KING COBRA HABITAT MONITORING AND EVALUATION AT AGUMBE, KARNATAKA USING GEOSPATIAL TECHNIQUES

Submitted by

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Chapter–1

INTRODUCTION

Indian Wildlife (Protection) Act 1972 Section 2(37) defines *wildlife as any animal, bees, butterflies, crustacean, fish and moths; and aquatic or land vegetation which forms part of any habitat.*

The term wildlife applies to all biotic elements that comprise every species of plants and animals in the world, excluding man and his domesticated pets. In the past, the term was often used to address a limited number of spectacular animals, which enjoyed public recognition (Chakraborti, 1990). Habitat is a key concept of wildlife conservation. A habitat (which is Latin for 'inhabit') is an ecological or environmental area that is inhabited by a particular species of animal, plant or other type of organism (Dickinson, 1963). The habitat must have proper arrangement of all the four essential elements *viz.* food, water, cover and space, which are crucial for the survival and reproduction of any organism. Each species of animal has its own habitat requirements. Habitat plays a vital role in the conservation of a species. Without protecting habitat, protecting individual animal becomes meaningless. Roy *et al.* (1986) has stated that conservation of wildlife requires complete knowledge of the habitat.

As human populations increase in size and demand for more resources, their expansion typically happens at the expense of wildlife habitat (Mwalyosi, 1991). The demand by the ever-growing population around the globe and especially in the developing countries results in rapid depletion of natural resources thereby posing threat to wildlife. Poaching, habitat destruction and fragmentation, impact of introduced species and chains of extinction are the four most general reasons that lead to the destruction of wildlife (Diamond, 1989).

The World Biodiversity Report of IUCN in 2004 stated that the rate of extinction had reached 100-1,000 times than that suggested by the fossil records before humans. Our lives are inextricably linked with the biodiversity and ultimately its protection is essential for our very survival. The wildlife conservation and management efforts were often hindered in the past due to non–availability of good quantity data on species and their habitats. This is more prominently seen in the developing countries, where wildlife conservation efforts were given less priority due to the increasing demand for food and economic security (Kushwaha, 2004). For the successful conservation and management of wildlife, habitat evaluation has to be carried out in a proper scientific manner. Evaluation of any habitat for its suitability or unsuitability for a particular species requires information on a host of parameters such as soil, topography, geology, geomorphology, temperature, rainfall, water availability and persistence, vegetation composition and cover characteristics including human influence on all of these factors.

1.1 Wildlife habitat evaluation

The U.S. Fish and Wildlife Service (USFWS) have developed habitat–based evaluation methodology (since 1974) for the use in impact assessment and project planning. This work has culminated in the development of three documents. The first document entitled *Habitat as a Basis for Environmental Assessments* addresses the rationale for a habitat–based technique and discusses the conceptual approach to habitat assessment. The second document entitled *Habitat Evaluation Procedures* (HEP), provides a quantification of the wildlife habitat that is based on two primary variables: (i) the Habitat Suitability Index (HSI), and (ii) the total area of available habitat. The third document entitled *Standards for the Development of Habitat Evaluation Procedures* provides guidance for the development of models that provide HSI values.

First developed in 1976, HEP has since been modified after detailed assessments and there are now many descriptions of models for HEP. This is the most comprehensive database anywhere in the world (Anon, 1981). The habitat models are used for predicting distribution of wildlife species in a geographical area with high species diversity (Butterfield, 1994). Location of concerned species (Sperduto, 1996), predicting areas of suitable habitat that are not currently used by that particular species (Lawton, 1991) and helps in species re–introduction or prediction of spread areas by the introduced species. They are also used in the prediction of species richness, presence or absence of a species (Butterfield, 1994). Probability of a species occurrence (Austin, 2007), or an index of habitat suitability for a species (Hepinstall, 1996). Many studies on habitat suitability have been carried out in India (Roy, 1995; Porwal, 1997; Kushwaha, 2000; Pant, 2000) by using different parameter–driven models.

1.2 Geospatial techniques in habitat evaluation

Remote sensing and Geographic Information System (GIS) surfaced as the most accurate and quickest way of wildlife habitat evaluation. Remote sensing has the capability to provide real time data with synoptic and repetitive coverage. Remote sensing aided by limited ground truth can supplement the limitations of the traditionally followed tedious ground survey methods. The role of remote sensing has been emphasized in quick appraisal of habitat attributes, identification of new sites for protected areas and current status of wildlife corridors (Kamat, 1986; Panwar, 1986).

The GIS is a system of hardware, software and procedures designed to support the capture, management manipulation, analysis modeling display of spatially referenced data for solving complex planning and management problems (Burrough, 1986). Remote sensing data coupled with GIS and Global Positioning System (GPS) together provide the capabilities to acquire, analyze, and interpret wildlife habitat information on various time-scales and cost effectively (Kushwaha and Roy, 2002). Many studies have used these tools for wildlife habitat analysis during the past three decades (George *et al.*, 1977; Hill & Kelly, 1987; Brian and West, 1997; Kushwaha *et al.*, 2000; Foley, 2002; Kushwaha, 2002; Rees, 2003; Kushwaha and Hazarika, 2004). Mongkolsawat and Thirangoon (1998) and Rout *et al.* (2000) demonstrated the potential of integrating remote sensing, GIS, and field information for habitat assessment.

1.3 King Cobra or Hamadryad (*Ophiophagus hannah* Cantor)

The king cobra is the world's longest venomous snake, averaging 3.6–4 m (12–13 ft) in length with a maximum length recorded up to 5.85 m (19.19 ft) in Thailand (Whitaker and Captain, 2004). It is locally known as nag raj (Hindi), ahi raj (Oriya), sankha chur (Bengali), fetty saap (Assamese), krishna nagam (Tamil), krishna sarpan (Malayalam) and kalinga (Kannada).

Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Reptilia
Order:	Squamata
Suborder:	Serpentes
Family:	Elapidae
Genus:	*Ophiophagus*
Species:	*Ophiophagus hannah* (Cantor, 1836)

Identification: The king cobra is the sole member of genus *Ophiophagus*, while most other cobras are members of the genus *Naja*. They can be identified from other cobras by size and hood marks. King cobras are larger than other cobras, and the stripe on the neck is like the symbol '^' instead of a double or single eye(s) shape that may be seen in most of the other cobras. The principal identification features are its scales and its head which is broader than its neck. The overall colouration varies from olive green to gray, black or yellowish brown usually with white or yellow cross bands. Whitaker and Captain (2004) stated that some forms in the Andaman islands are deep rust brown, unbanded and resemble Indian rat snake. Young (including those seen in Arunachal Pradesh) are black with narrow white or yellow bands that encircle the body and tail (Fig. 1.1).

Fig. 1.1 : A basking king cobra.

Behaviour: The king cobra's Latin name refers to its favorite meal—*ophiophagus* means the Latin words for snake "*ophio*" and eater "*phagus*". King cobras diet primarily consists of snakes such as Indian rat snake (*Ptyas mucosa*) (Fig. 1.2) but also eats venomous snakes such as Indian cobras, smaller king cobra and kraits (Coborn, 1991). When the food is scarce it may also feed on other small vertebrates, such as lizards, birds, and rodents (Mehrtens, 1987).

Fig. 1.2: King cobra feeding on Indian rat snake.

Like other snakes the king cobra receives chemical information via their forked shaped tongue, which picks up scent particles and transfers them to special sensory receptor organs called Jacobson's organs located in the roof of its mouth (Mehrtens, 1987). It also uses its keen eye sight for detecting prey upto 300ft away and is very sensitive to earth–borne vibrations (Taylor, 1997). Fast and extremely alert, this longest venomous snake in the world has a deserved reputation of being quick to attack. It is most reluctant to display aggression unless provoked or harmed. King cobras can raise their hood up to one-third of their length to look for prey or as a defensive gesture (Young, 1991). They rarely attack humans and prefer to avoid confrontation with humans. Its venom is much less toxic than spectacled cobra venom, but it can inject huge quantities (upto 7ml) at a time, enough venom to kill an elephant (Whitaker and Captain, 2004). The venom of king cobra is primarily of neurotoxic nature. During a bite, the venom is forced through the snake's 1.25 cm fangs into the wound and quickly attacks the victim's central nervous system (Capula; Behler, 1989). The primary protien component is the Ohanin which is responsible for causing hypolocomotion and hyperalgesia in mammals (Pung *et al*., 2006). One bite can cause the death of an adult human being within 15 minutes, hence it is regarded as one of the deadliest snakes in the world

(Tun-Pe *et al.*, 1995). The only anti venom serum for its bite is made in Thailand. Fortunately, bites from king cobra are very rare in India. In the past 20 years, four deaths from king cobra bites have been officially reported in south India (Whitaker and Captain, 2004).

Male cobras wrestle with each other in ritual mating contest for a female cobra. King cobras are the only snake that makes nest for their eggs. In building her nest the female scraps leaves together and makes a mould in which she lays 20-30 eggs. Female stays on or near her nest until eggs hatch 70 days later (Whitaker and Zia, 1986). King cobras are rarely seen at night, leading the most herpetologist to classify it as a diurnal species (Capula *et al.*, 1989).

Habitat: King cobra is an uncommon snake in India (Murthy, 1990). It requires conditions of heavy rainfall and inhabits thick primary forests and estuarine swamps. Also encountered in tea estates in south India and Assam, parts of Arunachal Pradesh and the mangrove forest of Andamans and Sundarbans, where they are often encountered in secondary forest close to river banks and small waterways near human habitation (Whitaker and Captain, 2004). It has been reported to occupy humid jungles with thick undergrowth, cool swamps and bamboo clusters (David and Vogel, 1996; Selich and Kestle, 2002; Leviton *et al.*, 2003; Anon, 2005; Das *et al.*, 2008). In terms of altitudinal distribution, this species is known to inhabit from 150m to 1530m in Nepal (Selich and Kestle, 2002), sea level to 1800m in Sumatra (David and Vogel, 1996). King cobras also goes beyond its preferred jungle habitat and are records of often seen in other types of habitat such as grasslands (Narayan and Rosalind, 1990; Chaoji, 2010) and even in the arid North Western tracts (Parshad, 1915). They are also seen foraging in the agricultural fields in search of rat snakes. Murthy *et al.* (1990) stated that these giant snakes are good climbers and are fond of water.

Distribution: King cobras have a very wide range, occurring in the dense highland forests of South East Asia including peninsular and North Eastern part of India upto Nepal, Bhutan, Bangladesh, Burma, Southern China, Thailand, Malaysia, Indonesia and Philippines. Indian ranges include the Western Ghats (Karnataka, Goa, Kerala, and Tamil Nadu), Uttar Pradesh (Terai), Bihar, Orissa, West Bengal and the Northeast (to Arunachal Pradesh) as well as Andaman islands (Murthy, 1990; Whitaker and Captain, 2004) (Fig. 1.3).

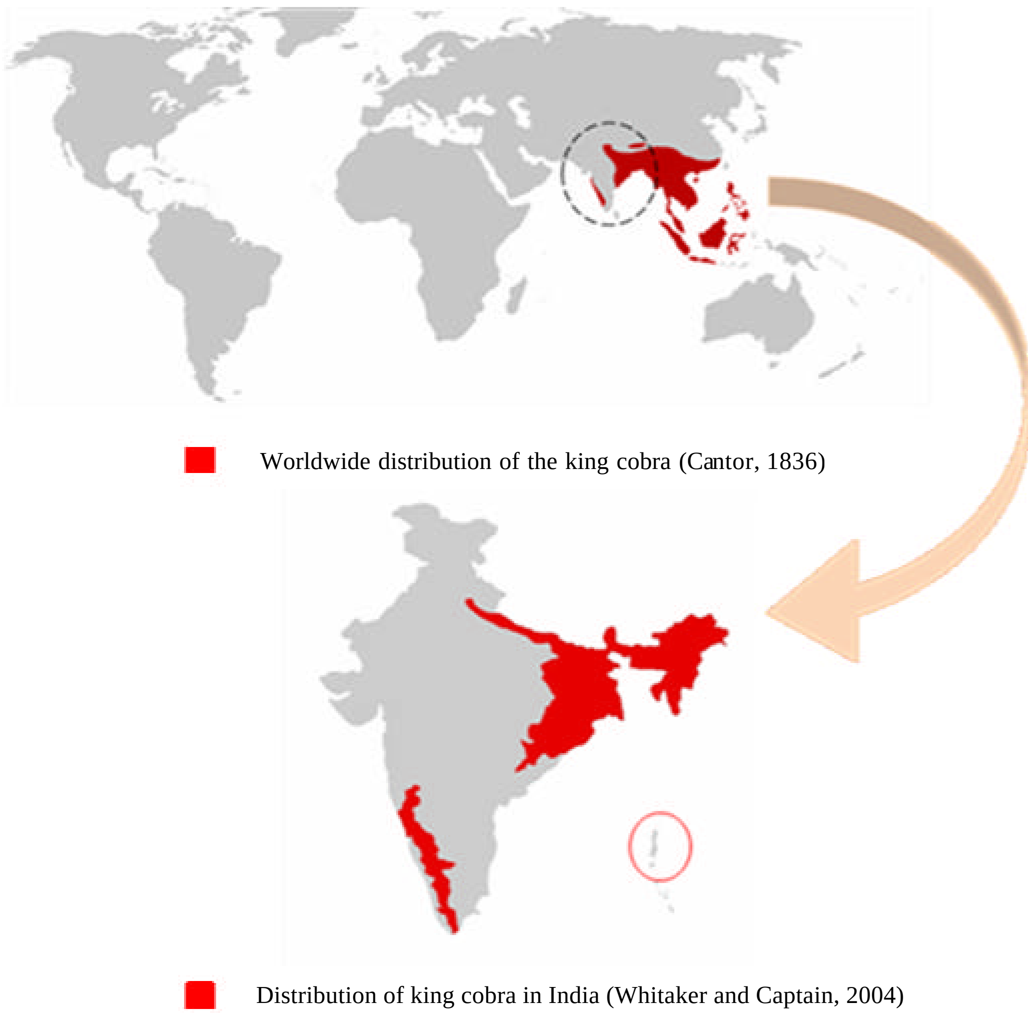

Fig.1.3: Distribution of king cobra–worldwide and India.

Status: Though, the exact number of king cobra population in India is yet to be known, they are considered as an endangered species in India. They are listed in the second highest order of protection, Schedule-II, of the Indian Wildlife (Protection) Act 1972. Humans are the king cobra's most dangerous threat. Deforestation, often due to growing populations, is shrinking the king cobra's native habitat throughout its range. In southern India, people kill a dozen or more king cobras each year when the snakes stray into tea estates and villages. Since king cobras feed primarily on large snakes like the rat snake, the common snake found within its range and which feeds on rats living on paddy fields and human settlement areas and there by bringing in direct confrontation with the humans. King cobras are also killed for their skin, used for making leather items. But inspite of dramatic drop in its population at certain places, king cobras are not listed by the IUCN as in danger of becoming extinct. However, it is listed as an A ppendix–II animal by CITES.

1.4 Agumbe Rainforest Research Station (ARRS)

Agumbe Rainforest Research Station (ARRS) is the only rainforest research station in India, which was set up by the renowned herpetologist Romulus Whitaker, in memory of his mother, Doris Norden in 2005 with the support of the Whitley Fund for Nature to encourage field studies in rainforest ecology. The main objective of setting up ARRS is to conserve and study the rainforests of South India using king cobra as the flagship species. This research station located at Agumbe, in the Western Ghats of south western Karnataka is trying to help the state to establish world's first king cobra sanctuary. Agumbe is also the place where Mr. Whitaker saw the first king cobra in wild. The research station is eco-friendly and runs on solar energy (Fig. 1.4).

Fig. 1.4 : Agumbe Rainforest Research Station (ARRS), Agumbe.

Agumbe Rainforest Research Station has been conducting various research related to wildlife ecology and conservation. It undertook the world's first king cobra radio telemetry project, which is also the first time on any snakes in India. The overall goal of this project is to study the ecology of these wild snakes, which will give a better understanding of its nature and its habitat. This information is expected to help in proper management and conservation of these remarkable serpents (Fig. 1.5).

Fig. 1.5 : King cobra radio tracking.

1.5 Research Questions

- What is the need to monitor wildlife habitat?
- How to evaluate habitat suitability for king cobra (*Ophiophagus hannah*)?

1.6 Objectives

- To find out the spatio – temporal pattern of land cover change at Agumbe.
- To monitor and evaluate king cobra habitat.

Chapter–2

LITERATURE REVIEW

A large number of ground-based studies have been carried out on habitat and corridor use by the wild animals (Hobaugh, 1984; Saxena, 1986; Tiwari, 1986; Rodgers, 1990; Johnsingh and Joshua, 1994; Bhat and Rawat, 1995; Mishra and Johnsingh, 1996). The U.S. Fish and Wildlife developed the Habitat Suitability Index (HSI) models in 1981, which was useful in a wide variety of planning, impact assessment and decision making. The first model to evaluate wildlife habitat was developed for rocky mountain elk (*Cervus elaphus*) by Thomas *et al.* in 1979. In 1982, Schamberger and Krohn used Habitat Evaluation Procedure (HEP) for the ecology of the marten (*Martes americana).* Verner *et al.* (1986) stated that habitat models became well accepted tools to understand the habitat characters of different organisms evaluating habitat qualities and developing wildlife management strategies.

Remote sensing played an important role in the generation of valuable information on forest cover, vegetation types, and land use change (Houghton and Woodwell, 1981; Botkin *et al.*, 1984; Malinggreau, 1991; Kushwaha, 1997). Miller *et al.* (1978) and Eden (1986) used temporal Landsat MSS data to detect changes in forest cover due to shifting cultivation. This technology has been well established in the quick assessment of habitat parameters, monitoring the present status of wildlife habitats and corridors, identifying new potential sites for protected areas (Kamat, 1986; Panwar, 1986). Wildlife habitat mapping is similar to any type of land cover mapping (Lindgren, 1985).

Remote sensing can be applied to wildlife habitat inventory, evaluation and wildlife census. A number of mammals and birds have been successfully censused using vertical aerial photography, including moose, elephants, whales, elk, sheep, deer, antelope, sea lions, caribou, beavers, seals, geese, ducks, flamingos, gulls, oyster catchers and penguins. Ericson *et al.* (1983) have discussed the use of aerial photographs for censusing sandhill cranes, *Grus canadensis*. Best (1994) stated that aerial photography has been used successfully to detect pocket gopher, *Thomomys sp.*, and prairie dog colonies, *Cynomys sp*. Wyatt *et al.* (1984) reported on the use of an airborne multispectral linear array scanner operating in the visible and near infrared wavelengths for detecting deer. Vertical aerial photography is the best method of accurately censusing many wildlife populations (Kushwaha & Roy, 2002). Ferguson *et al.* (1981) concluded that aerial photography on scale 1:2000 was cheaper than ground observation methods for determining the sex ratio among mallard (*Anas platyrhynchos*). Adams and Gentle (1978) used digitized aerial photos to monitor changes in waterfowl habitat over a 10-year period in the Manitoba parklands. Digitalanalysis of remote sensed data has been used for habitat assessment of elk, *Cervus Canadensis* (Bright, 1984), reindeer, *Rangifer tarandus* (George *et al.*, 1977) and kangaroo, *Macropus giganteus* (Hill and Kelly, 1987). Burkhalter and Kientz (1984) have indicated the role of thermal scanning for wildlife censusing.

Lyon (1983) predicted satisfactorily the nesting sites of American kestrel, *Falco sparverius* by using a nesting habitat model in combination with Landsat digital image classification. Loeffer and Margules (1980) were able to detect warrens of hairy-nosed wombats, *Lasiorhinus latifrons* on Landsat images. Visual Landsat image interpretation was an effective tool in the re-introduction programme of the white oryx, *Oryx leucoryx* (Harris 1983). Wiersema (1983) studied ibex habitat in French and Italian Alps using Landsat data and concluded that remote sensing data contributes in better understanding of environmental patterns and processes.

Remote sensing and GIS have been widely used in wildlife habitat studies (Roy *et al.*, 1995; Gratto and Trevor, 1996; Porwal *et al.*, 1996; Verlinden and Masogo, 1997; Williams and Dowdeswell, 1998; Kushwaha *et al.* 2000). Habitat evaluation normally requires integration of various habitat variables of both spatial and nonspatial nature that can be effectively managed and analyzed through GIS technology for automating the application of HIS models (Sawarkar, 1986). Mongkolsawat and Thirangoon (1998) used satellite imagery and GIS to evaluate wildlife habitat suitability mapping, mainly for Asian elephants in Thailand. Similar studies have been carried out by Zhix *et al.*, 1995; Foley, 2002 and Polce, 2004. Remote sensing and GIS techniques have been carried out to study habitat suitability analysis of Indian mammals such as *Nemorhaedus goral* (Roy *et al*, 1995); *Rhinoceros unicornis* (Kushwaha, 1997); C*ervus unicolor* (Porwal *et al*, 1996; Pant *et al*, 2000); and *Elephus maximus* (Rout *et al*, 2000). Alfred *et al.* (2001) used remote sensing and GIS for making out the habitat suitability for chinkara (*Gezella bennetti*) in entire Rajasthan state of India. Habib *et al.* (2010) evaluated habitat suitability models for four sympatric ungulate species viz. C*ervus unicolor*, *Boselaphus tragocamelus*, *Axis axis* and *Nemorhaedus goral* in Pathri Rao watershed area using geo-statistical analysis and geospatial tools. Yanez (2000), Beaumont (2005), Chefaoui (2005), Rotenberry (2006) and Anderson (2009) studied habitats for reintroducing species by identifying core habitats, effective habitat variables in influencing species distribution, providing spatially explicit assessment of habitat suitability and predicting habitat suitability for the area that no information about the occurrence of species. Imam *et al.*, (2009) used multiple logistic regression to evaluate suitable tiger habitats at Chandoli National Park. Strubbe in 2009 predicted sensitive habitats to invasive species and developed models on negative effect of non-indigenous species on native biota.

Remote sensing together with GIS have been found to provide reliable, relevant, timely and cost efficient information needed for conservation planning (Nellis *at al*, 1990; Kushwaha *et al*, 2000 and 2004). It has been now well established fact that the use of satellite remote sensing and GIS is an effective tool for wildlife habitat evaluation (Parihar *et al.*, 1986; Kushwaha and Madhavan Unni, 1986; Narendra Prasad *et al*., 1994).

Chapter–3

STUDY AREA

The study area lies between 75°01'10''E to 75°07'54''E and 13°29'41''N to 13°26'29''N within Agumbe state forest (Fig. 3.1).

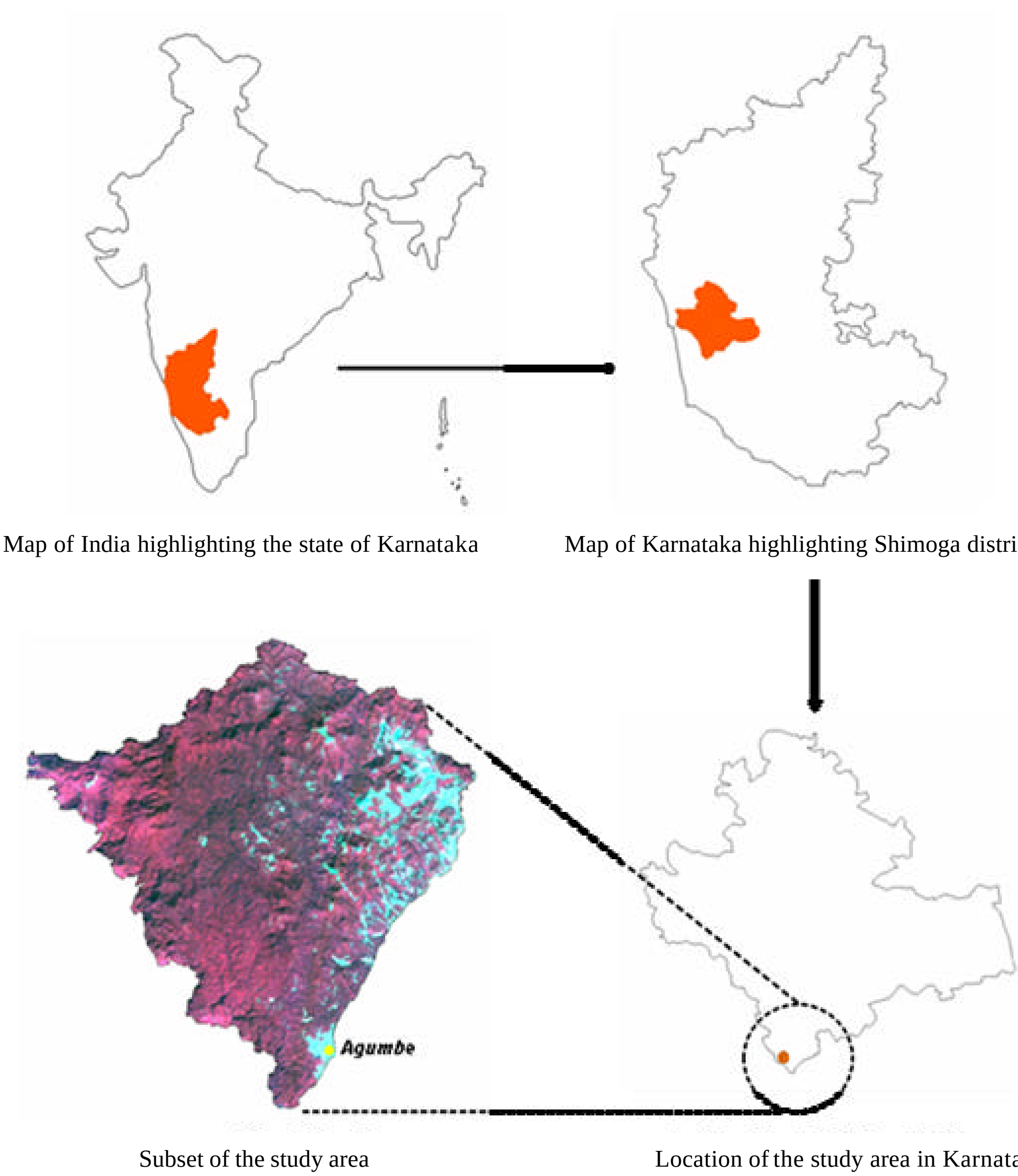

Fig. 3.1 (a): Study area location.

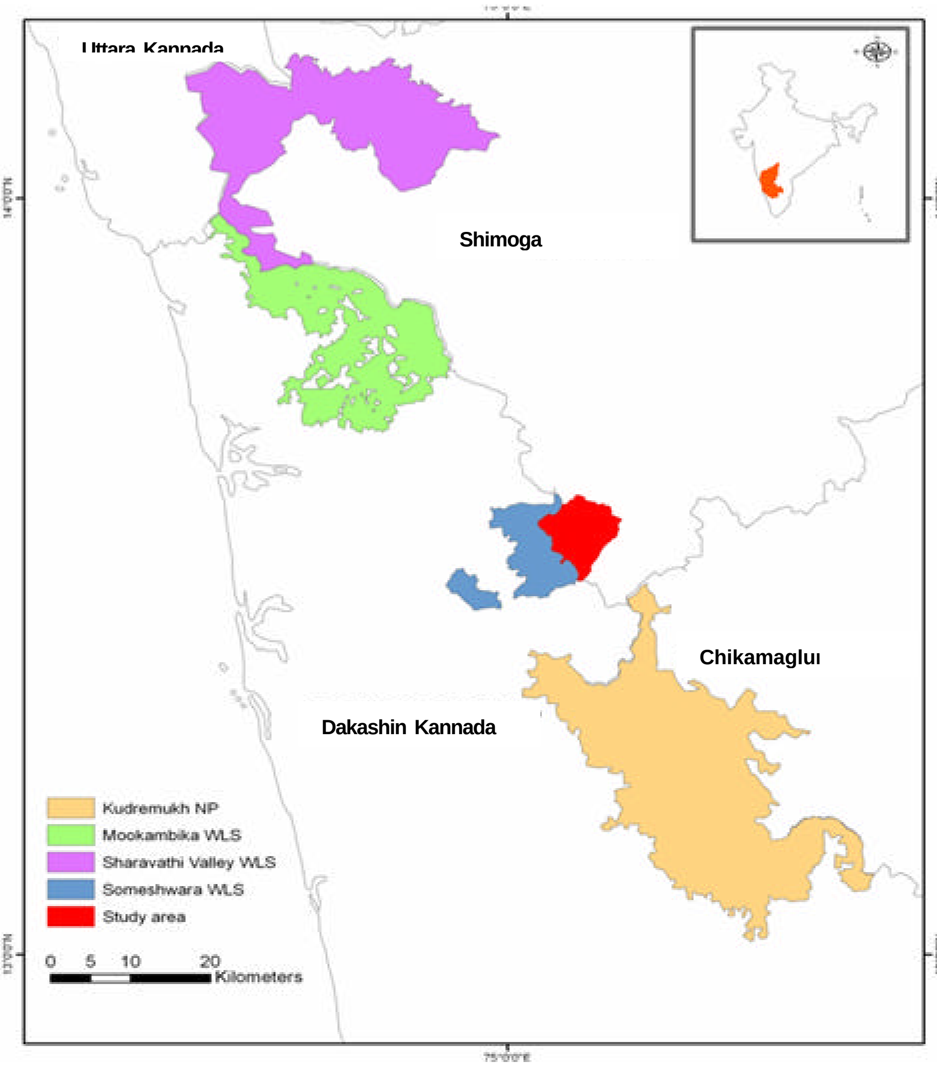

Fig. 3.1(b): Relative location of the study area in Karnataka

Fig. 3.1(c): Location of Agumbe Rainforest Research Station

Agumbe is a well known hill station, located in the Shimoga district at a height of 826 meters above the sea level, in the south western part of the state of Karnataka. It is at a distance of 380 km from Bangalore and 100 km from Mangalore. Agumbe receives the second highest rainfall in India, with a mean annual rainfall of 7640mm earning the reputation as the 'Cherrapunji of the south'. The summer temperature varies from 26–35° C while the winter temperature ranges between 14–25° C. Agumbe is one of the highest peaks of Western Ghats and is one of the four mountains which connect the plains to the coast (Fig. 3.2).

Fig. 3.3: The eastern view of Agumbe.

About two–fifth of the state of Karnataka's geographical area is under recorded forests (38,284 km^2). Reserved forest constitutes 74.94 percent, protected forest 10.27 percent and unclassed forests 14.79 percent of the total forest area. Karnataka has 51 National parks and 21 Wildlife Sanctuaries covering an area of 2,472 km^2 and 3,879 km^2 respectively. The state has 19 different forest types as per Champion and Seth's classification system (1968) belonging to 6 type groups *viz.* Tropical Wet Evergreen, Tropical Semi–Evergreen, Tropical Moist Deciduous, Tropical Dry Deciduous and Tropical Thorn, Sub–tropical Broadleaved Hill forests.

Being a part of Malnad and Western Ghats, Agumbe falls in one of the 34 biodiversity hotspots, recognised internationally– Western Ghats and Sri Lanka. It is a contiguous reserve forest linking the Someshwara and the Kudremukh Wildlife Sanctuaries. Agumbe and its surroundings being rich in biodiversity, lead to the establishment of Agumbe Medical Plants Conservation Area (MPCA) in 1999 for the conservation of medicinal plants. MPCA have identified 371 plant species of which 182 are found to have medicinal values, while some species are endangered and red- listed. These rainforest is also the home for the endangered king cobras. The renowned herpetologist Romulus Whitaker called Agumbe as the ‘capital of king cobra’.

Agumbe with its magnificent scenic beauty forms an excellent tourist destination. It is the location of many mesmerising waterfalls such as Barkana falls, Onake Abbi falls, Jogigundi falls and Kunchikal falls being the second height water fall in India. Many episodes of the famous television serial ‘Malgudi Days’ based on R.K. Narayan novel was filmed at Agumbe.

3.1 Floral diversity

Tropical evergreen forest forms the predominant forest type around the area.

West Coast Tropical Evergreen forest (1A/C_4): These forests are dense and evergreen and require high rainfall of 5000 mm or above. These forests occur at an elevation of 250m to 1200m whenever humidity and soil moisture condition are favourable. This type constitute trees such as *Dipterocarpus indicus, Poeciloneuron indicum, Mesua ferrea, Hopea parviflor* (o)*, Dysoxylum malabaricum, Calophyllum elatum, Machilus marcrantha, Palaquium ellipticum, Myristica* sp.*, Euphoria langana, Mangifera indica, Areca catechu, Calamus* spp. and many others.

3.2 Faunal diversity

Some of the spectacular fauna of Agumbe are: *Ophiophagus hannah, Vijayachelys silvatica, Macaca silenus, Rusa unicolor, Cuon alpinus, Draco blanfordii, Attacus atlas, Buceros bicornis, Panthera tigris, Panthera pardus* along with variety of birds, reptiles and amphibians (Fig. 3.3).

3.3 Land use types

The land use types seen within the study area (Fig. 3.4) are viz. dense wet evergreen forest, patches of grassland, settlements, agricultural land primarily paddy, small streams and various plantations (Fig. 3.5) of *Areca catechu*, *Acacia auriculiformis* and *Casuarina equisetifolia*.

Trimeresurus malabaricus.

Hoplobatrachus tigerinus.

Ahaetulla nasuta.

Fig. 3.4: Some of the reptilian fauna found in the study area.

Dense evergreen forest.

Scrub.

Natural grassland.

Settlements.

Paddy cultivation.

A natural water course.

Fig . 3.5: Various land use and land cover types.

Plantation – *Areca catechu*.

Plantation – *Acacia auriculiformis*.

Plantation – *Casuarina equisetifolia*.

Fig. 3.6: Different plantations.

Chapter–4

MATERIALS AND METHODS

The study involves procurement of satellite data, image rectification, image interpretation, field verification, preparation of digital database in GIS, modeling and report preparation. The detailed methodology is discussed below.

4.1. Materials

4.1.1 Hardware, software and other equipments used in the study area

Table. 4.1: Specifications of hardware and software used.

Sl. No.	Type	Particulars	Utility
1.	Hardware	Pentium ® 4 CPU 3.0 GHz; 4GB DDR3 RAM	Data storage and processing
2.	Software	*ERDAS Imagine 9.1*	Image processing and data analysis
3.	Software	*ArcGIS 9.1*	Spatial analysis and data base creation
4.	Hardware	*Trimble GPS*	Acquire geographical reference data
5.	Software	Microsoft Excel 2003	Data analysis
6.	Software	Microsoft Word 2007	Documentation

4.1.2 Satellite data

The land use and land cover map and the vegetation canopy density map were delineated from the merge image of high resolution Cartosat–1 PANA data dated 07 January, 2008 with multi spectral LISS–IV MX IRS–P6 data dated 05 January, 2006. Images from Landsat –1 MSS (February, 1973), Landsat–5 TM (January, 1991) and Landsat–7 ETM+ (December, 2000) were used to study the spatio–temporal pattern of land cover change. Table. 4.2 shows detailed specifications of the satellite data used.

Table. 4.2: Specifications of satellite data used.

Sl. No.	Satellite	Sensor	Swath (km)	Date of pass	No. of bands	Band width (µm)	Spatial resolution (m)
1.	Cartosat–1	PANA	27 X 27	07 January, 2008	1	PAN: 0.5–0.85	2.5
2.	IRS–P6	L4 MX	23 X 23	05 January, 2006	3	B2: 0.52–0.59	5.8
						B3: 0.62–0.68	
						B4: 0.77–0.86	
3.	Landsat–1	MSS	185 X 185	10 February, 1973	4	B4: 0.5–0.6	79
						B5: 0.6–0.7	
						B6: 0.7–0.8	
						B7: 0.8–1.1	
4.	Landsat–5	TM	185 X 185	02 January, 1991	7	B1: 0.45–0.52	30
						B2: 0.52–0.60	
						B3: 0.63–0.69	
						B4: 0.76–0.90	
						B5: 1.55–1.75	
						B6: 10.40–12.50	60
						B7: 2.08–2.35	30
5.	Landsat–7	ETM+	185 X 185	20 December, 2000	8	B1: 0.45–0.52	30
						B2: 0.52–0.60	
						B3: 0.63–0.69	
						B4: 0.76–0.90	
						B5: 1.55–1.75	
						B6: 10.40–12.50	60
						PAN: 0.5–0.90	15

4.2. Methods

4.2.1. Satellite data procurement

Satellite data of Cartosat–1 and IRS–P6 L4MX of good quality and minimum cloud cover was procured from NRSC Data Centre, National Remote Sensing Centre, Hyderabad. All Landsat data were freely downloaded from USGS website.

4.2.2. Image registration

The image correction involved

Radiometric correction: Radiometric correction was carried out to remove the topographic and atmospheric effects as well as the variations in the DN values due to malfunctioning of the detectors. Dark pixel subtraction technique (Lillesand and Kiefer, 2004) was carried out. This technique assumes that there are atleast a few pixels within an image which should be black (0% reflectance). However, because of atmospheric scattering, the image system records a non–zero DN value at a supposedly dark shadow pixel location. This represents the DN value that particular spectral band to remove the first order scattering component (Yang, 2001).

Geometric correction: Image was rectified geometrically with the ortho–rectified Landsat image. Common uniformly distributed ground control points (GCPs) were marked by considering root mean square error of less than one pixel and the image was resampled using nearest neighborhood interpolation method.

4.2.3. Image merging

The high resolution Cartosat–1 PANA image (Fig. 4.1) was merged with the multispectral IRS–P6 LISS IV image (Fig. 4.2) using spatial resolution merging technique in ERDAS Imagine 9.1. Principal component analysis method using cubic convolution resampling was used. The merged image is shown in the Fig. 4.3

4.2.4. Study area extraction

The boundary of the study area was delineated by taking Agumbe state forest as the core area. The Area of Interest (AOI) layer was thus created.

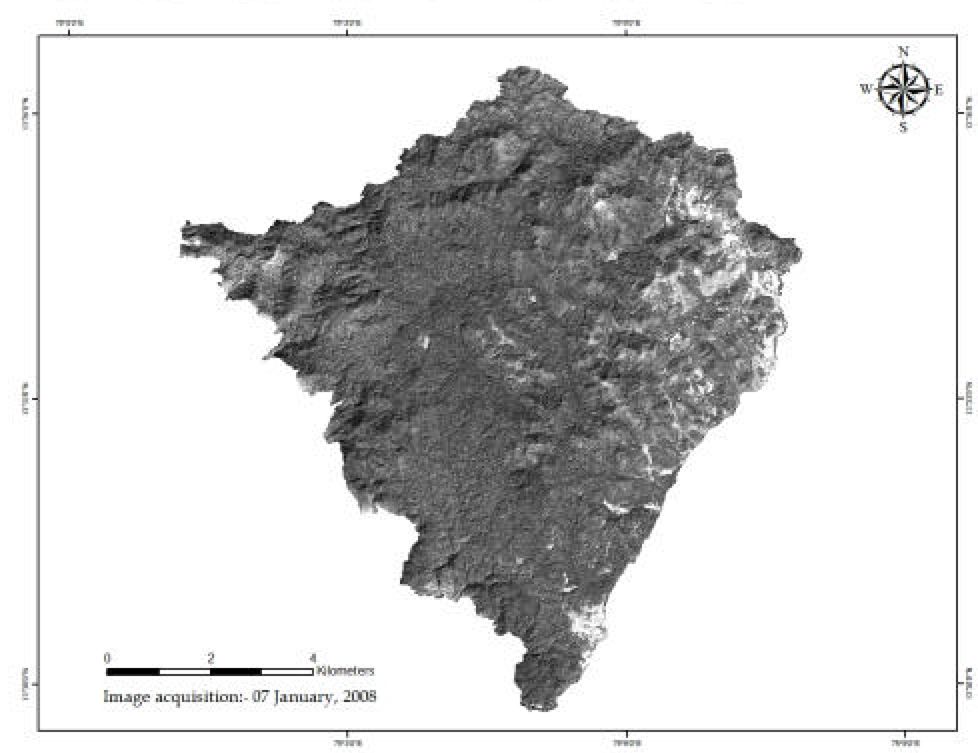

Fig. 4.1: Cartosat–1 image.

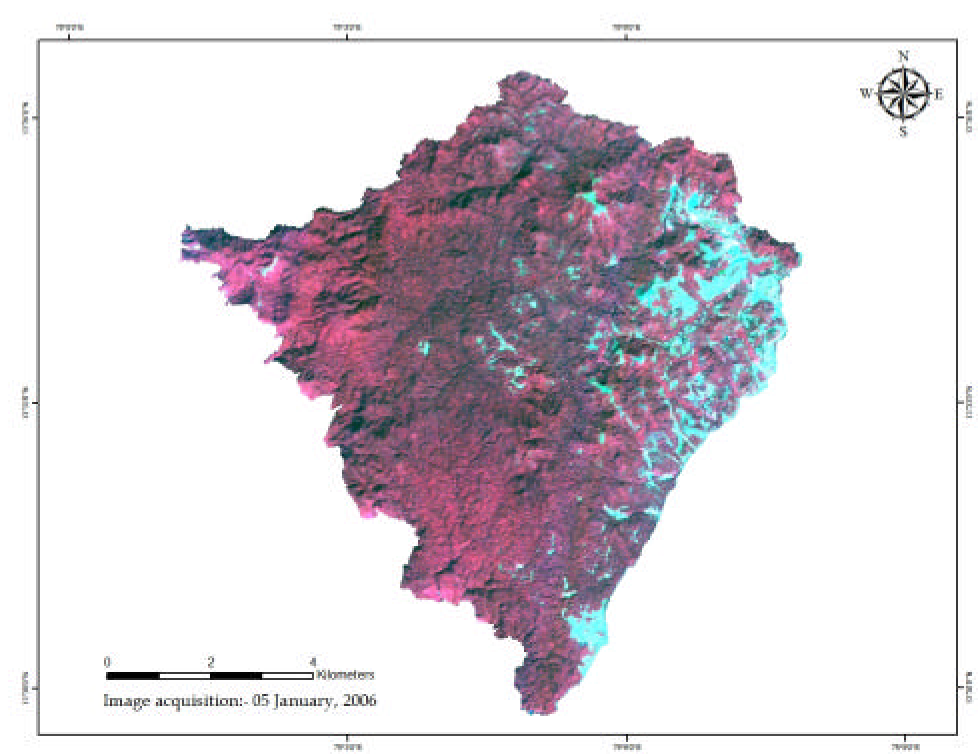

Fig. 4.2: IRS P6 L4MX image.

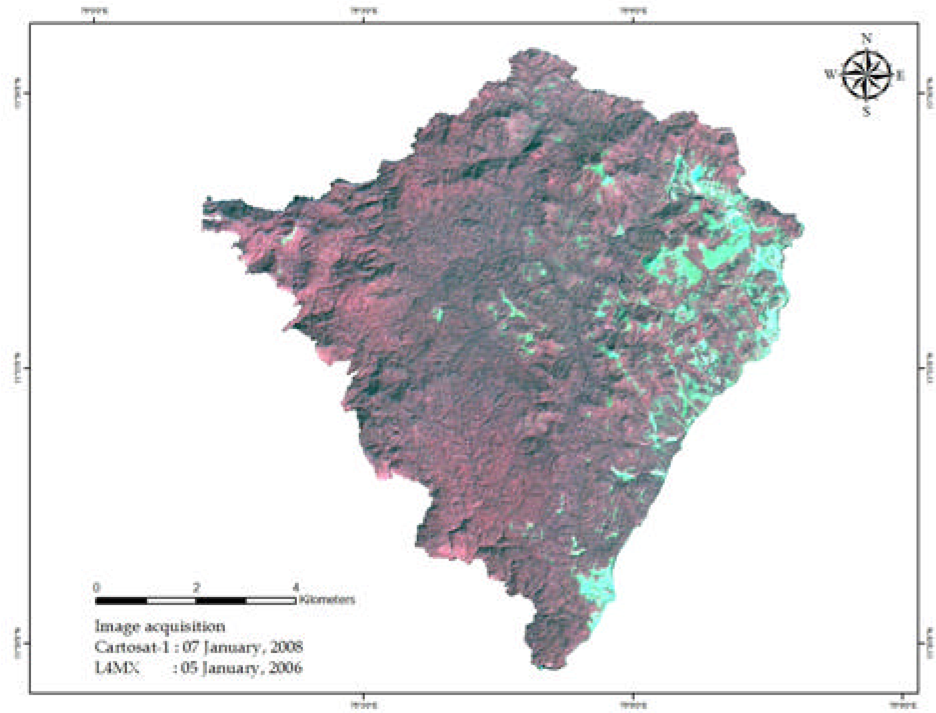

Fig. 4.3 (a): Merged image (Cartosat–1 + IRS P6 L4MX).

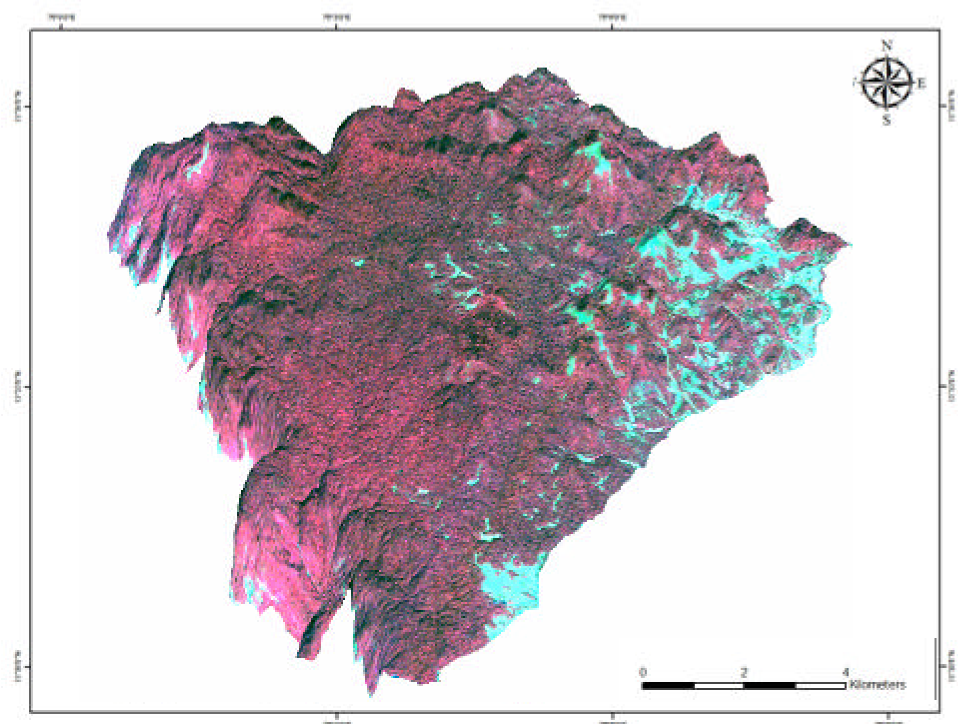

Fig. 4.3(b): FCC draped over DEM

4.2.5. Forest cover change detection

To observe the spatio–temporal patterns of forest cover/land use change in the study area, different period data were used. Satellite imagery of 1973 (Landsat–MSS), 1991 (Landsat–TM), 2000 (Landsat–ETM+) and 2006 (LISS–IV MX) were used to find out the pattern of land use/ land cover change. On–screen visual interpretation technique was carried out to generate land use/ land cover maps of three different time periods. The final maps were intersected in GIS environment (change matrix analysis) to generate change maps for 1973–1991, 1991–2000, and 2000–2006 periods.

4.2.6. Image interpretation

The image features on the satellite image were interpretated by on–screen visual interpretation for vegetation/ landuse cover types using the various image elements *viz*. tone, texture, pattern, shape, size, shadow, location and association (Fig. 4.4). The interpretation key for various land cover types were given in Table. 4.3. The land cover map and vegetation canopy density map of the study area were shown in the Fig. 4.5 and Fig. 4.6 respectively.

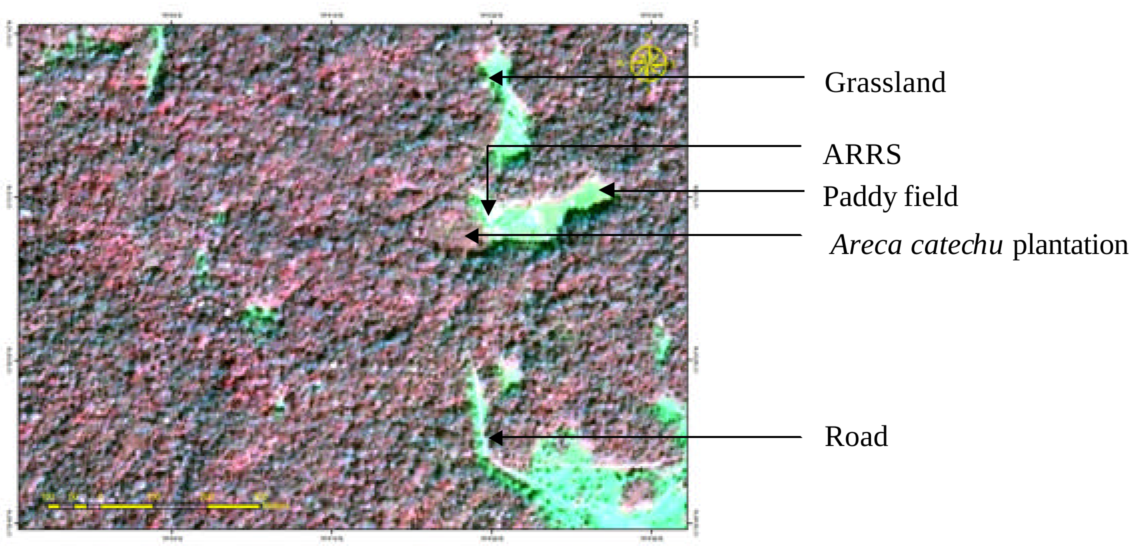

Fig.4.4: Forest cover and land use in Agumbe

Table 4.3 : Key used for land use/land cover interpretation.

Sl. No.	Classes	Tone	Texture	Pattern
1.	Evergreen forest	Dark red	Rough	Irregular
2.	Agriculture	Dark cyan	Fine	Regular
3.	Grassland	Bright green	Fine	Irregular
4.	*Areca catechu* Plantation	Pinkish red	Fine	Regular
5.	*Acacia auriculiformis* Plantation	Reddish brown	Coarse	Regular
6.	*Casuarina equisetifolia* Plantation	Dark greenish	Coarse	Regular
7.	River/ stream	Dark blue	Fine	Irregular
8.	Scrub	Cyan	Rough	Irregular
9.	Settlement	Bright cyan	Coarse	Irregular

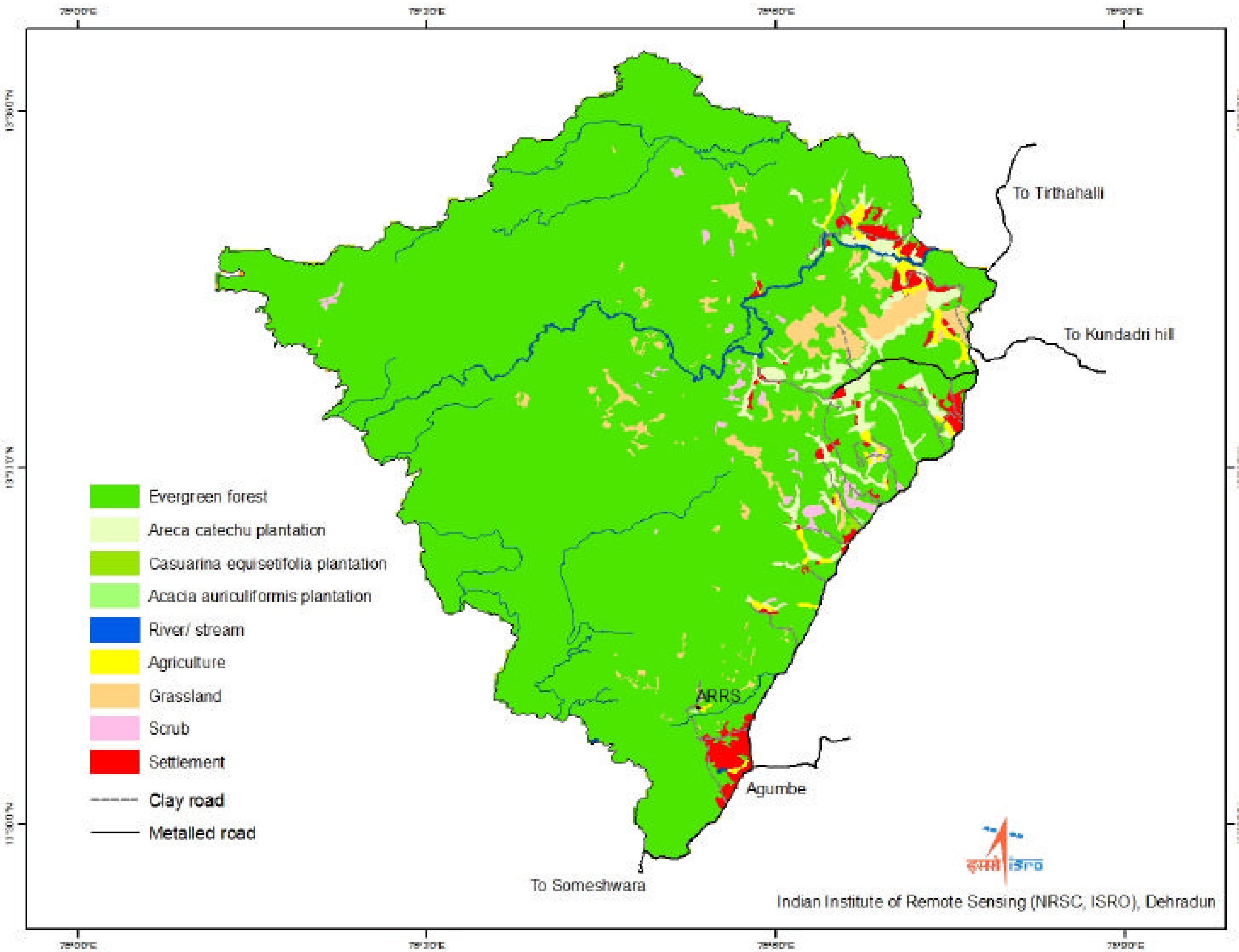

Fig. 4.5: Land use and land cover map.

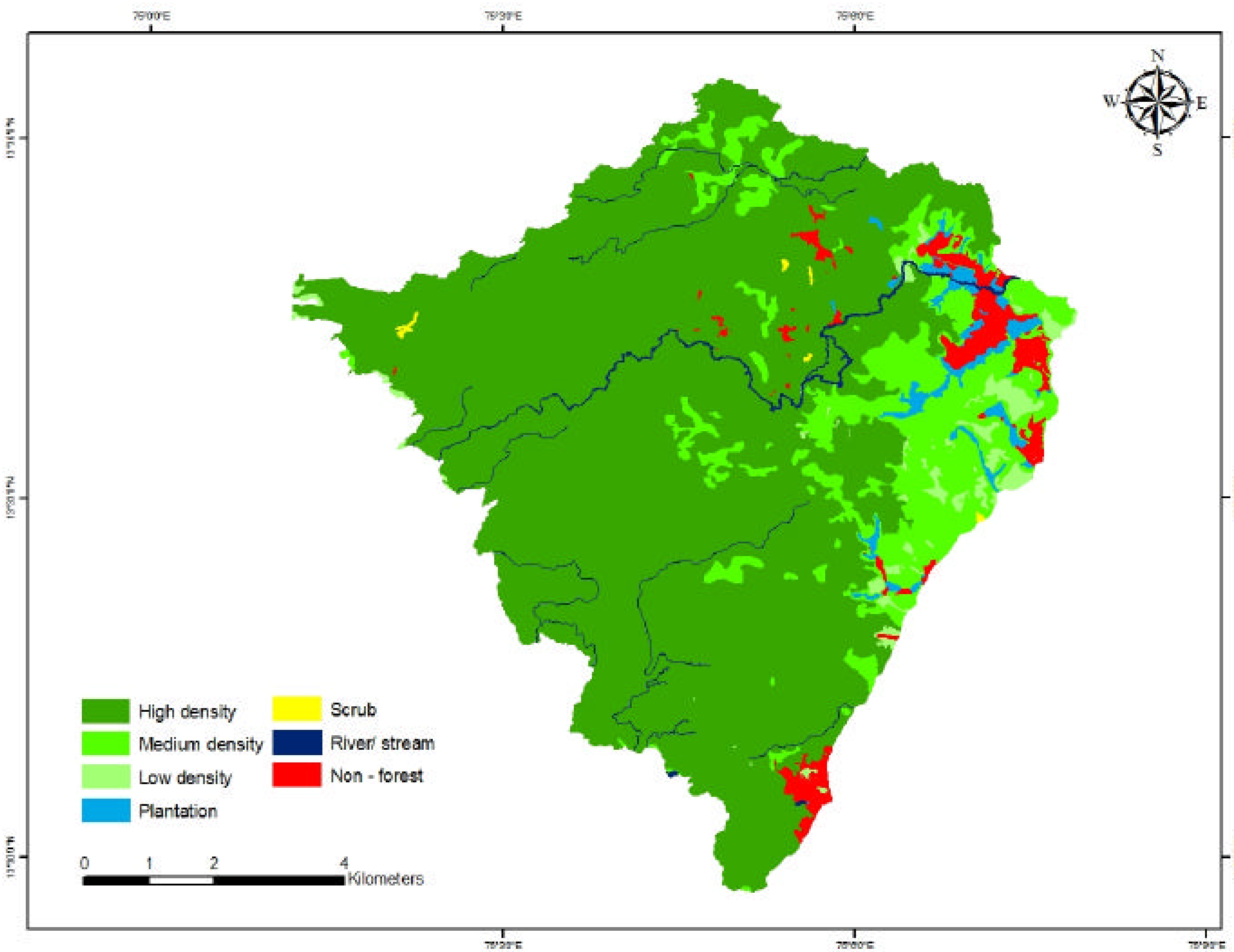

Fig. 4.6: Forest canopy density map.

4.2.7. Field work and ground truth collection

Ground truth or reconnaissance survey is important for any project work. Ground truth data are considered to be the most accurate (true) data available. An extensive field survey was undertaken from 18th of October, 2010 till 26th October, 2010. The field was planned in such a way that all the landuse classes are to be covered including variations in the forest canopy density. The false colour composite of LISS IV MX image was taken to the study area to relate the image characteristics and actual ground features. The vegetation/ land cover of the study area was marked on the satellite image during ground truth collection and geo-coordinates were recorded for the marked locations using Global Positioning System (GPS).

4.2.8. Database creation

Digital data base of the study area included various vector layers such as vegetation/ land cover type, tree crown density, drainage, settlement, road etc were prepared in the GIS environment. The details were given in Table. 4.4. Slope and aspect layers were generated from SRTM image of 90m resolution.

Table 4.4 : The input database layers.

Sl. No.	Name of layers	Format	Source	File type
1.	Vegetation/ land cover type	Polygon	Satellite image	Vector file
2.	Tree canopy density	Polygon	- do-	- do-
3.	Settlement	Polygon	- do-	- do-
4.	Drainage	Line	- do-	- do-
5.	Road	Line	- do-	- do-
6.	Slope	-	SRTM	Raster file
7.	Aspect	-	SRTM	Raster file

4.2.9. Habitat suitability analysis

The aim of any HEP is to evaluate an area on the basis of the suitability of the key habitat factors for the certain species. The characteristics of the habitat can be evaluated by using numerical rating schemes. The basic steps of HEP are as follows:

1. The area to be evaluated is divided into stands with relatively homogenous cover types using remote sensing or ground based studies.

2. A species is selected and its habitat and range requirements are investigated.

3. The HSI value is calculated for the species in the evaluated area using different ecological parameters. The HSI is defined as the value between 0 and 1 with the later being the best quality of habitat in the defined area.

All the different thematic layers were reclassified into habitat values by assigning numerical ranks on the scale of 1–4 based on their suitability (Table. 4.5).

Table 4.5: Habitat suitability rating

Class	Suitability rating
Highly suitable	1
Suitable	2
Moderately suitable	3
Least suitable	4

Habitat suitability rating for the vegetation/ land cover type is given in the Table. 4.6. The area classified as the evergreen forest was assigned the value 1 i.e. highly suitable for the king cobras as David and Vogel, 1996; Selich and Kestle, 2002; Leviton *et al.*, 2003; Anon, 2005; Das *et al.*, 2008 observed that the maximum abundance of the species were found in the humid jungles with thick undergrowths. Other than the preferred jungle habitat, king cobras are often seen in the grasslands (Narayan and Rosalind, 1990; Chaoji, 2010) therefore the grassland was assigned the value 2 as well as the *Areca catechu* plantations. The agricultural field and the water body were assigned the value 3 as king cobras are also seen foraging in the agricultural fields in search of rat snakes and are fond of water (Murthy *et al.*, 1990). While the areas, which is mostly disturbed due to human interferences were assigned the value 4 i.e. the least suitable habitat for the king cobra.

Table 4.6 : Habitat suitability rating forest cover and land use types.

Sl. No.	Class	Suitability rating
1.	Evergreen forest	1
2.	Grassland	2
3.	*Areca catechu* plantation	2
4.	Agriculture	3
5.	Scrub	3
6.	River/ stream	3
7.	*Acacia auriculiformis* Plantation	4
8.	*Casuarina equisetifolia* Plantation	4
9.	Settlement	4

Habitat suitability ratings were also allocated into different categories of the tree crown cover. As king cobra inhabits thick forest (Whitaker and Captain, 2004) so the highest suitability rating was given to the forest with high canopy density followed by the medium and the low density (Table. 4.7).

Table 4.7 : Habitat suitability rating for forest canopy density.

Sl. No.	Class	Suitability rating
1.	High density (>70%)	1
2.	Medium density (40% - 70%)	2
3.	Grassland	2
4.	*Areca catechu* plantation	2
5.	Low density (40% - 10%)	3
6.	Agriculture	3
7.	Scrub	3
8.	River/ stream	3
9.	*Acacia auriculiformis* Plantation	4
10.	*Casuarina equisetifolia* Plantation	4
11.	Settlement	4

Different buffer maps were prepared for the drainage (Fig. 4.7 (i) and ii), road (Fig. 4.8 (i) and ii) and settlement (Fig. 4.9 (i) and ii) and habitat suitability rating were assigned to different categories of these maps. There are four buffer layers generated for each category. As stated by Whitaker and Captain (2004) that king cobras were often encountered in the forest close to the river banks so the buffer area of less than 100m was given the highest suitability value of 1. The suitability rating decreases as the buffer layer increases (Table. 4.7). In case of road and settlement buffer maps the area near to the road and the settlement were considered as the least suitable area for the king cobras due to large disturbances by human interferences. Therefore, on increasing the buffer layers the suitability of the habitat increases i.e. area far away from the road or settlement were considered to be suitable habitat for king cobras. Details were given in the Table. 4.8 and Table. 4.9.

Table 4.8 : Habitat suitability rating for drainage buffer map.

Sl. No.	Class	Suitability rating
1.	Distance from watercourse (<100m)	1
2.	Distance from watercourse (100 - 200m)	2
3.	Distance from watercourse (200 - 300m)	3
4.	Distance from watercourse (>300m)	4

Table 4.9 : Habitat suitability rating for road buffer map.

Sl. No.	Class	Suitability rating
1.	Distance from road (> 150m)	1
2.	Distance from road (100 - 150m)	2
3.	Distance from road (50 - 100m)	3
4.	Distance from road (< 50m)	4

Table 4.10: Habitat suitability rating for settlement buffer map.

Sl. No.	Class	Suitability rating
1.	Distance from habitation (>300m)	1
2.	Distance from habitation (200 - 300m)	2
3.	Distance from habitation (100 - 200m)	3
4.	Distance from habitation (<100m)	4

Aspect and slope maps (Fig. 4.10 and Fig. 4.11) were generated from the Digital Elevation Model (DEM) of SRTM data. These maps were classified into four classes and suitability ranks were assigned into each class according to the king cobra habitat preferences (Table. 4.10 and Table. 4.11). As recorded from the radio–telemetry data, king cobra spends lot of time basking in the sun and as the southern aspect being warmer was assigned the highest rating. In Agumbe, most of these snakes were rescued from gentle slope, so the slope (0-8%) was attributed as 1.

Table 4.11: Habitat suitability rating for aspect map.

Sl. No.	Class	Suitability rating
1.	Southern	1
2.	Eastern	2
3.	Western	3
4.	Northern	4

Table 4.12: Habitat suitability rating for slope map.

Sl. No.	Class	Suitability rating
1.	Gentle slope (0 – 8%)	1
2.	Slopping (8 – 16%)	2
3.	Moderately steep (16 – 30%)	3
4.	Steep to very steep (30 - >65%)	4

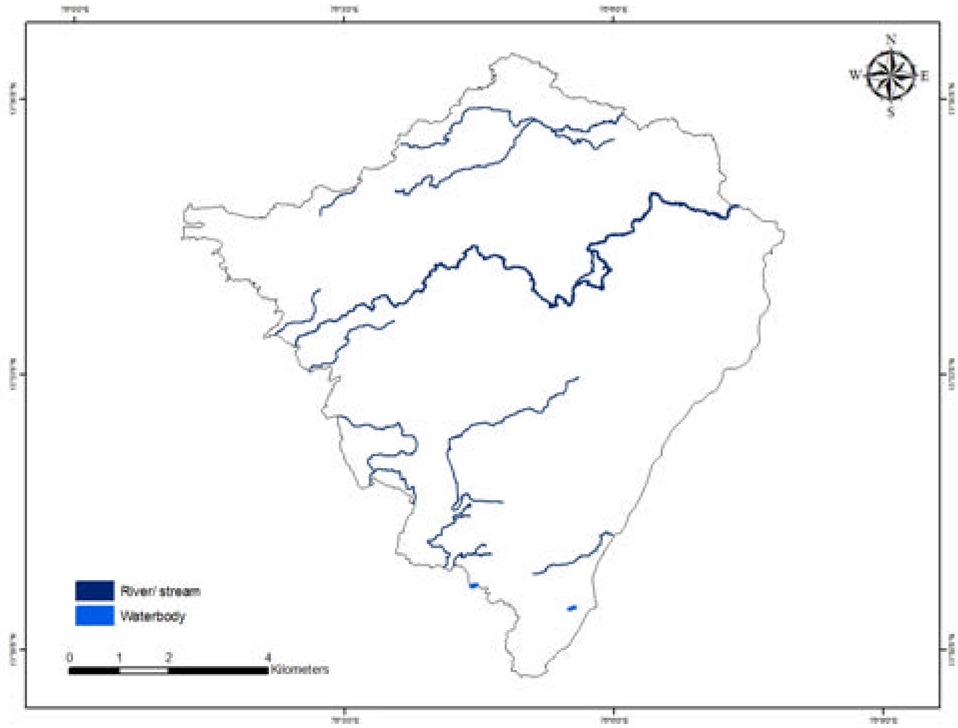

Fig. 4.7 (a): Drainage map.

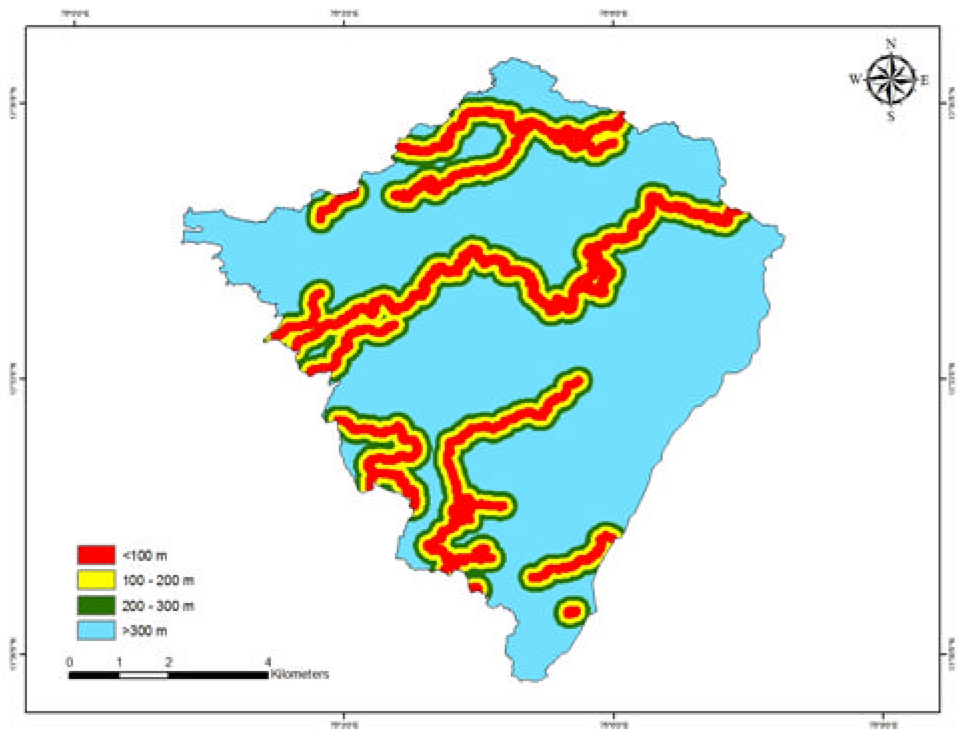

Fig. 4.7(b): Drainage buffer map.

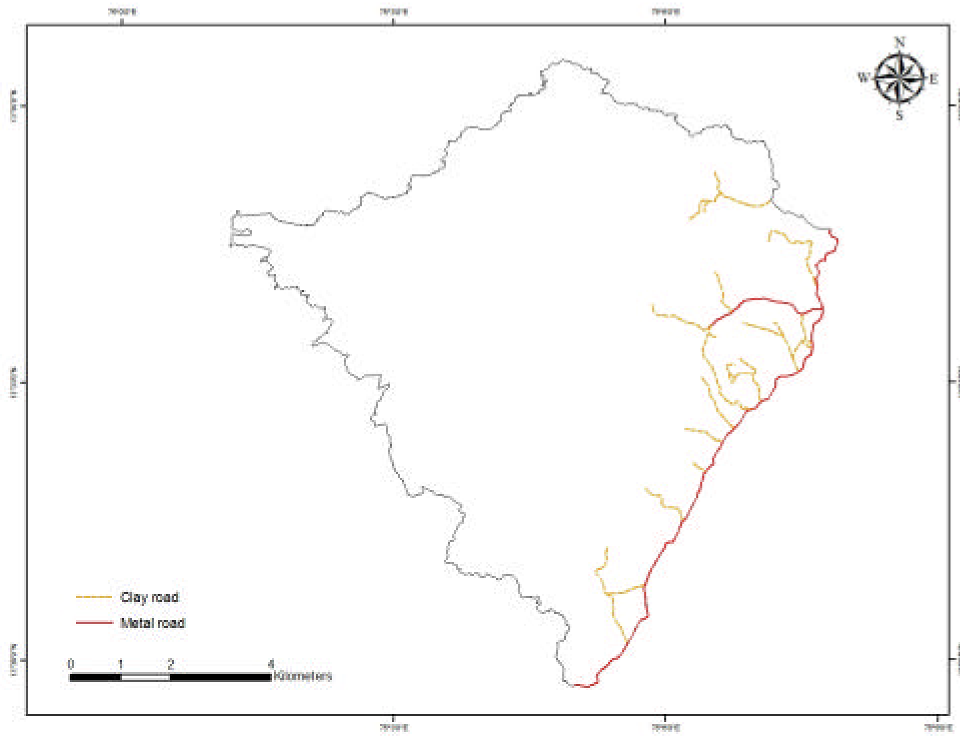

Fig. 4.8 (a): Road map.

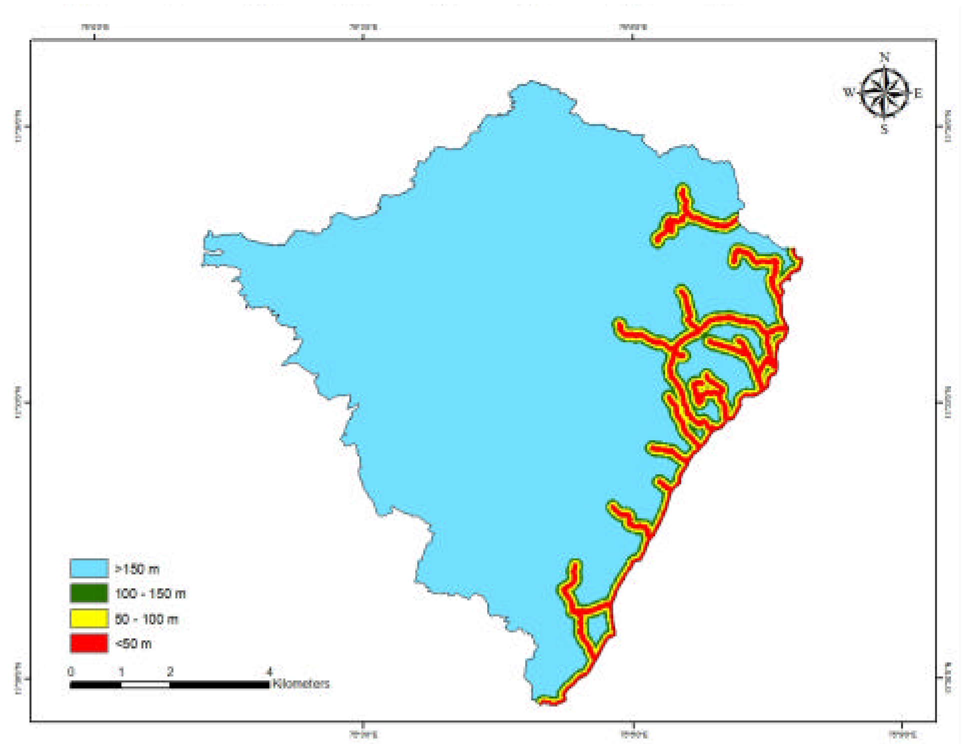

Fig. 4.8 (b): Road buffer map.

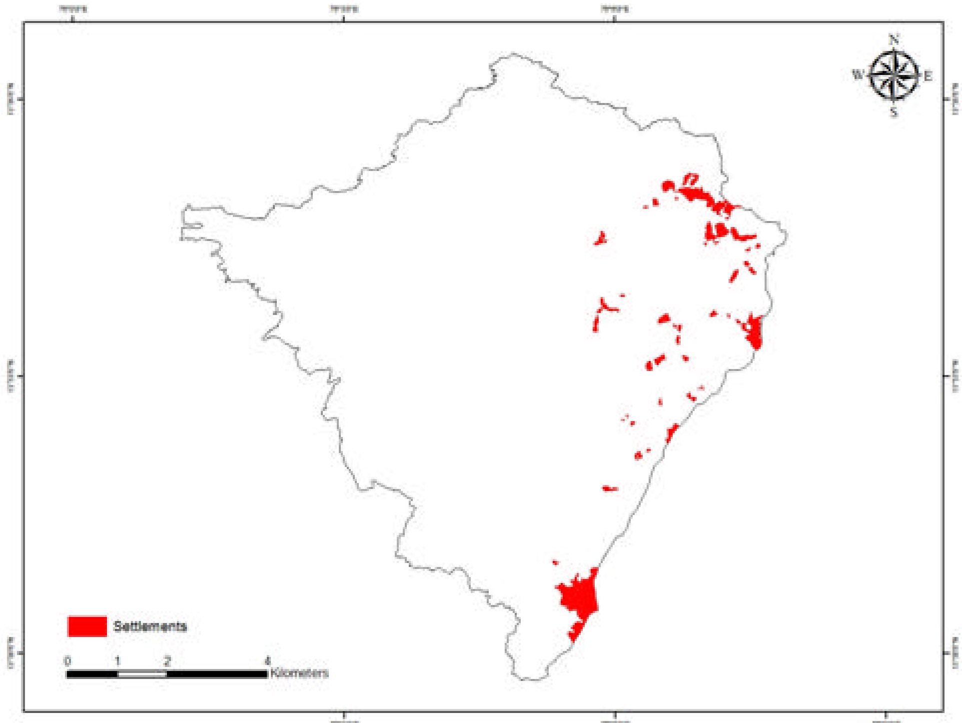

Fig. 4.9 (a): Settlement map.

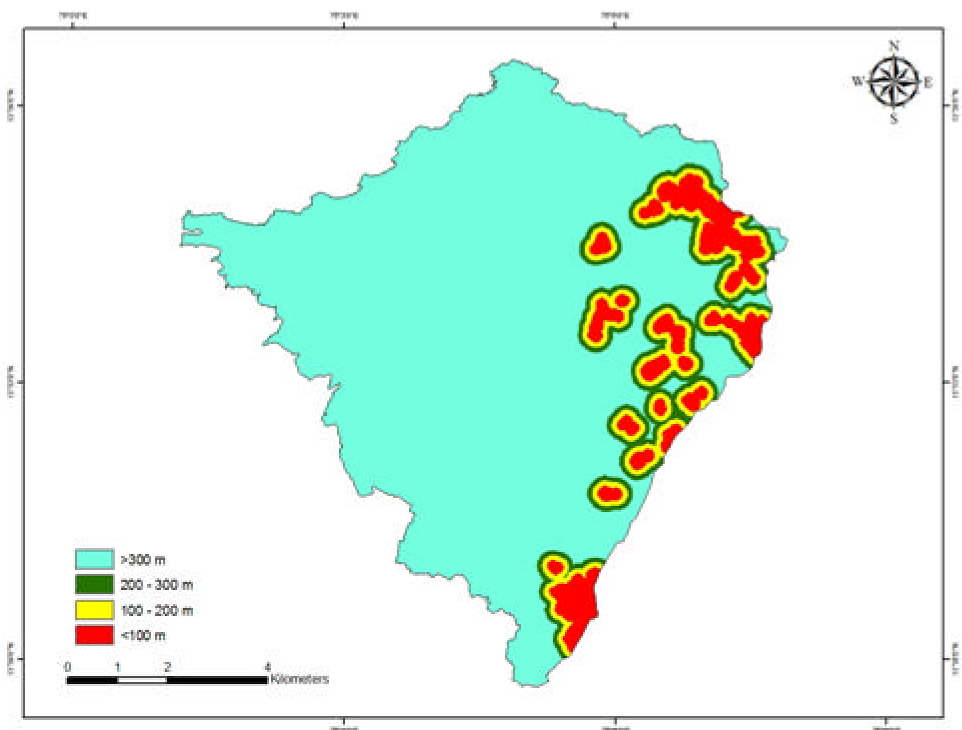

Fig. 4.9 (b): Settlement buffer map.

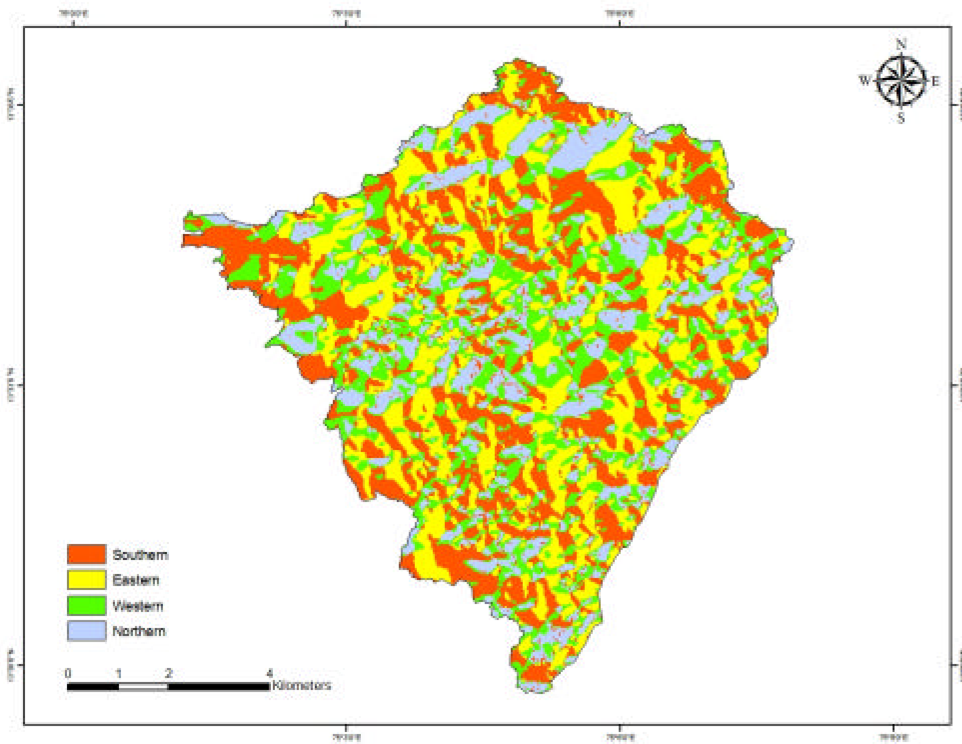

Fig. 4.10: Aspect map.

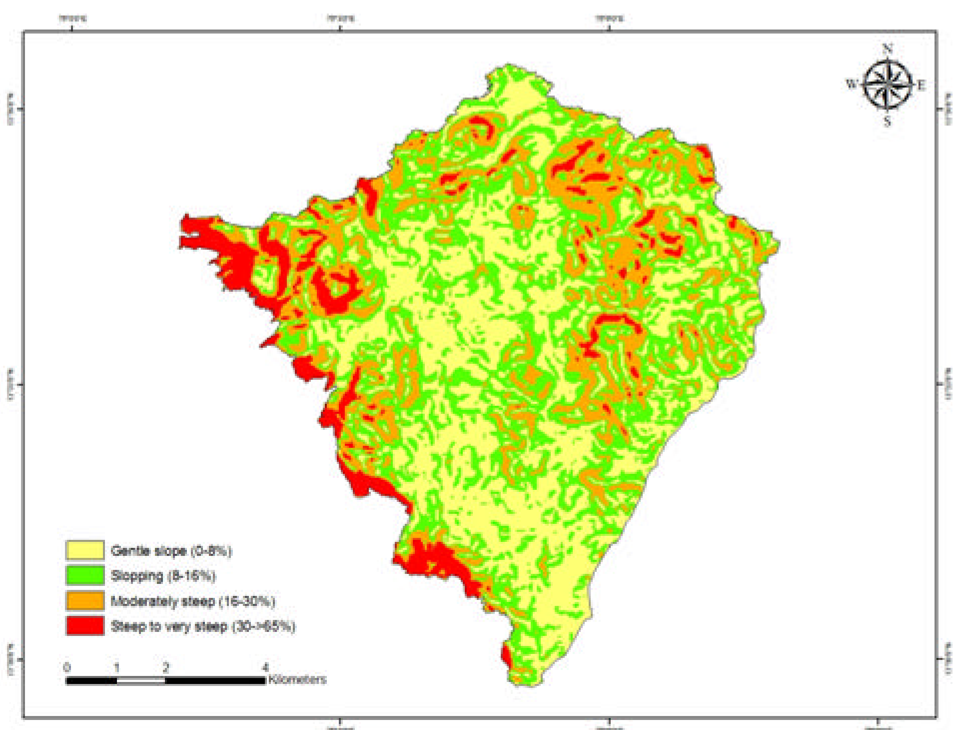

Fig. 4.11: Slope map.

After categorizing all thematic layers into four suitable classes, a linear additive model was used to evaluated the suitable habitat for king cobra. Weights were assigned to different layers which were derived using Analytical Hierarchy Process (AHP).

4.2.10. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a decision aiding method developed by Saaty (1980, 1985, 1990, 1991). It aims at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of decision maker and stresses the importance of the intuitive judgments of a decision maker as well as the consistency of the comparison of alternatives in the decision making process (Saaty, 1980).

Saaty (1980, 1985, 1990, 1991) developed the following steps for applying AHP:

1. Define the problem and determine its goal
2. Structure the hierarchy from the top (the objectives from a decision maker's view point) through the intermediate levels (criteria on which subsequent levels depend) to the lowest level which usually contains the list of alternatives.
3. Construct a set of pair–wise comparison matrices (size n X n) for each element in the level immediately above by using the relative scale measurement shown in Table. 4.12. The pair–wise comparisons are done in terms of which element dominates the other.
4. There are $n(n-1)/$ judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair–wise comparison.
5. Hierarchical synthesis is used to weight the eigen vectors by the weights of the criteria and the sum is taken over all weighted eigen vectors entries corresponding to those in the next lower level of the hierarchy.
6. Having made all the pair–wise comparisons, the consistency is determined by using eigen value, $?_{max}$, to calculate the consistency index, CI as follows: CI = $(?_{max} - n)/ (n - 1)$, where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with appropriate value in Table. 4.13. The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment should be reviewed and improved.
7. Steps 3–6 are performed for all levels in the hierarchy.

Table 4.13:

Pair–wise comparison scale for AHP preferences (Saaty, 1980, 1985, 1990, 1991).

Numerical rating	Verbal judgments of preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly preferred
5	Strongly preferred
4	Moderately to strongly preferred
3	Moderately preferred
2	Equally to moderately preferred
1	Equally preferred

Table 4.14: Average random consistency (RI) (Saaty, 1980, 1985, 1990, 1991).

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

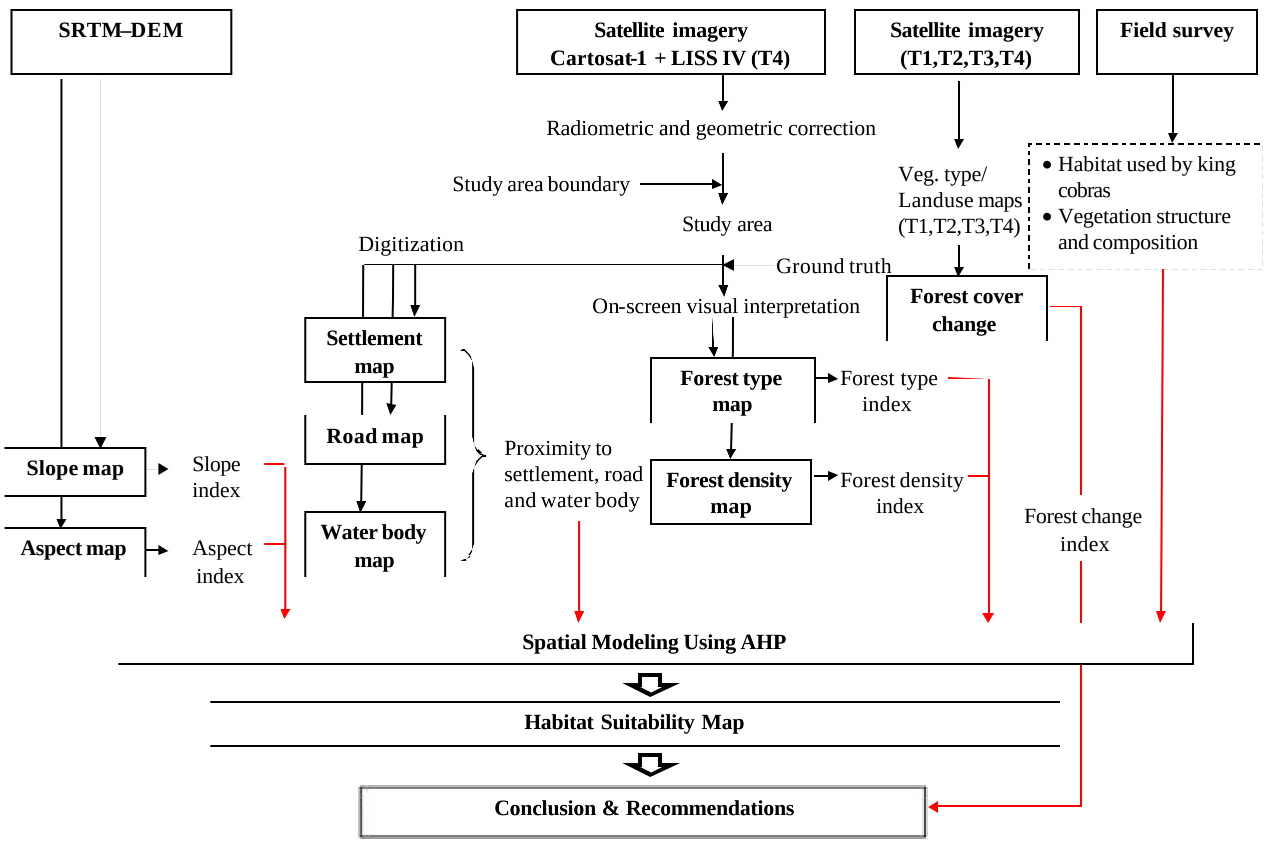

Fig. 4.12 : Paradigm of the study.

Chapter–5

RESULTS AND DISCUSSION

5.1 Forest cover and land use map

The land use and land cover map was classified into 8 major land use classes (Table.5.1), with 90.9% being covered by evergreen forest followed by plantations (2.8%) and grassland (2.7%) (Fig. 5.1). The study area consists of both perennial and annual streams occupying 0.4% of all the land cover types.

Table 5.1 : Area under different forest cover and land use types.

Sl. No.	Cover types	Area (km^2)	Percentage
1	Evergreen forest	72.75	90.94
2	*Areca catechu* plantation	2.21	2.76
3	Grassland	2.14	2.68
4	Settlement	1.42	1.78
5	Agriculture	0.61	0.76
6	Scrub	0.54	0.68
7	River/ stream	0.29	0.36
8	*Acacia auriculiformis* Plantation	0.01	0.01
9	*Casuarina equisetifolia* Plantation	0.03	0.04
Total		**80**	**100**

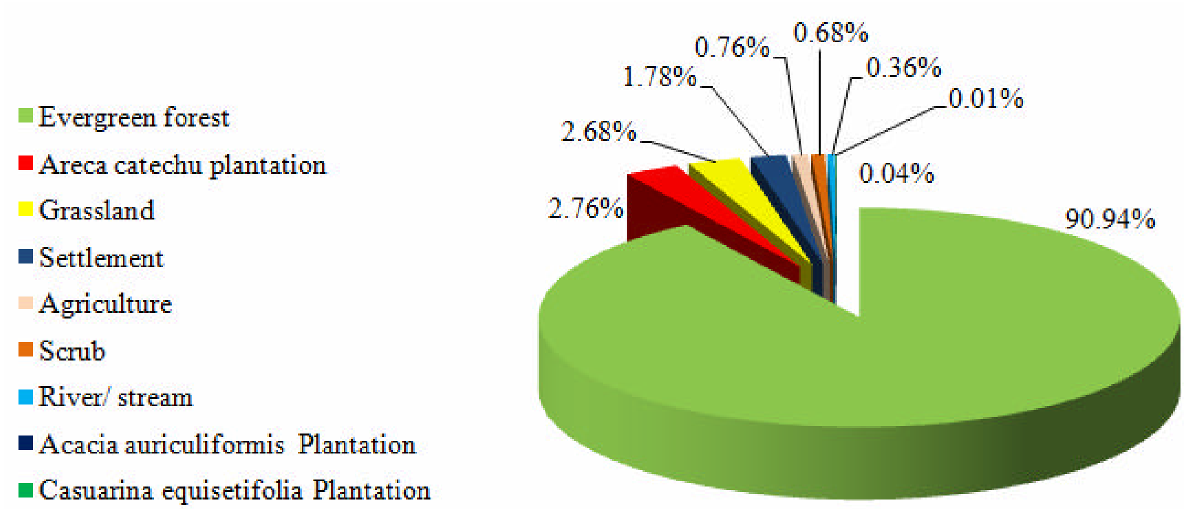

Fig .5.1 : Different land use and land cover types.

The *Areca catechu* plantation was found to be abundant of all the three types of plantations, occupying 97.98% as shown in the Fig. 5.2.

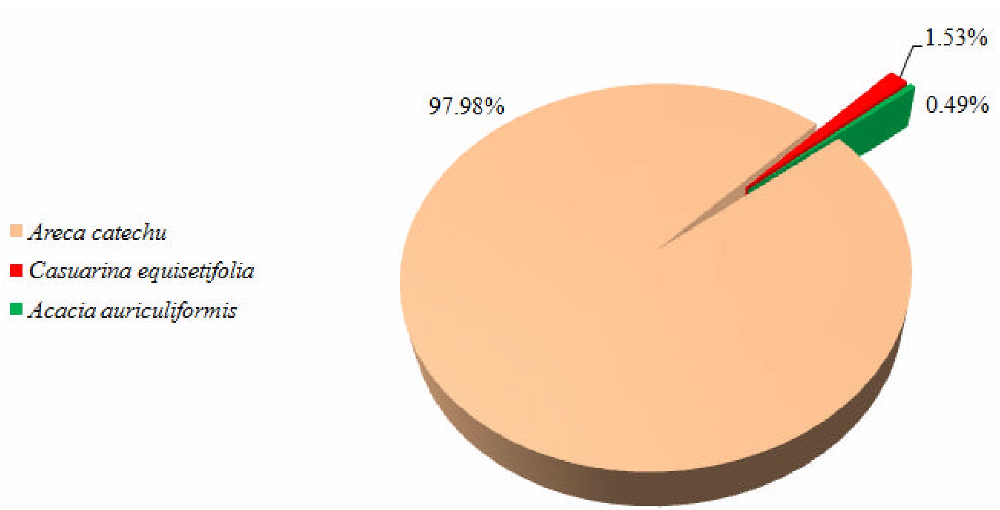

Fig .5.3 : Different types of plantations.

5.2. Forest change analysis

Forest cover and land use change of different time periods were prepared from the Landsat –1 MSS (February, 1973) (Fig. 5.4), Landsat–5 TM (January, 1991) (Fig. 5.5), Landsat–7 ETM+ (December, 2000) (Fig. 5.8) and IRS P6 L4MX (January, 2006) (Fig. 5.11). Forest cover and land use dynamics were summarized in the Table. 5.2.

Table 5.2 : Land use/land cover change from 1973 to 2006 through 1991 and 2000

Land use/ land cover change		**Area change in (km^2)**			
From	**To**	**1973-1991**	**1991-2000**	**2000-2006**	**1973-2006**
Scrub	Forest/plantation	0.478	0.171	-	0.649
Grassland	Forest/plantation	0.362	0.347	-	0.709
Forest	Settlement	0.003	-	-	0.003
Scrub	Settlement	0.159	-	-	0.159

From the table during the period 1973–2000, forest area increased by 1.36 km^2 where as 0.162 km^2 of forest and scrub land turned into settlement areas. Between the period 2000–2006, no changes in the land cover was observed (Fig. 10. and Fig. 11). Forest cover dynamics from the period 1973 to 1991, 1991 to 2000 and 1973 to 2006 were shown in the Fig. 5.6, Fig. 5.9 and Fig. 5.12 respectively.

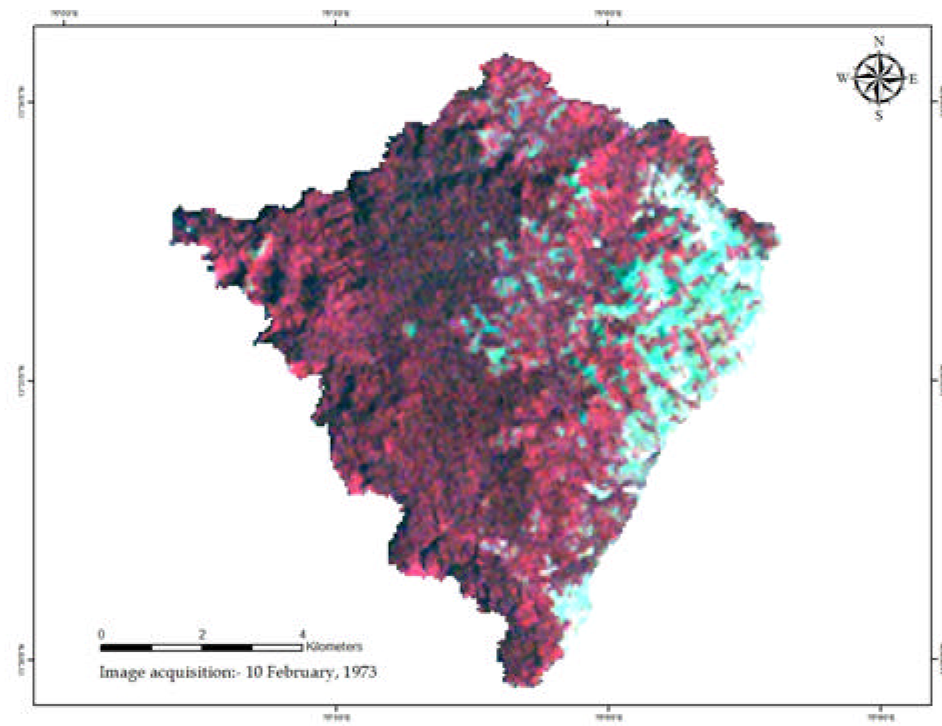

Fig .5.4: False colour composite (Landsat–1 MSS) of the study area in 1973.

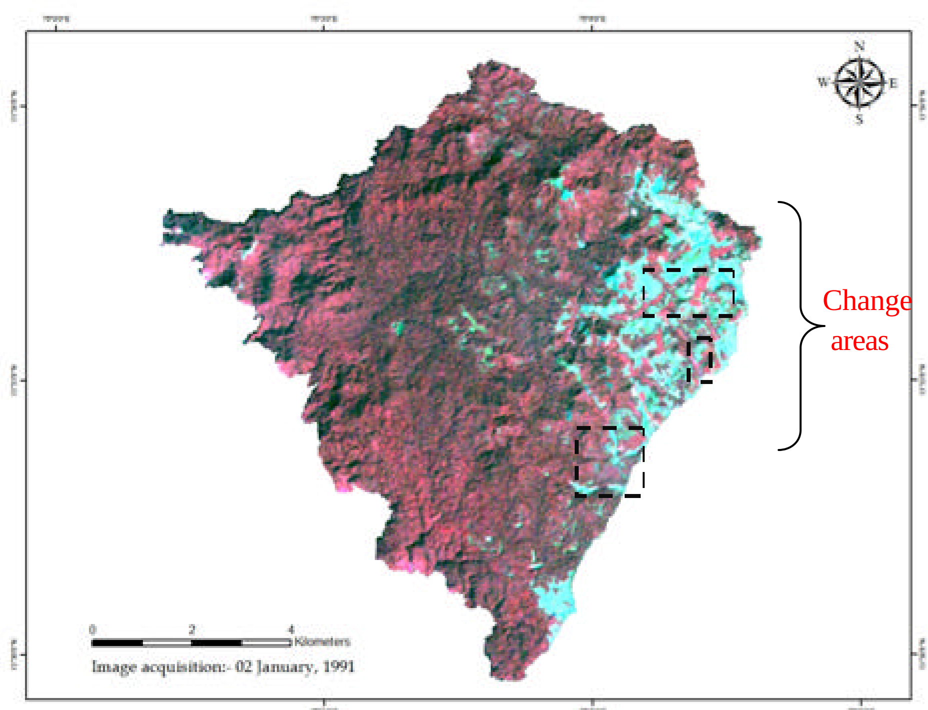

Fig .5.5: False colour composite (Landsat–5 TM) of the study area in 1991.

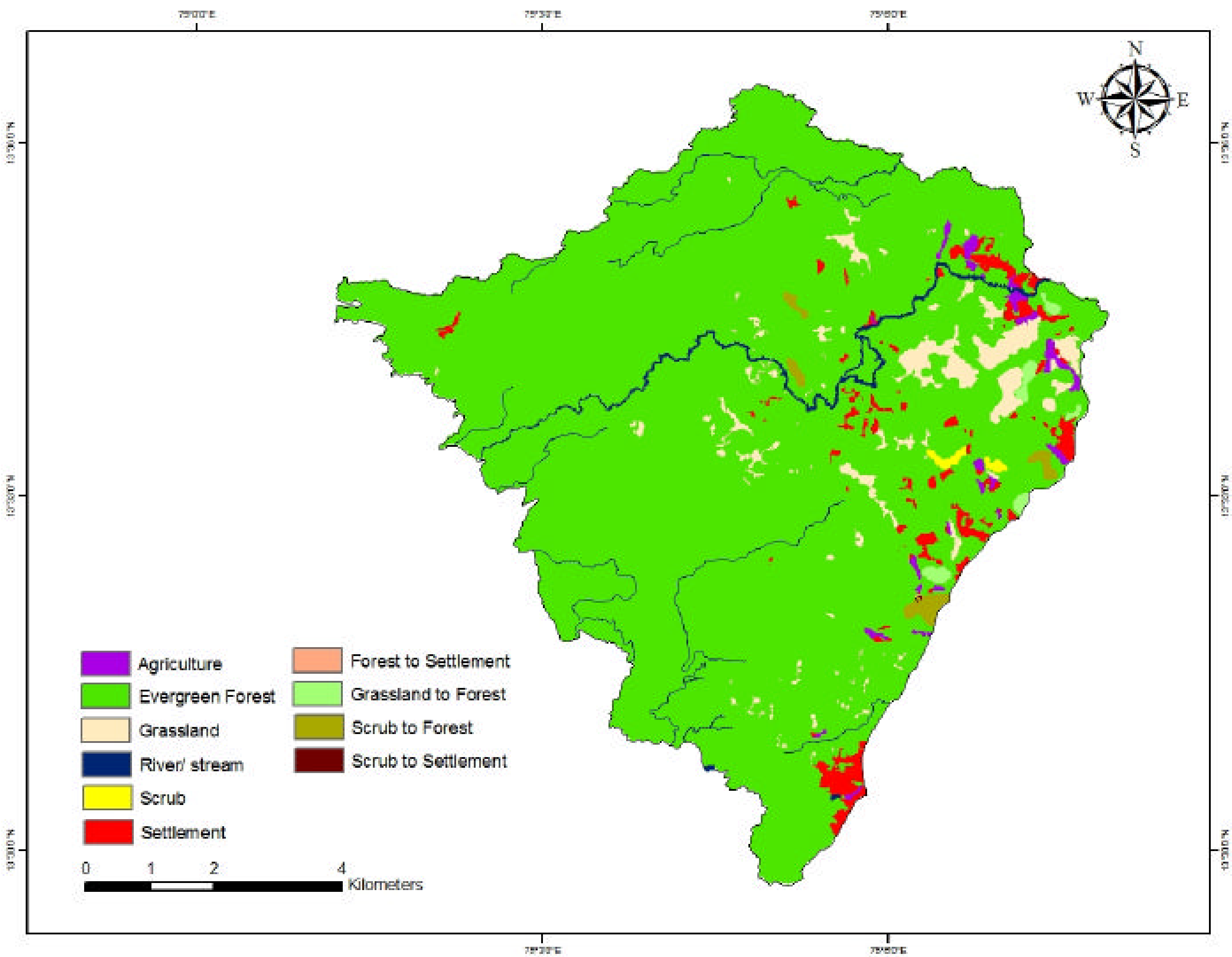

Fig .5.6: Forest cover and land use changes from 1973 to 1991.

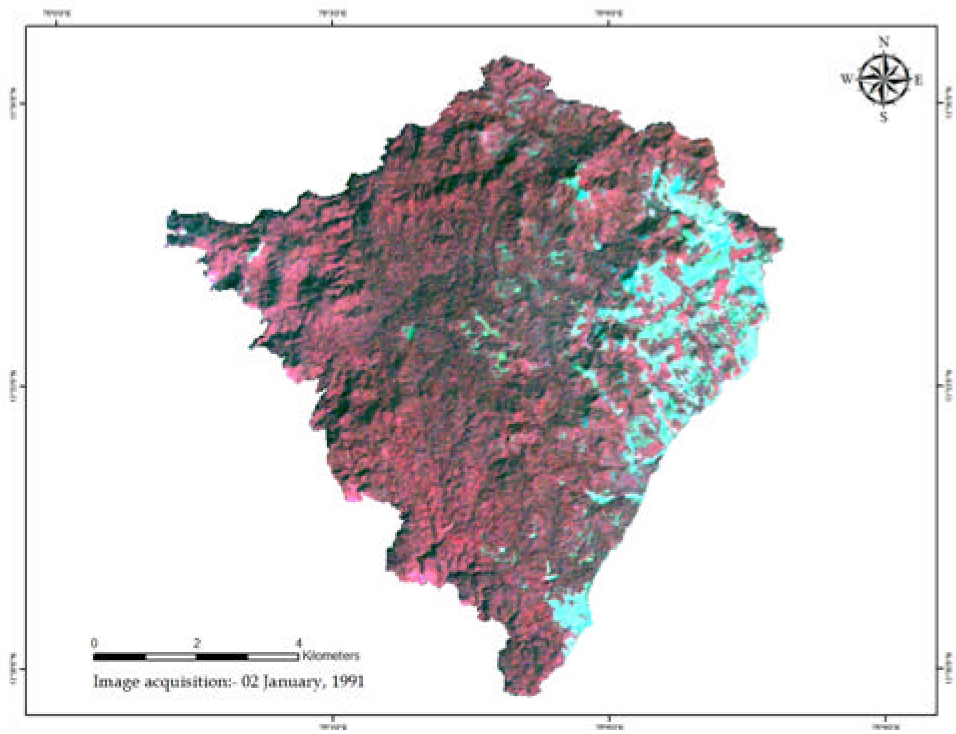

Fig .5.7 : False colour composite (Landsat–5 TM) of the study area in 1991.

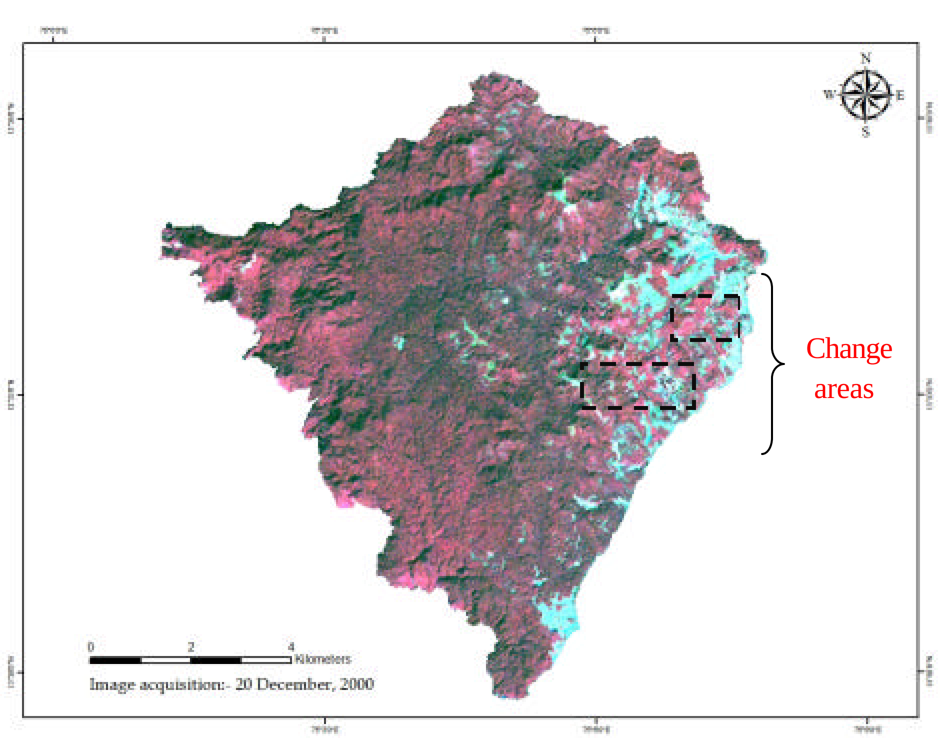

Fig .5.8: False colour composite (Landsat–7 ETM+) of the study area in 2000.

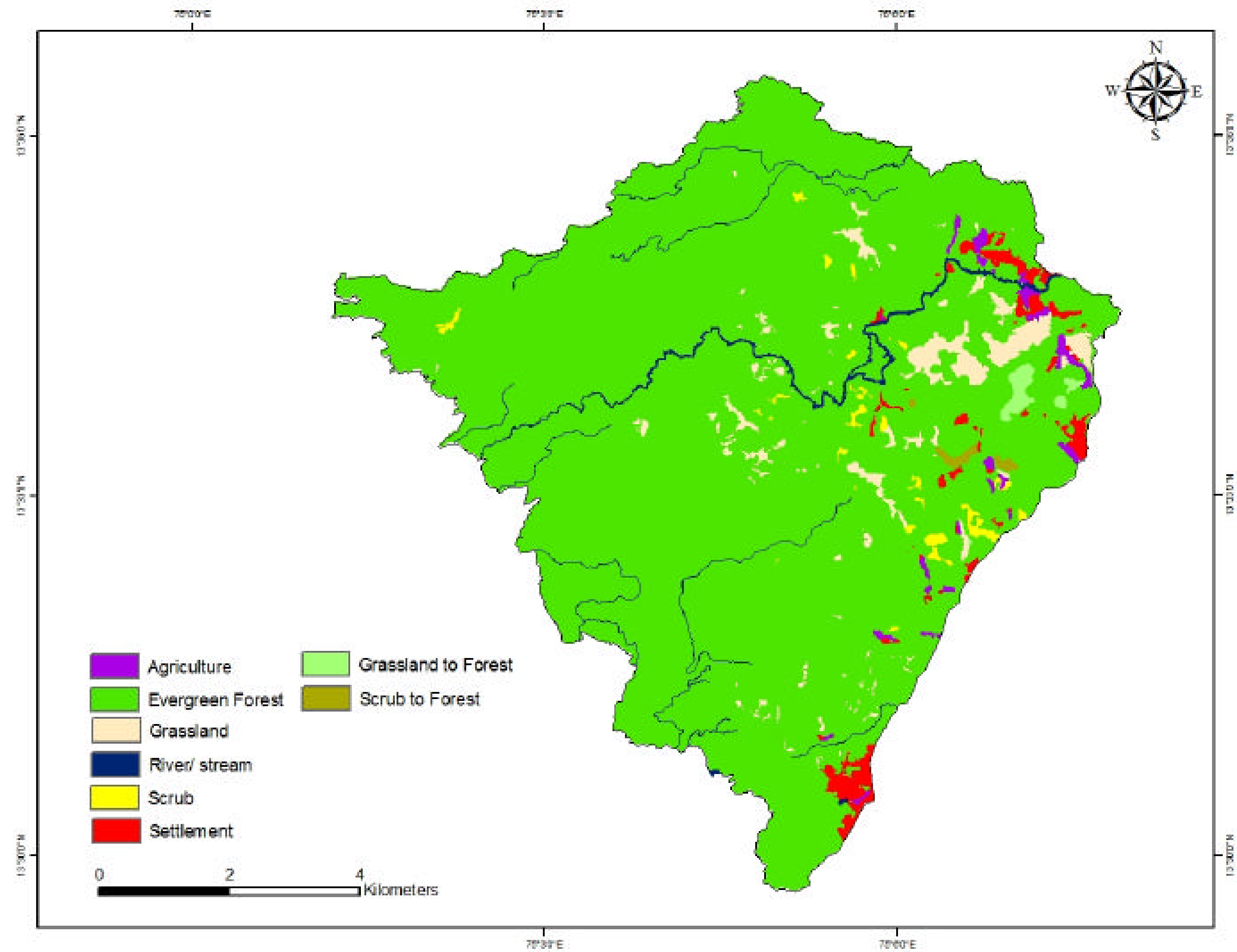

Fig .5.9: Forest cover and land use changes from 1991 to 2000.

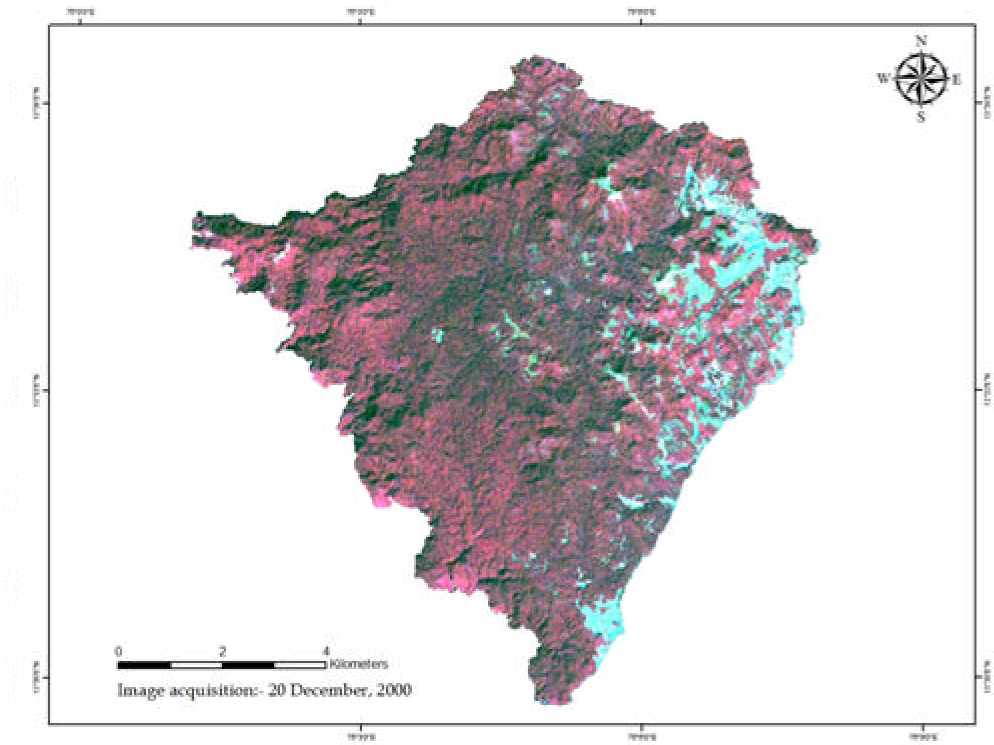

Fig .5.10: False colour composite (Landsat–7 ETM+) of the study area in 2000.

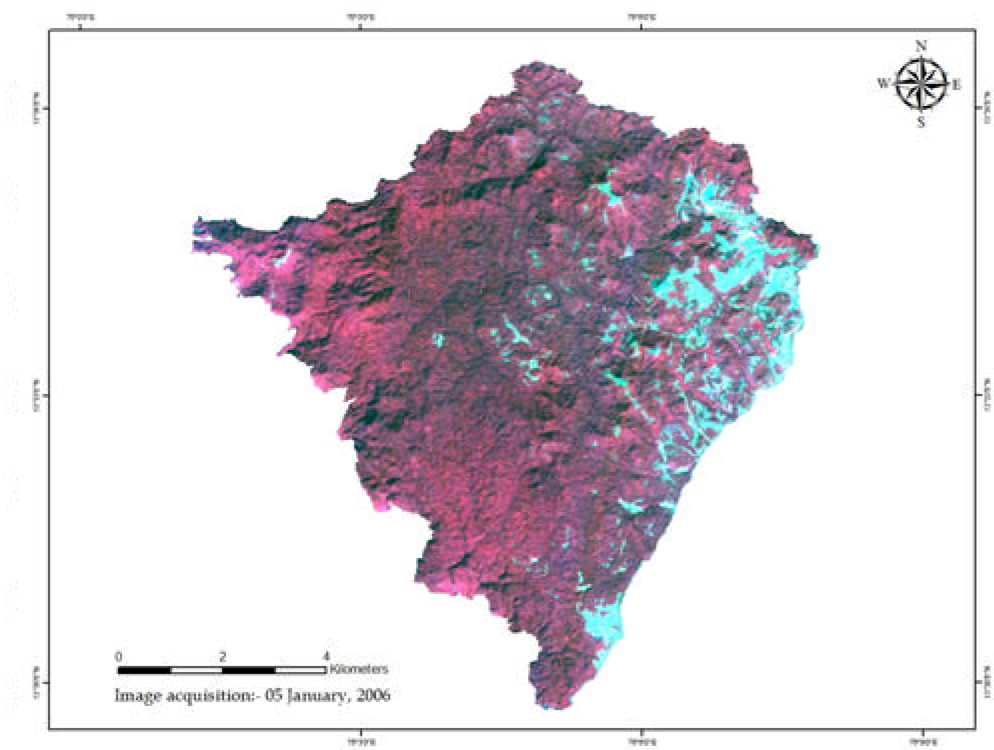

Fig .5.11: False colour composite (IRS P6 L4MX) of the study area in 2006.

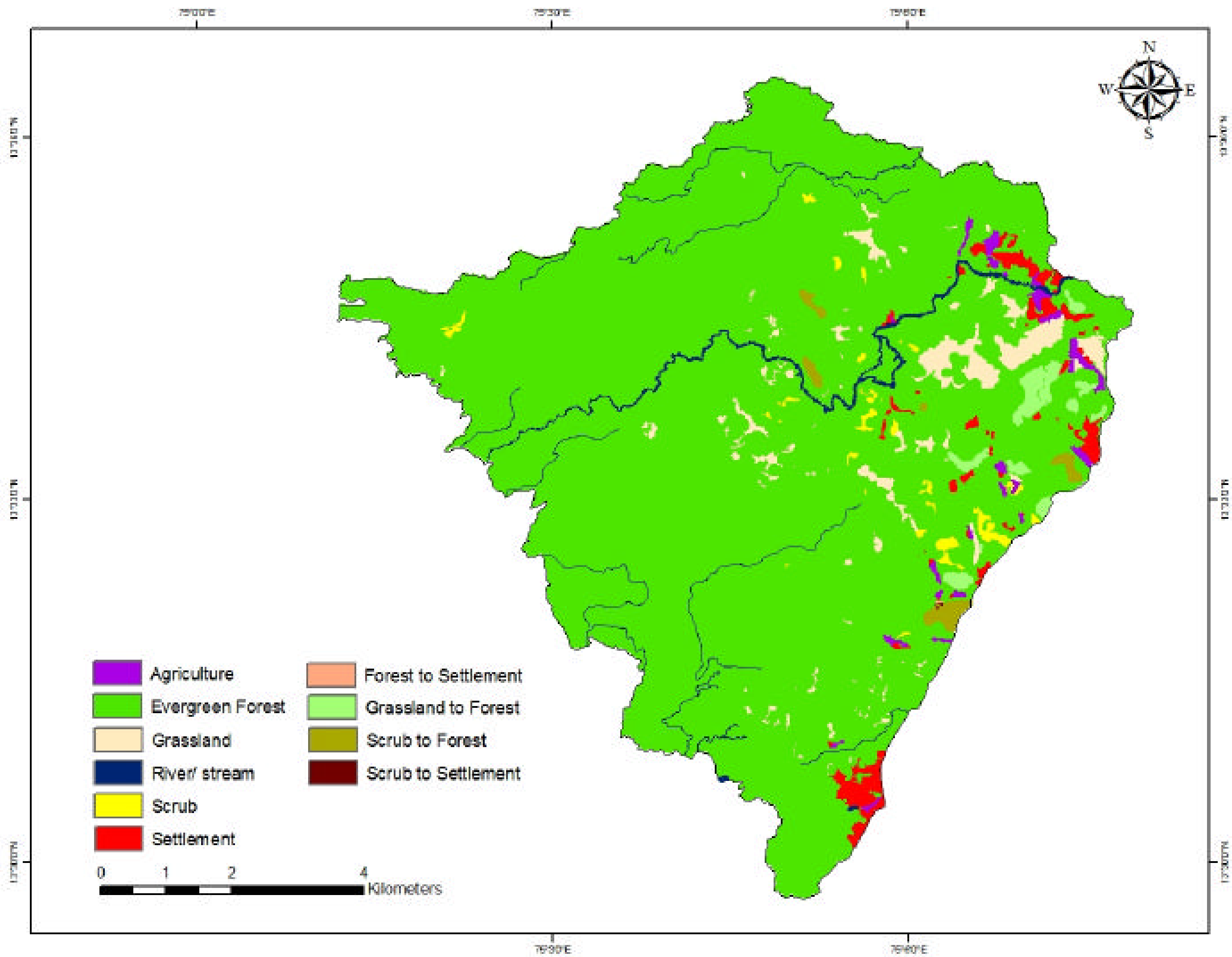

Fig .5.12 : Forest cover and land use changes from 1973 to 2006.

5.3. Habitat suitability map

The study uses the AHP technique to analyze the king cobra habitat suitability within the study area. The following steps were done by the AHP model:

- Prepare pair–wise comparison matrix;
- Synthesizing the pair–wise comparison matrix;
- Calculating the priority vector;
- Calculating the consistency ratio;
- Calculating the ?$_{max}$;
- Calculating the consistency index, CI;
- Selecting appropriate value of the random consistency ratio;

Pair–wise comparison matrix of seven variables for the study area is shown in the Table. 5.2.

Table 5.3 : Pair–wise comparison matrix.

	Forest type	Forest density	Drainage	Slope	Aspect	Road	Settlement
Forest type	1	2	3	4	5	7	8
Forest density	0.50	1	3	4	5	6	7
Drainage	0.33	0.33	1	2	4	5	6
Slope	0.25	0.25	0.50	1	2	5	6
Aspect	0.20	0.20	0.25	0.50	1	3	4
Road	0.14	0.17	0.20	0.20	0.33	1	2
Settlement	0.13	0.14	0.17	0.17	0.25	0.50	1
Total	**2.55**	**4.09**	**8.12**	**11.87**	**17.58**	**27.50**	**34.00**

The pair–wise comparison matrix was then synthesized by dividing each element of the matrix by its column total. The priority vector in Table. 5.3. can be obtained by finding the row averages.

Table 5.4 : The synthesized matrix.

	Forest type	Forest density	Drainage	Slope	Aspect	Road	Settlement	Priority vector
Forest type	0.39	0.78	1.18	1.57	1.96	2.74	3.14	**1.68**
Forest density	0.20	0.39	1.18	1.57	1.96	2.35	2.74	**1.48**
Drainage	0.13	0.13	0.39	0.78	1.57	1.96	2.35	**1.05**
Slope	0.10	0.10	0.20	0.39	0.78	1.96	2.35	**0.84**
Aspect	0.08	0.08	0.10	0.20	0.39	1.18	1.57	**0.51**
Road	0.06	0.07	0.08	0.08	0.13	0.39	0.78	**0.23**
Settlement	0.05	0.06	0.07	0.07	0.10	0.20	0.39	**0.13**

?$_{max}$ = 7.643; Consistency Index (CI) = 0.107; Consistency Ratio (CR) = 0.081

As the value of CR was less than 0.1, the above calculation is acceptable.

The weightages of various variables was obtained from the above analysis and then the linear additive equation was calculated as follows:

HSI = 1.68 * VTI + 1.48 * CCI + 1.05 * DI + 0.84 * ASI + 0.51 * SLI + 0.23 * RI + 0.13* SI

where,

HSI = Habitat Suitability Index

VTI = Vegetation Type Index

CCI = Canopy Crown Index

DI = Drainage Index

ASI = Aspect Index

SLI = Slope Index

RI = Road Index

SI = Settlement Index

The habitat suitability map for king cobra is shown in the Fig. 5.14.The different habitat suitability classes are discussed in the Table. 5.4.

Table 5.5 : Habitat suitability status.

Sl. No.	Suitability class	Area (km^2)
1.	Highly suitable	33.71
2.	Suitable	33.54
3.	Moderately suitable	10.78
4.	Least suitable	1.97
Total		**80**

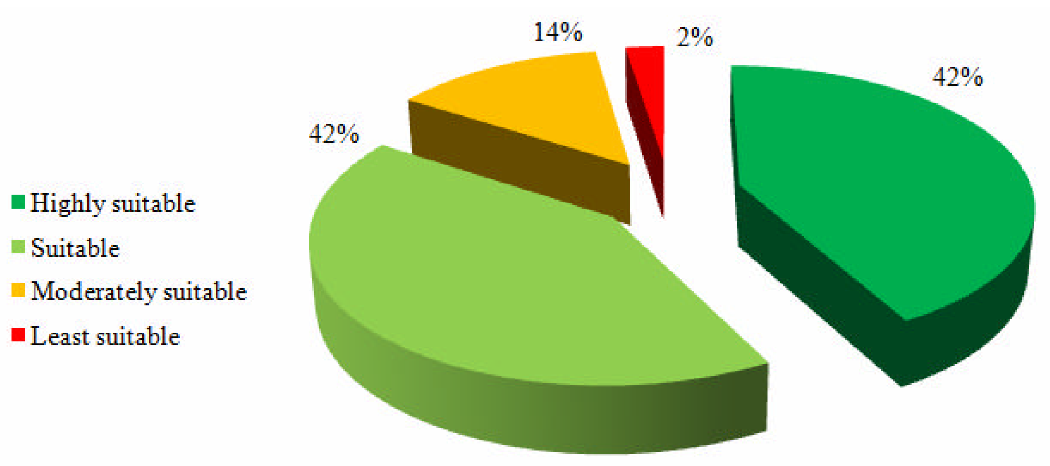

Fig .5.13: Percentages of different suitability classes.

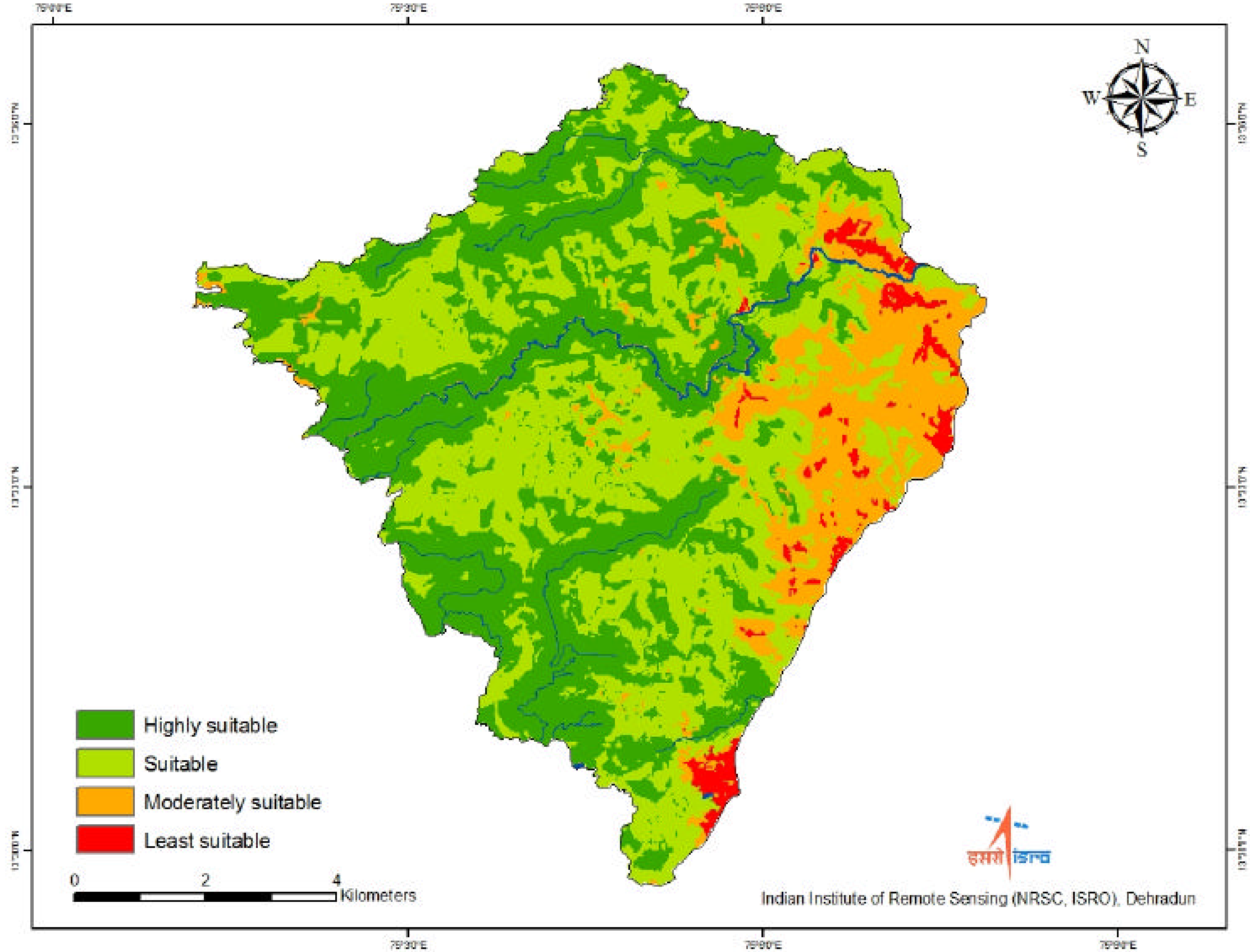

Fig .5.14: King cobra habitat suitability map.

Chapter–6

CONCLUSION AND RECOMMENDATIONS

As seen from the temporal data, the rate of deforestation within the study area is relatively less as compared to other forested land in India. Since the area is not easily accessible, that has indirectly helped in the conservation of the forest. During the period form 1973 to 2000, 1.35 km^2 area of plantations took place, which is mostly of *Areca catechu* (Arecanut). *Areca catechu* being a fast growing cash crop is more preferred among the locals. Other than Arecanut, the State Forest department initiated both monoculture and mixed plantations of *Acacia auriculiformis* and *Casuarina equisetifolia* seen in some small patches within the study area. Natural grasslands are important ecosystems and need to be conserved. But some of the afforestations were carried out on these grasslands particularly the one seen on the way to the Agumbe Rainforest Research Station (ARRS).

The Habitat Suitability Index (HSI) model classified the areas into four different classes i.e. highly suitable, suitable, moderately suitable and least suitable. Majority of the area i.e. 67.25 km^2 was found to be highly suitable to suitable for king cobra habitat. An area of 10.78 km^2 turned out to be moderately suitable and while an area of 1.97 km^2 around human habitations was categorized into least suitable habitat. Though the study wasn't carried out in the neighbouring protected areas. It is also expected that the jungles of Kudermukh National Park, Bhadra Wildlife Sanctuary and Someshwara Wildlife Santuary would act as suitable habitats for king cobras.

With a species like king cobra, habitat may not be a key factor that determines its distribution it is the intra and inter specific interactions like competitions and predation that actually determines the distribution and abundance of a species. Although settlement areas were listed as the least suitable habitat in the HSI model, ARRS field track record shows king cobras were often cited from areas like the paddy fields and the arecanut plantations. The fact behind this might be the easy availability of prey species such as Indian rat snake, which feeds on rats found abundantly on these areas.

The king cobra radiotelemetry project carried out by ARRS in March, 2008 revealed many unknown secrets of these giant snakes. This will further help in the better management and conservation of these endangered snakes. We believe that the rainforest of Southern India has been the home for king cobra for many years. The untiring efforts made by Mr. Romulus Whitaker and his team to declare this area as the World's first king cobra Sanctuary will definitely help in the conservation and protection of these majestic snakes. Portraying king cobra as a flag ship species bio–diversity of this pristine forest can also be well protected.

Chapter–7

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