18/08/2000, Vol. 5, No. 13*.
- DUTT, C.B.S., UDAYALAKSHMT, V., and SADHASIVAIAH, A.S., 1994, "Role of Remote Sensing in Forest Management," Retrieved on 24/03/04 from the

World Wide Web:

<http://www.gisdevelopment.net/aars/acrs/1994/ts5/ts5002.shtml>

FIORIO, F., 1974, "Concerning Remote Sensing of the Earth from Space," *Indian Administrative & Management Review*, vol. 6, no. 1, pp. 33-35.

FOREST DEPARTMENT, GOVERNMENT OF KARNATAKA, 1993, Retrieved 19/01/04 from the World Wide Web: <http://www.teriin.org/jfm/guide/ka.pdf>

FORESTS OF KARNATAKA, 1999, Retrieved 19/01/04 from the World Wide Web: <http://www.wildernesskarnataka.org/forofkar.asp>

FOREST SURVEY OF INDIA (FSI), 1999-2000, Forest cover in India: A Report, Retrieved 20/03/2003 from the World Wide Web: <http://envfor.nic.in/fsi/sfr99/sfr.html>

FOOD and AGRICULTURAL ORGANIZATION (FAO), 1993, *Forest Resources Assessment*, 1990, FAO, Rome, Italy.

FOOD and AGRICULTURAL ORGANIZATION (FAO), 2000, Global Forest Resources Assessment 2000: main report, FAO forestry paper, 140, pp 145-155, 167-172.

FRIEDMAN, S.Z., 1980, *Mapping Urbanized Area Expansion through Digital Image Processing of Landsat and Conventional Data*, Pasadena, California: Jet Propulsion Laboratory Publication, pp. 79-113.

GADGIL, M. 1987, "Depleting Renewable Resources: A case study from Karnataka Western Ghats," *Indian Journal of Agricultural Economics*, vol. 42, no. 3, pp. 376-387.

GADGIL, M., 1989, "Deforestation: Problems and Prospects," document 13, *Indian journal of Public Administration, Quarterly journal*, Vol. XXXV, no. 3, July-September 1989, pp. 752-811.

GADGIL, M., 1996, "Western Ghats: A Lifescape," *Journal of the Indian Institute of Science*, vol. 76, no. 4, pp. 495-504.

GADGIL, M., and GUHA, R., 1992, *This Fissured Land: An Ecological History of India*. Oxford University Press, New Delhi, pp. 113-140

GHOSE, A., 1986, "Developing Wasteland: A Compulsion," *Yojana*, May 1-15, pp. 21-23.

GIRI, C.P., OFREN, R.S., PRADHAN, D., KRATZSCHMAR, E., and SHRESTHA, S., 1998, "Land use / land cover change in Southeast Asia," *UNEP Environment Assessment Programme for Asia and the Pacific*, Bangkok, 68p.

GOVERNMENT OF INDIA (GOI), MINISTRY OF ENVIRONMENT AND FORESTS (MOEF), Annual reports, 2002-2003, 2001-2002, 2000-2001, 1999-2000, 1998-1999, 1997-1998 (Archives section). Retrieved 04/04/2003 from the World Wide Web: <http://www.enfor.nic.in/report/report.html>

GROVER, K., QUEGAN, S., and DA COSTA FREITAS, C., 1999, "Quantitative estimation of Tropical forest cover by SAR," *IEEE Transactions on Geoscience and Remote sensing*, vol. 37, no. 1, pp. 479-490.

GUILD, L.S., COHEN, W.B., and KAUFFMAN, J.B., 2004, "Detection of deforestation and land conversion in Rondonia, Brazil using change detection techniques," *International journal of remote sensing*, Vol. 25, no. 4, pp. 731-750.

HOEKMAN, D.H., and QUINONES, M.J., 2000, "Land cover type and biomass classification using AirSAR data for evaluation of monitoring scenarios in the Colombian Amazon," *IEEE Transactions on Geoscience and Remote sensing*, Vol. 38, no. 2, pp. 685-696.

HUNTER, I.R., and CALDER, I.R., 2001, 'Forests and Water' in Matti Palo, J. Uusivuori, G. Mery (Eds). *World Forests, Markets and Policies*, Vol. III. Kluwer Academic Publishers, Dordrecht /London /Boston, pp 107-114

JAIN, K.S., and CHAUDHARY, A., 2002, "Forest cover assessment of Uttaranchal state." National Institute of Hydrology, Roorkee, Uttaranchal, India, Retrieved 17/03/2003 from the World Wide Web: <http://www.gisdevelopment.net>

JENSEN, J.R., 1986, *Introductory Digital Image Processing: A Remote Sensing Perspective*, Prentice-Hall: Englewood Cliffs, New Jersey.

JENSEN, J.R., 1996, *Introductory Digital Image Processing: A Remote Sensing Perspective*, Second Edition, Prentice-Hall: Englewood Cliffs, New Jersey.

JENSEN, J.R., 2000, *Remote Sensing of the Environment: An Earth Resource Perspective*, Prentice-Hall series in geographic information science.

JHA, C. S., DUTT, C. B. S., and BAWA, K. S., 2000, "Deforestation and land use changes in Western Ghats, India," *Current Science*, vol. 79, no. 2, pp. 231-238.

JOSHI, G., 1983, "Forests and forest policy in India," *Social Scientist* (January), pp. 43-52.

JUSTICE, C.O., TOWNSHEND, J.R.D., HOLBEN, B. N., and TUCKER, C.J., 1985, "Analysis of the phenology of global vegetation using meteorological satellite data," *International Journal of Remote Sensing*, vol. 6, pp. 1271-1381.

- KANT, S., 2001, 'The Evolution of Forest Regimes in India and China' in Matti Palo, J. Uusivuori, G. Mery (eds). *World Forests, Markets and Policies*, Vol. III. Kluwer Academic Publishers, Dordrecht/London/Boston, pp. 341-351.
- KAUTH, R.J., and THOMAS, G.S., 1976, The tasselled cap – A graphic description of the spectral temporal development of agricultural crops as seen by Landsat, *Proceedings of the Symposium on Machine Processing of Remotely Sensed Data*, Perdue University, West Lafayette, Indiana, pp. 41-51.
- KLANKAMSORN, B., 1987, "Application of remote sensing in forest inventory of Thailand," Paper presented at the forest management and inventory working group, Danum valley field center, Sabah, Malaysia, 18-24 January 1987.
- KRISHNAN, R., Dr., 2002, "Classification methods," *IAPRS & SIS. Vol. 34, Part 7, "Resource and Environmental Monitoring," Hyderabad, India*, pp. 48-54.
- KUMAR, N., SAXENA, N., ALAGH, Y. and MITRA, K., 2000, "India Alleviating Poverty through Forest Development: An Evaluation of India's Forest Development and World Bank Assistance." Operations Evaluation Department, The World Bank, Washington D.C., Retrieved 20/02/2003 from the World Wide Web:
[http://wbIn0018.worldbank.org/oed/oeddolib.nsf/0/c14758e94c1f79e985256970007b95b1/\\$FILE/India.pdf](http://wbIn0018.worldbank.org/oed/oeddolib.nsf/0/c14758e94c1f79e985256970007b95b1/$FILE/India.pdf)
- KUSHWAHA, S. P. S. and KUNTZ, S., 1993, "Detection of environmental changes in Tropical forests of North-east India," *Presented at the 25th International Symposium, Remote Sensing and Global Environmental Change. Graz, Austria, 4-8 April 1993*, pp. I-551 to I-550.
- LILLESAND, T.M., and KIEFER, R.W., 1999, *Remote sensing and Image Interpretation*, John Wiley & Sons, Inc.: New York.
- LILLESAND, T.M. and KIEFER, R.W., 2000, *Remote sensing and Image Interpretation*, Fourth Edition, John Wiley & Sons, Inc.: New York, pp. 236-246, 431-434, 513-518, 579-580.
- LILLESTRAND, R. L., 1972, "Techniques for Change Detection" *IEEE Transactions on Computers*, vol. 21, pp. 654-659.
- LU, D., MAUSEL, P., BRONDIZIOS, E., and MORAN, E., 2003, "Change detection techniques," *International Journal of Remote Sensing*, vol. 25, no. 12, pp.2365-2407.

- LUNETTA, R.S., and ELVIDGE, C.D., 1999, *Remote sensing change detection Environmental Monitoring Methods and Applications* (edition), Taylor and Francis Ltd., 318p.
- MAS. J.F., 1999, "Monitoring land-cover changes: a comparison of change detection techniques," *International journal of remote sensing*, Vol. 20, no. 1, pp. 139-152.
- MATHER, 1989, *Computer processing of remotely-sensed images: an introduction*, New York: Wiley.
- MAXWELL, S.K., HOFFER, R.M., and CHAPMAN, P.L., 2002, "AVHRR composite period selection for land cover classification," *International Journal of Remote Sensing*, vol. 23, no. 23, pp. 5043-5059.
- MAY, A.M.B., PINDER, J.E., and KROH, G.C., 1997, "A comparison of Landsat Thematic Mapper and SPOT multi-spectral imagery for the classification of Shrub and meadow vegetation in northern California, USA," *International Journal of Remote Sensing*, vol. 18, no. 18, pp. 3719-3728.
- MEERA, C., NAGESWARA RAO, M., GANESHAIAH, K.N., UMA SHAANKER, R., and SWAMINATH, M.H., 2000, "Conservation of Sandal genetic resources in India: I Extraction patterns and threats to Sandal resources in Karnataka," *My Forest*, vol. 36, no. 2, pp. 125-132.
- MENON, S., and BAWA, K. S. 1997, "Applications of geographic information systems, remote sensing, and a landscape ecology approach to biodiversity conservation in the Western Ghats," *Current Science*, vol. 73, no. 2, pp. 134-145.
- MENON, S., and BAWA, K. S., 1998, "Deforestation in the Tropics: Reconciling disparities in estimates for India," (Synopsis), *Ambio*, vol. 27, no. 7, pp. 576-577.
- MINISTRY OF ENVIRONMENT AND FORESTS (MOEF), 1999, *National Forestry Action Programme-India*, Volume 1: Status of Forestry in India, Ministry of Environment and Forests, Government of India. New Delhi, 79p.
- MINISTRY OF ENVIRONMENT AND FORESTS (MOEF), Sept. 2001, "Factors, Processes and Impacts of Desertification," Chapter-5, *National Action Programme to combat Desertification*, pp. 49-61, Retrieved on 20/01/04 from the World Wide Web:
<http://sdnp.delhi.nic.in/resources/desert/uncccd/dhap-5.pdf> .
- MINISTRY OF ENVIRONMENT AND FORESTS (MOEF), 2002, "Conservation of natural resources (Chapter-6)" Forest Survey of India (FSI), Ministry of Environment and Forests, Govt. of India, Dehradun, pp.31-41. Retrieved

04/042003 from the World Wide Web:
www.envfor.nic.in/divisions/ic/wssd/doc1/references.htm

- NAIR, C.T.S., 1985, "Crisis in forest resource management." In: Bandyopadhyaya, J., Jayal, N.D., Schoettli, U. and Singh, C., eds. *India's Environment: Crisis and Responses*, Natraj Publishers, Dehradun, pp. 7-25.
- NAGARAJA, R., 2002, "Land use/ Land cover studies using remote sensing data: Indian experience" *IAPRS & SIS*, Vol. 34, Part 7, "Resource and Environmental Monitoring", Hyderabad, India, pp. 538-546.
- NAGENDRA, H., and GADGIL, M., 1999, "Satellite imagery as a tool for monitoring species diversity: an assessment," *Journal of Applied Ecology*, vol. 36, pp. 388-397.
- OLIVER, C.J., 2000, "Rainforest classification based on SAR texture," *IEEE Transactions on Geoscience and Remote sensing*, vol. 38, no. 2, pp. 685-696.
- PCI Inc., (2000), PCI Geomatica User's Manual (version 8.0), PCI Inc., Richmond Hill, Ontario, Canada.
- PHUA, M.H., FURUYA, N., and TSUYUKI, S., 2002, "Detecting deforestation in the tropics using change vector analysis with pattern decomposition coefficients," Retrieved 24/03/04 from the World Wide Web: <http://www.gisdevelopment.net/aars/acrs/2002/for/191.pdf>
- POFFENBERGER, M., and McGEAN, B., 1996, *Village voices, forest choices, joint forest management in India*, Oxford University Press, Delhi, 356 pp.
- POORE, D., 2003, *Changing Landscapes The development of the International Tropical Timber Organization and its influence on Tropical Forest Management*, Earthscan Publications Ltd. London, Sterling, VA, 290 pp.
- PRAKASH and GUPTA, R.P., 1998, "Land-use mapping and change detection in a coal mining area – a case study in the Jharia coalfield, India," *International Journal of Remote Sensing*, Vol. 19, pp.391-410.
- PRASAD, R., AND RATHORE, C.S., 2000, "Country Paper: Status of National Forestry information system in India" in Proceedings of the Programme Inception Workshop, Forestry Information Processes and Planning- Bangkok, Thailand 10-12 July 2000. Retrieved 12/11/2003 from the World Wide Web: <http://www.fao.org/DOCREP/003/X6638E/X6638E20.htm>
- RAMAKRISHNAN, P.S., and KUSHWAHA, S.P.S., 2001, "Secondary forests of the Himalaya with emphasis on the northeastern hill region of India," *Journal of Tropical Forest Science*, vol. 13, no 4, pp. 727-747

- RAMESH, B. R., MENON, S., and BAWA, K. S., 1997, "A Vegetation based approach to biodiversity gap analysis in the Agastyamalai region, Western Ghats, India," *Ambio*, vol. 26, no. 8, pp. 529-536.
- RANGAN, H., 1996, 'From Chipko to Uttaranchal: Development, environment, and social protest in the Garhwal Himalayas, India' in Richard Peet and Michael Watts (Ed). *Liberation Ecologies: environment, development, social movements*, Routledge Publishers, London and New York, pp. 205-226.
- RAO, D.P., 2000, "Geographic data needed in the interpretation of Indian satellite-based remote sensing data: Opportunities and realities," *Special edition, Current Science*, Vol. 79, no. 4, pp. 468-473.
- RAVINDRANATH, N.H., and HALL, D.O., 1994, "Indian forest conservations and tropical deforestation," *Ambio* 23, pp. 521-523.
- REDDY, D.V., 1988, "Deforestation and its Impact on Ecological Problems with Special Reference to Western Ghats," *Indian journal of environmental protection*, Vol. 8, no. 12, Dec. 1988, pp. 930-936.
- REDDY, Y.Y., PRASAD, K.S.S., AND REDDY, J., 1990, "Deforestation and Its Consequences-A Formidable Situation in India (Review)," *Environment & Ecology*, vol. 8, no. 1, pp. 192-196.
- REDDY, V.R., BEHERA, B., AND RAO, D.M., 2001, "Forest Degradation in India: Extent and Determinants," *The Indian Journal of Agricultural Economics*, vol. 56, no. 4, pp. 631-651.
- ROGAN, J., FRANKLIN, J., and ROBERTS, D. A., 2002, "A Comparison of methods for monitoring Multitemporal vegetation change using Thematic Mapper Imagery," *Remote Sensing of Environment*, vol. 80, Issue 1, pp. 143-156.
- ROUSE, J.W., HASS, R.H., SCHELL, J.A., and DEERING, D.W., 1974, "Monitoring Vegetation Systems in the Great Plains with ERTS," *Proceedings, Third Earth Resources Technology Satellite-1 Symposium, and Greenbelt: NASA SP-351*, 3010-317.
- ROY, P.S., 1993, Remote sensing for forest ecosystem analysis and management. *In Environmental Studies in India*, edited by M. Balakrishnan (New Delhi: IBH), pp.335-363.
- ROY, P.S., and JOSHI, P.K., 2002a, "Forest cover assessment in northeast India-the potential of temporal wide swath satellite sensor data (IRS-1C WiFS)," *International Journal of Remote Sensing*, vol. 23, no. 22, pp. 4881-4896.
- ROY, P.S., RANGANATH, B.K., DIWAKAR, P.G., VOHRA, T.P.S., BHAN, S.K., SINGH, I.J., and PANDIAN, V.C., 1991, "Tropical forest type mapping and

- monitoring using remote sensing," *International journal of remote sensing*, Vol. 12, no. 11, pp. 2205-2225.
- SAADI, M., and ABOLFAZL, R., 2003, "Analysis and estimation of deforestation using satellite imagery and GIS," Retrieved 04/04/2003 from the World Wide Web: <http://www.gisdevelopment.net>
- SAHU, K.C., PRADHAN, S., MISHRA, B.N., SUDHAKAR, S., 2002, "Land use/land cover mapping of Vishakhapatnam district, Andhra Pradesh, India using remote sensing and GIS," *IAPRS & SIS, Vol. 34, Part 7, "Resource and Environmental Monitoring," Hyderabad, India*, pp. 581-583
- SALIM, E., and ULLSTEN, O., 2000, *Our Forests Our Future: Report of the World Commission on Forests and Sustainable development*. Cambridge University Press (Reprinted version, first printed in 1999)
- SATTERWHITE, M.B., 1984, "Discriminating Vegetation and Soils Using Landsat MSS and Thematic Mapper Bands and Band Ratios," *Technical Papers*, 50th Annual Meeting of the American Society of Photogrammetry, Vol. 2, pp. 479-485.
- SAXENA, N.C. 2001 "The new forest policy and Joint Forest Management in India" Chapter-11, in Evans, J. (Eds.) *The forest handbook Vol. 2 Applying Forest Science For Sustainable Management*, Blackwell Science Ltd., pp. 233-259.
- SCHMIDT, R., BERRY, K. J., and GORDON, C. J., 1999, *Forests to Fight Poverty, Creating National Strategies*, Yale University Press: New Haven and London
- SEKHSARIA, P., 1999, Deforestation in India Overview and Proposed Case Studies. Kalpavriksh-Environment Action Group, India, pp. 76-86. Retrieved 04/04/2003 from the World Wide Web: <http://www.iges.or.jp/en/fc/phase1/1ws-9-pankaji.pdf>
- SHARMA, R.C., 1975, *Population trends, resources and environment: handbook on population education*, Dhanapati Rai & Sons, Delhi, India.
- SHI, H., SINGH, A., and KANT, S., 2003, "Vegetation cover, closed forests, protection status and human pressure in Biodiversity hotspots and Mega-diversity countries," Faculty of Forestry, University of Toronto, Toronto, Canada (Unpublished), 48 pp.
- SHIVARAJ, B., BARVE, N., KIRAN, M.C., UMA SHAANKER, R., and GANESHAIAH, K.N., 2000, "Mapping of forests based on biological diversity to identify conservation sites: A case study from Udupi and South Canara districts of Karnataka," *Journal of the Indian Institute of Science*, vol. 80, pp. 531-536.

- SINGH, A., 1989, "Digital change detection techniques using remotely-sensed data," (Review Article), *International Journal of Remote Sensing*, vol. 10, no. 6, pp. 989-1003.
- SINGH, A., and HARRISON, A., 1985, "Standardized principal components," *International journal of remote sensing*, Vol. 6, pp. 883-896.
- SINGH, S., 1999, *Environmental Geography*, Prayag Pustak Bhawan, Allahabad, India.
- SINGH, T.P., DUTTA, S. and VARALAKSHMI, V., 2001, "Resource rehabilitation with rural development: The new JFM paradigm," *Indian Forester*, Tata Energy Research Institute, New Delhi (India), pp. 661-670.
- SINGH, R.P., ROY, S., and KOGAN, F., 2003, "Vegetation and temperature condition indices from NOAA AVHRR data for drought monitoring over India," *International Journal of Remote Sensing*, vol. 24, no. 22, pp. 4393-4402.
- SMYTHIES, E.A., 1925, *India's Forest Wealth*. London.
- SOUTHWORTH, J., 2004, "An assessment of Landsat TM band 6 thermal data for analyzing land cover in tropical dry forest regions," *International Journal of Remote Sensing*, Vol. 25, No. 4, pp. 689-706.
- STATE OF THE ENVIRONMENT: INDIA, 2001, "Land degradation" Part III: key issues, pp. 61-75. Retrieved 02/01/2004 from the World Wide Web: http://sdnp.delhi.nic.in/soer/ind_land.pdf
- SUNDAR, N., 2000, "Unpacking the 'Joint' in Joint Forest Management" Chapter-11, in Doornbos, M., Saith, A., and White, B. (Eds.) *Forests Nature, People and Power*, Blackwell Publishers Inc, pp. 249-273.
- TOLE, L., 2000, "An estimate of forest cover extent and change in Jamaica using Landsat MSS data," *International Journal of Remote Sensing*, Vol. 23, No. 1, pp. 91-106.
- TOTTRUP, C., 2004, "Improving tropical forest mapping using multi-date Landsat TM data and pre-classification image smoothing," *International journal of remote sensing*, vol. 25, no. 4, pp. 717-730.
- TUCKER, R.P., 1988, "The British Empire and India's Forest Resources: The Timberlands of Assam and Kumaon, 1914-1950" in Richards, J.F. and Tucker, R.P. (Eds.) *World Deforestation in the twentieth century*, Duke Press Policy Studies, Duke University Press, Durham and London 1988, pp. 91-112.

- TUCKER, C.J., HOLBEN, B.N., ELGIN, J.H., JR, and McMURTREY, J.E., 1981, "Remote sensing of total dry matter accumulation in winter wheat," *Remote Sensing of Environment*, vol. 11, pp. 171-189.
- TUCKER, C.J., and TOWNSHEND, J.R.G., 2000, "Strategies for monitoring tropical deforestation using satellite data," *International Journal of Remote Sensing*, vol. 21, no. 6, pp. 1461-1471.
- UNNI, N. V. M., 1978, "Computer classification and delineation of types using Landsat data in two areas of Tropical forests in India," Remote sensing of Environment, *Proceedings of International Symposium on Remote sensing of environment*, 12th, Manila, Philippines, 1978, vol. 2, pp. 1471-1476.
- USGS, 2000, Level 1 Product output files, Data format control book, Vol. 5, Book 2, Revision 5, <http://landsat7.usgs.gov/documents/L7-DFCB-04-L1p-DFCB.pdf>, 90pp.
- VIRA, B., 1995, "Institutional change in India's Forest sector, 1976-1994: reflections on state policy" Oxford Centre for the Environment, Ethics and Society (OCEES) Research Paper No 5, Retrieved 02/01/2004 from the World Wide Web: <http://www.mansfield.ox.ac.uk/ocees/pages/pubs%20PDF%20files/RPF.pdf>.
- VOHRA, B. B., 1975, "Land Management Problems in India: A Macro View," *Indian Administrative & Management Review*, vol. 7, no. 4, pp. 6-8.
- WANG, G., GERTNER, G., FANG, S., and ANDERSON, A.B., 2004, "Mapping vegetation cover change using geostatistical methods and Bitemporal Landsat TM images," *IEEE Transactions of Geoscience and Remote sensing*, vol. 42, no. 3, pp. 632-643.
- WATER RESOURCES DEVELOPMENT ATLAS OF INDIA, 1996, National Atlas and Thematic Mapping Organisation, Plate 30, Karnataka.
- WIETZE, LISE, 2000, "Factors influencing people's participation in forest management in India" (Analysis), *Ecological Economics*, 34, pp. 379-392.
- WILSON, E.H., and SADER, S.A., 2002, "Detection of forest harvest type using multiple dates of Landsat TM imagery," *Remote sensing of Environment*, vol. 80, pp. 385-396.
- WORKSHOP ON HIMALAYAN ECOLOGY, 2001-2, Background paper on Himalayan Ecology: Main Issues and Concerns, Retrieved 02/02/2003 from the World Wide Web: www.terina.org/himalayan.pdf.
- YEFREMENKO, V.V., MOSHKOV, A.V., SEMENOV, A.A., and CHIMITDORZHIYEV, T. N., 1998, "Use of False-colour scanner imagery to detect vegetation

stress," *Mapping Sciences and Remote Sensing*, vol. 35, no. 3, pp. 218-226.

YOUNG, S.S. and WANG, C.Y., 2001, "Land-cover change analysis of China using global-scale Pathfinder AVHRR Landcover (PAL) data, 1982-92," *International journal of remote sensing*, Vol. 22, no. 8, pp. 1457-1477.

APPENDIX A

Landsat ETM + and TM spectral band images with linear enhancement

Grey level brightness values

FIGURE A: LANDSAT SPECTRAL BANDS
Landsat ETM+ and TM blue band

1986

2003

Landsat ETM+ and TM green band

1986

2003

Landsat ETM+ and TM red band

1986

2003

Landsat ETM+ and TM near infrared (NIR) band

1986

2003

Landsat ETM+ and TM mid-infrared (MIR) band

1986

2003

Landsat ETM+ and TM thermal infrared (TIR) band

1986

2003

Landsat ETM+ and TM mid-infrared (MIR) band

1986

2003

APPENDIX B

Transformed images

Grey level brightness values

FIGURE B: DATA TRANSFORMS
Normalized Difference Vegetation Index (NDVI) image

Principal Component images (PC 1)

1986 (PC 1)

2003 (PC 1)

Principal Component images (PC 2)

1986 (PC 2)

2003 (PC 2)

Principal component images (PC 3)

1986 (PC 3)

2003 (PC 3)

Principal component images (PC 4)

1986 (PC 4)

2003 (PC 4)

Principal component images (PC 5)

1986 (PC 5)

2003 (PC 5)

Principal component images (PC 6)

1986 (PC 6)

2003 (PC 6)

Kauth-Thomas Tasseled Cap brightness image

1986

2003

Kauth-Thomas Tasseled Cap greenness image

1986

2003

Kauth-Thomas Tasseled Cap moistness image

1986

2003

APPENDIX C

Difference images: Calibrated and Transformed data

Grey level brightness values

FIGURE C-1 DIFFERENCE IMAGES – CALIBRATED DATA

Blue band difference image

Green band difference image

FIGURE C-1 DIFFERENCE IMAGES – CALIBRATED DATA (Cont.)

Red band difference image

Near infrared band difference image

FIGURE C-1 DIFFERENCE IMAGES – CALIBRATED DATA (Cont.)

Mid-infrared band difference image

Thermal infrared band difference image

FIGURE C-2 DIFFERENCE IMAGES – TRANSFORMED DATA

NDVI difference image

TM6 / (TM3 + TM5) difference image
(Boyd et al. 1996)

Principal component difference images

(a) PC 1 difference image

(b) PC 2 difference image

Kauth-Thomas Tasseled Cap difference images

(a) Brightness

(b) Greenness

Kauth-Thomas Tasseled Cap difference images

(c) Moistness