Research Journal of

Environmental Sciences

ISSN 1819-3412

Academic Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 5 (2): 105-123, 2011
ISSN 1819-3412 / DOI: 10.3923/rjes.2011.105.123

Monitoring Forest Cover Changes Using Remote Sensing and GIS: A Global Prospective

Devendra Kumar
Ecosystem Research Laboratory, Centre for Advanced Studies in Botany, School of Life Science, North-Eastern Hill University, Shillong 793022, Meghalaya, India

ABSTRACT

Forest is a major resource and play vital role in maintaining the ecological balance and environmental setup. Over utilization of forest resources has resulted in the depletion. The changes in forest cover are the matter of global concern due to its ability of promoting role in carbon cycle. This study reviewed the potential application of remote sensing worldwide for assessing and monitoring the changes in forest cover during the past decades, an increasing urgent task. However, advances in the spatial and spectral resolutions of sensors are available for ecologist which mainly feasible, to study the certain aspects of biological diversity through direct remote sensing. Global and regional scale of temporal remote sensed data is now available for monitoring the changes in forest cover over the last few decades viz. Landsat, MODIS, ASTER, AWiFS and SPOT. Monitoring the changes in forest cover at global and regional scale can contribute to reducing the uncertainties in estimates of emissions of green house gases from deforestation. Remote sensing coupled with GIS (Geographical Information System) as a potential tool, for monitoring the changes in land cover at regional as well as global scale in developing countries, mainly by identifying the conservation priorities in global hotspots, rate of deforestation and quantification of overall forest cover loss at finer scale.

Key words: Forest cover changes, remote sensing, deforestation, landsat, satellite, sensor

INTRODUCTION

Forests provide several ecologically, economically and social perspective functions to life viz., water supplies, soil conservation, nutrient cycling, species and genetic diversity and green house gases regulation (Rao and Pand, 2001). Increasing anthropogenic pressure such as land use/land cover changes, air, water and soil pollution (Fearnside, 2001; Sherbinin *et al.*, 2007), degradation of soil quality and losses in biological diversity are some important threat to productivity of ecosystem at regional and global scales (Kilic *et al.*, 2004; Trigg *et al.*, 2006). Current scenario illustrated that the agricultural practices have been the important factor for land transformation in this world. The increment of nearly one third of the earth's land surface is currently being used for growing crops or grazing cattle (FAO, 2004). Much of this agriculture land has been created at the expense of natural forests, grassland and wetlands that provide valuable habitats for species and services for humankind (MEA, 2003). It is estimated that approximately half of the original forests (ca. 8000 year ago) have been vanished (Billington *et al.*, 1996). As the rate of habitat and species destruction continue to raise, the need for conserving the biological diversity increasingly imperative during the last decades (Wilson and Peter, 1988; Kondratyev, 1998). In order to design the meaningful conservation strategies, comprehensive information and current status of forest cover/forest types on the basis species composition as well as information of changes in forest cover with time, is required. It is difficult task, to acquire such information on the basis of field assessment and monitoring (Heywood, 1995). Forest cover changes can be documented locally through field-based studies; however, at regional to global scales it requires an approach based on remote sensing (Trigg *et al.*, 2006; Kumar *et al.*, 2010a, b). Remote sensing involves measuring or acquiring information about surface properties using sensors typically found onboard aircraft or satellites (Colwell, 1983).

Remote sensing provide a systematic, synoptic view of earth cover at regular time intervals and useful for changes in land cover and to revels aspect of biological diversity directly (Hall *et al.*, 1988; Roughgarden *et al.*, 1991; Turner *et al.*, 2003; Cohen and Goward, 2004; Kumar *et al.*, 2010a, c). Satellite image classification, change analysis (Armenteras *et al.*, 2004) and econometric modelling are extensively used to identify the rates and drivers of deforestation in global hotspots of biodiversity and tropical ecosystems. Recently, a joint collaborative efforts between NASA (National Aeronautics and Space Administration) and World Conservation Union, IUCN (International Union for Conservation of Nature) for conserving the biological diversity in terms of driver of changes in forest cover and rate of deforestation in overall 34 global hotspots has been signed (Millington *et al.*, 2003).

However, many airborne and satellite sensors with high spatial and spectral resolution, are currently available, to study land cover changes for over the last decades such as Landsat (approximately 30 m pixel size). Landsat is a series of US satellites launched between 1972 and 1999 (Goward *et al.*, 2001; USGS, 2003; Arvidson *et al.*, 2006; Trigg *et al.*, 2006) for monitoring the temporal and spatial changes in land cover (Kumar *et al.*, 2010c). The satellites main sensors have been the Multispectral Scanner (MSS) carried by Landsat 1-5, the Thematic Mapper (TM) carried on Landsat 4-5 and Enhanced Thematic Mapper Plus (ETM+) carried on current Lansat 7 satellite. Landsat data have relied on to perform detailed assessments of changes in tropical forests worldwide (Foody, 2003; Kumar *et al.*, 2010a). Combination of the three Landsat sensors, MSS, TM and ETM+, have provided the longest time series of images suitable for monitoring changes in the earth's vegetation at high spatial resolution. A part of the Landsat satellite images, several sensors have the potential tool to provide useful data to monitor the forest cover loss in different parts of the world. The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor carried on NASA's Aqua and Terra satellite provides global map of percent tree cover, vegetation fires and land cover changes (Savtchenko *et al.*, 2004). However, MODIS data has capacity for global monitoring and forest loss is limited by its 250 m spatial resolution. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a high spatial resolution (15 to 90 m) multispectral imager with along-track stereo capabilities (Abrams, 2000). The Indian multisensor ResourceSat's Advanced Wide Field Sensor (AWiFS) uses twin cameras to provide a spatial resolution (56 m) of forest cover loss. The high resolution instrument SPOT (European sensor) can provide images at spatial resolution from 5 to 20 m and a useful complement to Landsat for mapping changes in land cover (King, 2002).

In several studies, the satellite remote sensing at regional scale have been used to monitoring the changes in forest cover on the basis of spatial and temporal remote sensed data, throughout worldwide. Fine resolution, spatially explicit data on landscape fragmentation were required to understand the impact of forest cover changes on biological diversity (Liu *et al.*, 2003; Kumar *et al.*, 2010a). Satellites data have became a major application in change detection because of the repetitive coverage of the satellites at short time intervals (Mas, 2005). Using remote sensing, spatially explicit time series of environmental data can be quickly obtained and update (Dewan and

Yamaguchi, 2009), with GIS (Geographical Information System) techniques provide information about landscape history, topography, soil, rainfall, temperature and factors on which the distribution of species depends (Noss, 2001).

This study attempts to provide a review of the utility of remote sensing coupled with GIS to understand the changes of forest cover at global and regional scale based on the, highlight of several case studies and emphasized has been given to compare the changes of forest cover in different forest types at temporal and spatial scale, of the Indo-Burma hotspot region during last two decades.

DEFINITIONS

Forest is a minimum area of land of 0.05-1.0 ha with tree crown cover (or equivalent stocking level) of more than 10-30% with trees with the potential to reach a minimum height of 2-5 m at maturity in situ. A forest may consist either of closed forest formations where trees of various stories and undergrowth cover a high proportion of the ground or open forest (UNFCCC, 2001).

Deforestation is the direct human-induced conversion of forested land to non-forested land (UNFCCC, 2001).

GLOBAL FOREST COVER MAPPING

Forest cover mapping provides a static depiction of land cover. It does not on its own indicate changes within forest area. However, forest cover maps fulfil several functions in monitoring changes in forest cover (Kumar *et al.*, 2010a, b). These maps serve as a baseline against which future change can be assessed and also facilitate to conserve and establish forest areas that need to be monitored for change. When using a land cover map to assess future change, consistent methodology and spatial resolution are critically important for interpretation of results. Static forest cover maps used in concert with change detection studies provide the basis for establishing rates of change and are particularly useful as a stratification tool in developing sampling approaches for forest change estimation (Mayaux *et al.*, 2005; Achard *et al.*, 2007).

Land cover classes of the whole world were mapped for the first time by Tucker *et al.* (1985) by using 4 km spatial remote sensed at different continent level in the mid of 1980s. Consequently during late 1990s, Loveland *et al.* (2000) produced pan-continental map at around 1 km spatial resolution from the NOAA-AVHRR sensor data. More recently new global land cover datasets at finer resolution (250-500 m) were generated from TERRA-MODIS (Hansen *et al.*, 2003) or ENVISAT-MERIS (Arino *et al.*, 2007) sensors (Table 1).

Table 1: Main global land cover map derived from remote sensing data from 1 km to 300 m spatial resolution

Map title	Spatial resolution	Sensor	Sources
IGBP	1 km (Global)	NOAA-AVHRR	Loveland *et al.* (1999)
University of Maryland (UMD)	1 km (Global)	NOAA-AVHRR	Hansen *et al.* (2003)
TREES	1 km (Tropics)	NOAA-AVHRR	Achard *et al.* (2001)
FRA 2000	1 km (Global)	NOAA-AVHRR	FAO (2001)
MODIS Land cover	1 km (Global)	TERRA MODIS	Friedl *et al.* (2002)
Global land cover	1 km (Global)	SPOT-VEG	Bartholome and Belword (2005)
Vegetation continuous field	1 km (Global)	NOAA-AVHRR	DeFries *et al.* (2000)
Vegetation continuous field	500 m (Global)	TERRA MODIS	Hansen *et al.* (2003)
GLOBECOVER	300 m (Global)	Envisat MERIS	Arino *et al.* (2007)

GLOBAL FOREST COVER CHANGES: AN OVERVIEW

Deforestation, one of the most commonly accepted forms of forest cover changes, is nevertheless plagued by inconsistencies in definitions (Williams, 2003). Food and Agriculture Organization of the United Nations defines deforestation as occurring where tree canopy falls below 10% in natural forest. On the basis of this definition and using forest inventories in different countries, expert estimates, forest department data and satellite remote sensing, the Global Forest Resources Assessment (2000) (FAO, 2000) estimated a net decrease in forest area of 9.4 million ha year^{-1} from 1990 to 2000. This change was result of a 12.5 million ha year^{-1} net decrease in natural forest. Most of the deforestation Occur in tropics, while most of the natural forest regrowth occurred in Western Europe and Eastern North America, the total net forest cover change was positive for the temperate regions and negative for tropics regions. The changes in forest cover in six different continents are under presented in followings.

Asia: Extensive research on forest cover changes in tropical Asia is available for the period 1880-1980 (Flint and Richards, 1991). This involves an area of 8 million km^2 and 13 countries (India, Sri Lanka, Bangladesh, Myanmar, Thailand, Laos, Cambodia, Vietnam, Malaysia, Brunei, Singapore, Indonesia and Philippines). In this area as a whole, forest and wetland decline over the hundred year period by 131 million ha (47%). In India, Richards and Flint (1994) estimated a forest loss of 40% during 1880 to 1980. Important driving force were an increased in cultivated area by more than 42 million ha (40%), a staggering tripling of the population (increase of half billion people) and livestock increase of 193 million head (105%). Increasing food demand was often met through an expansion of cultivated area, often at the expense of forests (Lambin and Geist, 2006).

North America: The United States had 747 million acres of forest land in 1997, amounting to 33% of the country's total land area. Reserved forest land has doubled since 1953 and now stands at 7% of all forest land. This reserved area includes state and federal parks and wilderness areas but not conservation easements, i.e., areas protected by nongovernmental-organizations or most urban and community parks and reserves. Timber land is fairly evenly distributed among the three major regions of the United States, but other forest land, such as slow-growing spruce forests in the interior of Alaska or pinyon-juniper forests in the interior West, dominate many Western landscapes and comprise more than one-fourth of all US forest land. The US forests are predominantly natural stands of native species, with planted forests most common in the East and South. After intensive logging in the late 19th century and early 20th century, 55% of the forests on the nation's timber land were less than 50 years old and 6% more than 175 years old. While most timber products harvested from US forests have been increasing in quantity since 1976, the greatest gains have been in fibre for pulp and composite products. Much of this increase has been in hardwoods, as new technologies improve the utilization of these species. Canada is steward of about 10% of the world's forests and 30% of the world's boreal forests. Around 34% of the country's total area of 909 million hactares is classified as forest land and 293 million hactares of these forests are potentially available for commercial forestry at the present time. In terms of forest type, 66% of Canada's forests contain softwood, 12% hardwood and 22% are mixed forests. The forest land is mainly owned by public instances (the provincial governments 77% and federal government 16%) and only 7% is in private ownership. Provincial forest lands may or may not be assigned to industry for timber harvesting under a wide variety of agreements (SCF, 2004).

Europe and the Former Soviet Union: Forest cover change in Europe and the Former Soviet Union has long history. Extensive forest clearing in the Mediterranean Basin has been ascribed to economic and political activities during the Greek and Roman Empires. Deforestation continued through to the medieval period in temperature Western and Central Europe, driven by the increase population from 18 million in ca. A.D. 600, to 39 million in A.D. 1000, to 76 million in the early 13th century. Forests and Swamps decreased from 80% of the land area to about half between A.D. 500 and A.D. 1300 (Williams, 2003). In Russia, there is some evidence for clearing accompanying the Eastward movement of Slavs into the mixed-oak forest zone; but the clearing rates were slow and less extensive in comparison to central and Western Europe. By the 1960s, crop production increases in the temperate zones of the world came almost solely from increase in yields. New agriculture settlement and expansion had stopped in the former temperate forest and steppe zones, which were for all intents and purpose deforested in many Western and central Europe countries (Ramankutty *et al.*, 2006).

Australia: There is widespread evidence for forest modification through the aboriginal use of fires on the savanna-forest interface in Australia (Pyne, 1991). The expansion of cultivation resulted in the modification and loss of dense eucalyptus forests of Southern and Eastern Aurstralia. It is estimated that 69% of the vegetation in Victoria and 50% of the vegetation of New South Wales were modified since 1780 (Wells *et al.*, 1984; Ramankutty *et al.*, 2006).

Africa: Before the 19th century, land in Sub-Saharan Africa was used largely for hunting, gathering, herding and shifting cultivation (Kimble, 1962). Some settled agriculture existed in Africa long before the imposition of the colonial rule in the late nineteenth century, but in the pre-colonial period, demographic and economic needs allowed for land cleared for cultivation to be left fallow for long periods or abandoned as cultivators moved on land cleared new land. Cropland area in Sub-Saharan Africa is estimated to have been 119 million ha in 1961 and 163 million ha in 2000 (FAO, 2004), an increase of 37% in 40 years. The rate of clearing for long-term shifting cultivation has been even greater than the rate of clearing for permanent croplands in recent decades (Houghton and Hackler, 2006).

In the 20th century Miombo woodland of Central Africa plateau, the largest contiguous dry forest area, exceptionally high rate of change in forest cover (Mayaux *et al.*, 2005). For example, Lusitu in Southern Zambia Petit *et al.* (2001) assessed, an annual rate of land cover change 4% between 1986 to 1997, while in the Lake Malawi National Park of the Southern Malawi, intensive timber wood extraction caused rapid loss of closed forest cover canopy between 1982 to 1990 and ultimately replaced by sparse woodland cover which increased by almost 300% (Abbot and Homewood, 1999).

South America: Forest exploitation in Brazil started with Brazil-wood extraction along the Atlantic Coast nearly 500 year ago soon after the first Portuguese arrived. The discovery gold in Minas Gerais in 1960 stimulated mining here and in other scattered pockets elsewhere, which led to large-scale destruction of forests (Williams, 1990). This was followed by large, export-oriented sugar cane plantations, strengthening Portugal's supremacy in the world sugar trade. Large-scale forest conversion started with coffee plantations in the 19th century that resulted in the nearly complete loss of the Brazilian Atlantic Forest. The Atlantic forest once stretched all the way from Rio Grande do Norte to Rio Grande do Sul; three million ha had been converted into coffee

Table 2: Comparison of rate of deforestation (million ha $year^{-1}$) in tropics

Net forest change	All tropics (FAO, 2000)	All tropics (FAO, 2001)	All tropics (DeFries *et al.*, 2002)	All tropics (FAO, 2000)	Humid tropics (Achard *et al.*, 2002)
1990s					
Tropical Asia	-2.4	-2.0	-2.0	-2.5	-2.0
Tropical Africa	-5.2	-2.2	-0.4	-1.2	-0.7
Tropical latin America	-4.4	-4.1	-3.2	-2.7	-2.2
Pantropics	-12.0	-8.3	-5.6	-6.4	-4.9
1980s					
Tropical Asia	-2.4		-1.2		
Tropical Africa	-3.9		-0.3		
Tropical latin America	-7.1		-3.6		
Pantropics	-13.4		-5.1		

plantations during the 19th, century and more than 90% had been cleared by the end of the last century. Much of the rapid deforestation in the 1990s was in subtropical South America, particularly in the Brazilian Cerrado (Jepson, 2005). Rapid deforestation in the Santa Cruz department of Bolivia, in the vicinity of Mennonite settlements and more recently in industrial soybean farms, as well as in the Chaco region of Argentina have been documented (Steininger *et al.*, 2001; Zak and Cabido, 2002).

A comparison between the FAO country data and the independent remote sensing survey showed reasonably good agreement in Latin America and tropical Asia, but poor agreement in tropical Africa (Table 2). Two recent studies using remote sensing (Landsat derived estimates from the Tropical Ecosystem Environment Observations by Satellite (TREES) project of Achard *et al.* (2002) and Advanced Very Resolution Radiometer (AVHRR) based estimates (DeFries *et al.*, 2002b) also lend credence to the idea that FRA 2000 country estimates deforestation are too high specially in tropical Africa (DeFries and Achard, 2002). Achard *et al.* (2002) estimated deforestation rates for the humid tropics that were 23% lower than FRA while DeFries *et al.* (2002b) estimated deforestation rates for the entire tropics that were 53-62% lower. The TREES data is considered more reliable because of its high resolution as well as being restricted to more observed humid tropical forest cover changes; however, it is only covers a statistically-selected subset of the total area (6.5%) based on a stratification determined from expert opinion.

REMOTE SENSING AS POTENTIAL TOOLS FOR MONITORING CHANGES IN FOREST COVER

A basic requirement for performing analyses of the kind just mentioned is mapping forest extent and change over time. Satellite data offer a synoptic information source for mapping forest types at the global scale (Fig. 1). Estimates of change in forest cover based on satellite data can help researchers to understand the likely outcomes in terms of carbon dynamics, climate change and threats to biodiversity. Improving the basic understanding of forest extent and change through satellite-derived map, benefits these research areas. The map of the main areas of forest-cover changes is based on three types of data sources: expert opinion gathered through formal procedure (Achard *et al.*, 1998; Hoffman, 1999; AGO, 2000; NRCS, 2001), remote sensing-based products (Isaev, 1990; Skole and Tucker, 1993; Barson *et al.*, 2000; Sierra, 2000; Aksenov *et al.*, 2002; Alves, 2002; DeFries *et al.*, 2002a; Bartalev *et al.*, 2003; Trigg *et al.*, 2006; Kumar *et al.*, 2010b) and national statistics (Hongchang, 1995; Eurostat, 2000; FAO, 2001; INPE, 2002). Most of these data directly measure deforestation and forest degradation.

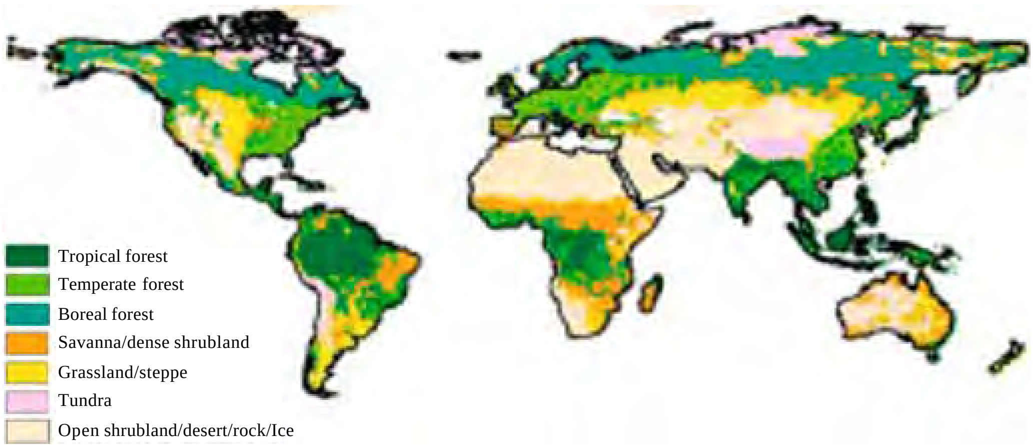

Fig. 1: The global distribution of potential natural vegetation (Lambin and Geist, 2006)

Microwave sensor data is useful to monitor forest coverage since presence of cloud often obscures for a continuous and periodic monitoring by optical sensors. Rahman and Sumantyo (2008) used Advanced Land Observation Satellite (ALOS) PALSAR polarimetric data for forest interpretation and mapping in the tropical forest region of South-Eastern Bangladesh. Forest map was prepared for Tanana River flood-plain, interior Alaska from multi-date three-frequency polarimetric SAR and SPOT data (Rignot *et al.*, 1994). The study separated open water of rivers and lakes and various types of vegetations. The study examined the classification accuracy with different polarimetry, frequency and time of AIRSAR and optical (SPOT) sensor data. SIR-A and Landsat MSS data were jointly used to prepare land use maps of Tianjin, North China (Jiyuan *et al.*, 1986). The study developed an interpretation key for SIR-A images.

Approximately 30% of total forest cover is under pressure of rapid land use changes in North-East India, recognized two of the hotspots viz., Himalaya and Indo-Burma (Lele and Joshi, 2009). It also has a strong bearing on regional climatic conditions. Extensive shifting cultivation, compounded by increasing population pressure and demands for agriculture land are the prime drivers in addition to other proximate drivers of deforestation (Kumar *et al.*, 2010c). Lele and Joshi (2009) perform changed detection in between 1972 to 1999 and analyzed that 40% of the entire region falls in the dynamic areas where rapid forest cover changes have been taking place. This constitutes around 97,875 km^2 area. Among the dynamic areas, 23% area is less dynamic and 17% area is highly dynamic in nature. This also suggests 60% of the area has not changed its forest cover since 1972 and hence is classified as non-dynamic areas.

Australian native forests cover about 164 million hectares (or about 21% of the continent). These forests range from lush tropical and monsoon forests in the North, to the diverse coastal plains and wetlands, tall forests and woodlands of the South. In between 2000 to 2004, 1.5 million hactares of forest (including native and non-native vegetation) was cleared across Australia. After forest re-growth, the net change was a loss of 287,000 ha. Similarly, high altitude montane ecosystems are sensitive to climate change-induced reductions in winter snow cover and the highland rainforests of Northern Australia are projected to decrease by 50% for just a 1°C increase in temperature. Given higher magnitudes of warming, adverse effects for certain groups of species are expected to become progressively worse (Preston and Jones, 2006).

Satellite data, particularly Landsat TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper plus) series of sensor, are important tools in the interdisciplinary study of tropical forests that are increasingly integrated into studies that monitor changes in vegetation cover within tropical forests and tropical protected areas and also applied with other types of data to investigates the drivers of land cover changes (Trigg *et al*., 2006; Kumar *et al*., 2010a). Satellite images offer the possibility of spatially and temporally consistent estimates of forest cover to complement national reports. Data acquired by the Landsat platform, with a pixel resolution of 30 m for the TM sensor and 60 m for the Multispectral Scanner Sensor (MSS) before the early 1980s, have provided estimates of deforestation rates for individual regions such as the Amazon basin (Skole and Tucker, 1993). However, ETM+ data were used to investigate the effectively monitoring of forest cover changes in Gunung Palung National Park in West Kalimantan, Indonesian Borneo (Trigg *et al*., 2006). Land cover changes in tropical dry forest and woodland ecosystems are thought to be wide-spread, but continental to global scale estimates are not available at this time (Ramankutty *et al*., 2006). Remote sensing techniques, even 30 m resolution Landsat TM data, have difficulty in distinguishing different land-cover types in the dry season, while most rainy season images are contaminated by cloud cover (Asner, 2001). A high resolution IKNOS satellite images and Synthetic Aperture Radar (SAR) data are some potential solutions for inclusion of cloud-free rainy season images (Saatchi *et al*., 2001; Sanchez-Azofeifa *et al*., 2003). Thermal band 6 data of Landsat TM, measure the emission of energy from the land surface allow for the differentiation between successional stages of forest growth in dry forest ecosystems (Southworth, 2004).

DeFries *et al*. (2002a) estimate Carbon fluxes from tropical deforestation and regrowth for the year 1980s and 1990s using sub-pixel estimates of percent tree cover derived from coarse (Advanced Very High Resolution Radiometer) satellite data in combination with a terrestrial carbon model. The satellite-derived estimates of change in forest area are lower than national reports and remote sensing surveys from the United Nations Food and Agriculture Organization Forest Resource Assessment (FRA) in all tropical regions, especially for the 1980s and the results indicate that the net rate of tropical forest clearing increased 10% from the 1980s to 1990s, most notably in Southeast Asia, in contrast to 11% reduction reported by the FRA. Now, higher resolution data with frequent coverage become available for the entire tropics, estimates of forest clearing will become more accurate (DeFries *et al*., 2002a). Hansen and DeFries (2004) using 8 km Pathfinder Advanced Very High Resolution Radiometer (AVHRR) data sets monitored forest cover change during 1982 to 1990 and finally conclude that, the percent tree cover was found to have decreased globally, from the 1980s to 1990s, in contrast to United Nations Food and Agriculture Organization (FAO) reports of a global increase in forest cover. Latin America and tropical Asia are the two dominant deforestation regions. Paraguay shows the highest rate of forest clearing over the time series, while Indonesia had the greatest increase in deforestation from the 1980s to 1990s.

Estimating forest cover change and deforestation would be a major challenge without the use of satellite imagery, in particular for remote regions. Satellite remote sensing combined with ground measurements plays a key role in determining loss of forest cover (Kumar *et al*., 2010a, b). Technical capabilities have advanced since the early 1990s and operational forest monitoring systems at the national level are now a feasible goal for most developing countries (DeFries *et al*., 2005). However, reducing uncertainties in the land use change flux of the global carbon budget requires the capability to estimate changes in forest area throughout all forests of the tropical belt. Bodart *et al*. (2009) monitored tropical forest cover changes in Latin America, South Asia and Africa by using sampled based and object oriented classification of Landsat satellites images for the year

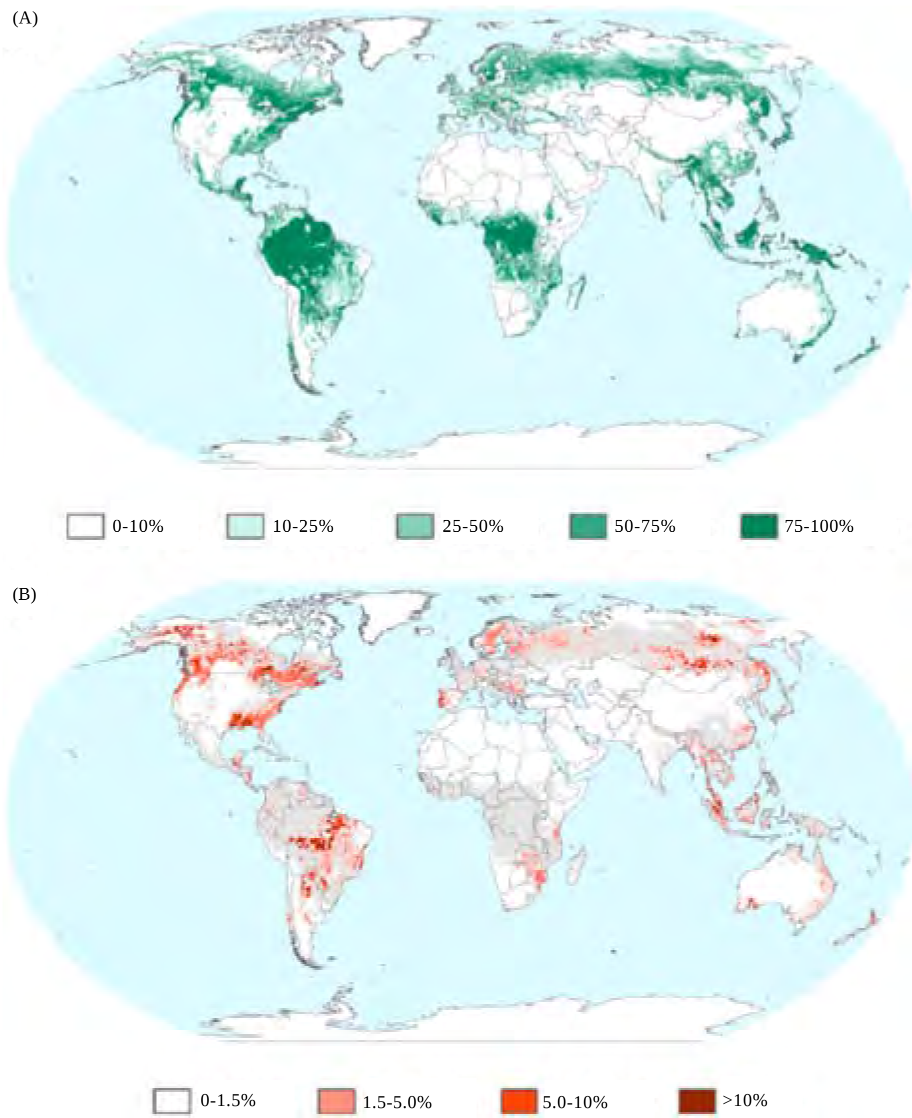

Fig. 2: (A) Estimated percent of forest cover and (B) percentage of gross forest cover loss during 2000-2005 (Hansen *et al.* 2010)

of 1990 to 2000 and develop an operational and robust approach able to pre-process a very large amount of data from different conditions in an automatic fashion to put the multitemporal and multi-scene data on the same radiometric scale and segment the images prior to the supervised classification. Hansen *et al.* (2010) consistent a globally methodology using satellite data (MODIS and Landsat ETM+), was implemented to quantify Gross Forest Cover Loss (GFCL) from 2000 to 2005. GFCL is defined by an area of forest cover removed because of any disturbance, including both natural and human-induced causes. The global consistency of the methodology allows for comparisons of GFCL among biomes, continents and countries. GFCL was estimated to be 1,011,000 km^2 from 2000 to 2005, representing 3.1% (0.6% year^{-1}) of the year 2000 estimated total forest area of 32,688,000 km^2. The boreal biome experienced the largest area of GFCL, followed by the humid tropical, dry tropical and temperate biomes (Fig. 2A, B).

FOREST COVER CHANGE MONITORING IN GLOBAL HOT-SPOTS

The principal monitoring of changes in forest cover, requirement to support policies for reducing deforestation falls at the national level (Kumar *et al.*, 2010a, b). Analyses coordinated at an international level that span the tropics, using coarser resolution data than would be used at the national level, can supplement these efforts by providing consistency and ensuring that major areas of deforestation are detected (Hansen *et al.*, 2003, 2010). Improvement of Landsat 7 mission is its Long Term Acquisition Plan (LTAP), which aims to guarantee a systematic archive suitable for investigating land cover changes globally (Arvidson *et al.*, 2006). Trigg *et al.* (2006) monitored the changes of forest cover using Landsat series of sensor data in protected area of South-East Asia. Quantified the forest cover changes by using a series of Landsat data (MSS, TM and ETM+) for monitoring the spatial and temporal changes in protected area of Indo-Burma hot spot (see the case study).

FOREST COVER CHANGES IN CHAKRASHILA WILDLIFE SANCTUARY (1978-2006): A CASE STUDY

The Chakrashila Wildlife Sanctuary (CWS) is located in the estern end of Kokrajhar district of Assam (India) and lies between 26°24'- 26°16' N° latitude and 90°16'- 90°24' E° longitude . It covers an area of 45.568 km^2 (4556.8 ha) with hills of 90-430 m altitude. It encompasses one of the global biodiversity hotspots, i.e., Indo-Burma. The climate of the area typically has a minimum rainfall of 11.6 mm to a maximum of 845 mm and annual temperature ranges from 25 to 40°C which exhibits forest types such as tropical semi-evergreen, tropical moist-deciduous, tropical dry-deciduous and degraded forest exist in the study site.

The present data analysis was carried out using Landsat Multispectral Scanner (MSS), Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper plus (ETM+) for the year of 1978, 1991 and 2006 respectively. The orthorectified Landsat data was downloaded from GLCF (Global Land Cover Facilities) websites (http://glcf.umiacs.umd.edu/) at EROS data center, University of Maryland served as the primary data source to evaluate land use and Land cover. The images were downloaded as separate bands 1-5 and 7 and then stacked in ERDAS Imagine 8.5 to give the multispectral images. Landsat orbits the earth at an altitude of circa 705 km, according to Sun-synchronous, near-polar orbit with an inclination angle of 98.22 with respect to the equator. This orbital pattern provides the opportunity to collect imagery at high latitude regions. The revisit time and hence maximal temporal resolution of the sensor is 16 day. The ETM+ sensor is an imaging radiometer collecting reflected and emitted energy from the earth's surface in eight bands of the electromagnetic spectrum. The ETM+ is designed to collect, filter and detect radiation from the earth in a swath 185 km wide as it passes over head and provides the necessary cross-track scanning motion while the spacecraft orbital motion provides motion an along-track scan. Landsat data contains different spatial and the spectral wavelength analyzed for the study of forest cover changes in different years (Table 3). Apart from this Landsat satellite images Survey of India (SOI) topographical maps of 1:50,000 scale was used as a baseline map for the Area of Interest (AOI). Different Images of Landsat data were registered geometrically using topographical map of Survey of India (SOI) on 1:50,000 scale in ERDAS Imagine 8.5. The common uniformly distributed GCPs (Ground Control Points) were marked with root mean square of one pixel and the image was resampled at nearest neighbor method. After that the study area (Area of Interest) extracted from georefrence images of different year by overlaying the boundary data provided by SOI. Supervised classification method was used for, the area of known identity was used to classify pixels of

Table 3: Spatial and spectral behavior of different series of landsat satellite sensors

	Satellite		
	Landsat MSS	Landsat TM	Lamdsat ETM+
	Resolution (spatial (m))		
Band	80	30	30
1	0.50-0.60 (Green)	0.45-0.52 (Blue)	0.45-0.52 (Blue)
2	0.60-0.70 (Red)	0.52-0.60 (Green)	0.53-0.61 (Green)
3	0.70-0.80 (Blue)	0.63-0.69 (Red)	0.63-0.69 (Red)
4	0.80-1.10 (IR)	0.79-0.90 (NIR)	0.75-0.90 (NIR)
5		1.55-1.75 (SWIR)	1.55-1.75 (SWIR)
6		10.4-12.5 (TIR)	10.40-12.50 (TIR)
7		2.08-2.35 (SWIR)	2.1-2.35 (SWIR)
8			0.52-0.90 (PAN)

IR: Infrared, NIR: Near infrared, SWIR: Short wavelength infrared, TIR: Thermal infrared, SWIR: Short wavelength infrared, PAN: Panchromatic

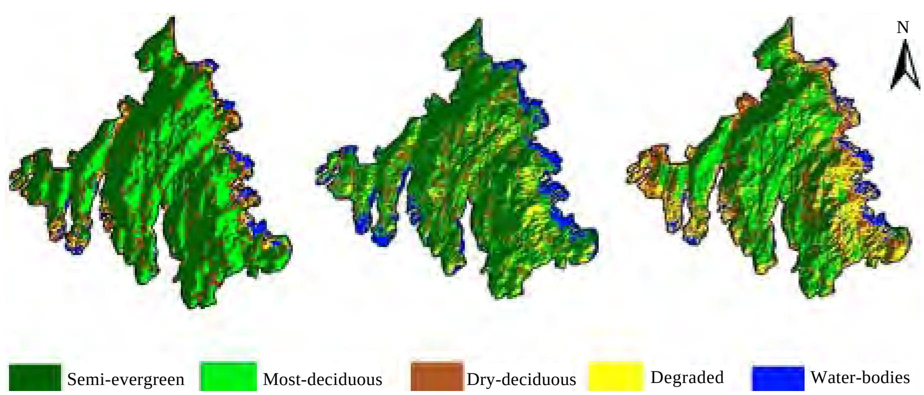

Fig. 3: Changes in forest cover (1978-2006) in different classes in Chakrashila Wildlife Sanctuary, Assam (India)

unknown area and training sites is closely controlled by analyst. The spectral behaviour of training sites gives information of the classes of land cover such as dense forest, open forest, degraded forest, agriculture land, scrub and water bodies in the images.

Five major forest cover types were delineated using Landsat data viz., semi-evergreen, moist-deciduous, dry-deciduous, degraded forest and water bodies (Fig. 3). In 1978, semi-evergreen forest cover accounted about 50.05% (2,281 ha), in 1991 year 37.56% (1,712 ha) and in 2006 only 28.31% (1290 ha) of the entire study area 4,557 ha (Table 4). The semi evergreen and moist deciduous forests of the CWS have undergone rapid degradation since the two and half decades and resulting of 22% of the semi evergreen and 5% of moist deciduous forest being degradation primarily in the form of selective logging, fire, grazing, fuel and timber wood collection, leading to growth of secondary successional stages such as degraded forests out of the major phenological types. In this study, the semi evergreen forest cover (991 ha) is transformed to another category of land cover, indicated that high anthropogenic pressure in the sanctuary. Accuracy assessment

Table 4: Vegetation and forests class distribution in Chakrashila Wildlife Sanctuary, Kokrajhar district of Assam, India for the year of 1978-2006 using satellite remote sensed Landsat data

	Area of different year (ha)		
Forests type class	1978	1991	2006
Semi-evergreen	2281	1712	1290
Moist-deciduous	1052	992	828
Dry-deciduous	796	985	1282
Degraded forest	221	372	865
Water bodies	207	496	292
Grand total	4557	4557	4457

Table 5: Accuracy assessment evaluation in different classify images of different time scale

	1978		1991		2006	
Classes	UA*	PA**	UA*	PA**	UA*	PA**
Semi-evergreen	78.30	91.3	87.40	92.5	88.50	94.6
Moist-deciduous	86.20	92.5	91.50	96.3	93.80	96.4
Dry-deciduous	85.60	94.6	89.30	93.4	99.20	100.0
Degraded forest	90.50	97.5	96.70	97.8	96.80	98.9
Water bodies	100.00	100.0	100.00	100.0	100.00	100.0
Overall accuracy	88.12		92.98		95.66	
Kappa statistics	0.89		0.90		0.94	

*UA: User's accuracy (%); **PA: Producer's accuracy (%)

is conceded out to evaluate the quality of thematic maps revealed from remote sensed data in a consequential way. The overall accuracy of classification was 88.12% for the 1978 MSS, 92.98% for the 1991 TM image and 95.66% for the ETM+ images and the Kappa Coefficient was 0.89, 0.90 and 0.94, respectively (Table 5).

Present study ascertained that maximum loss (991 ha) was recorded in the case of semi-evergreen forests and decline was more pronounced between 1978 and 1991 (569 ha) than between 1991 and 2006 (422 ha). An area of 224 ha under moist deciduous forest was lost, while area of deciduous forest and degraded forest increases simultaneously i.e., 486 and 644 ha, respectively. The significance increase of degraded forest and deciduous forest area were 14.33 and 10.66% during the period of 1978 to 2006, respectively (Table 4). The present analysis permitting the conclusions that the high intensity of anthropogenic pressure in CWS is going on and in turn forest cover had changed (Fig. 3).

The present investigation, highlights the forest cover change detection was observed with integration of remote sensing and GIS. Results show the consequence change in the forest cover. The changes in area of different forests type categories viz., semi-evergreen and moist deciduous into degraded forest in a form of lesser vegetation causes of degradation of natural forest. The study underlying threats for forest cover change such as illegal timber harvestation, lopping, grazing, fire and intense population of local villager on the periphery of sanctuary.

CONCLUSIONS

In the present scenario deforestation is a global issue with many implications and hence constraint in resources leads to exploitation of biological diversity and thereby fulfilment of necessitate, large forest area is being encroached by populace, resultant in the loss of overall environmental conditions including soil quality degradation, surface run off, siltation of river. This challenge is made all more urgent by ongoing and escalating loss of biodiversity (Kumar *et al.*, 2010b). The launch of many new satellite systems over the past years and the development of new technologies, some available only on airborne platforms, have given us an unprecedented number of remote sensing tools with which to address these challenges. Remote sensing brings together a multitude of tools to better analyze the scope and scale of the deforestation. Multi temporal data provides for change detection analyse (Kumar *et al.*, 2010a, b). Assessment of forest cover using remote sensing techniques has established recent trends of forest cover change at regional to global scale. Long term monitoring the changes in forest covers using high resolution remotely sensed data sets provide a detailed view of forest depletion, while radar can provide a view that many be obscured by clouds. Space technologies have been successfully utilized worldwide in natural resources and disaster management. With the availability of high-resolution satellite data, monitoring of land cover at local scales has become possible to resource managers as a way to create timely and reliable assessments. GIS offers powerful tools for collection, storage, management and display of map related information and supports in judging management decisions. Multiresolution and multisensor remote sensing data can be used to meet these goals.

Different processes of forest cover change have taken place in different parts of the world in the last two decades (such as tropical deforestation for agricultural practices) and have different impacts. Reliable data at global scale is lacking on changes in tropical and subtropical dry forest (for example Miambo and Chaco forests) and forest cover changes caused by selective logging, timber harvestation, fire and increase in an area of shifting cultivation. There are different trajectories of forest cover change in different parts of the world (e.g., increase in forest cover in temperate areas and decrease in the tropics). Asia currently has the greatest concentration of areas of rapid land cover changes and in particular to dry land degradation. Tropical deforestation remains in the Amazon basin hotspots, which are important for numerous endemic and threatened, plant and animal species. Rapid increase an agriculture settlement, often associated with large scale deforestation is prominent in South-East Asia. Forest degradation in Siberia, mostly related to logging activities, has been increasing rapidly. Changes in forest cover in Chakrashila Wildlife Scanctuary, Assam (India), mainly due to anthropogenic practices such as timber harvestation, logging, grazing and encroachment of protected area for agriculture practices (author's case study).

The estimations of global tropical humid forest cover change (1990-1997), shows a marketable reduction of natural dense and open forests: the annual deforestation rate is estimated around 6 million ha (0.5%) and annual degradation rate around 2 million ha (0.2%), furthermore shows that the actual change is confined to several hot spots areas in which change rate are alarming high (Achard *et al.*, 2002). The ability for monitoring forest change at global scale is still being developed. Remote sensing offers an efficient and synoptic method for doing so. It is helpful, that such information sources are made available to as wide a user group possible. A series of satellite data, namely MODIS and Landsat, meet these requirements and are the only ones viable for global scale inquiry (Hansen *et al.*, 2005). In many science applications, spatially explicit map products are required at finer scale resolution. For e.g., exhaustive Landsat-scale resolution mapping has been performed to characterize patterns of forest disturbance and recovery at a continental scale, resulting in map outputs appropriate for calibrating carbon cycle models. Spatially explicit global scale mapping of forest cover dynamics at Landsat-scale will be required for many global change studies opined by many researchers. Although, effort on quantifying the forest degradation is ongoing, operational methods are yet to ready for implementation at the global scale.

The remote sensing and GIS technologies can be exploited in creating a wealth of relevant information about various components of biodiversity in developing countries and generating an integrated Decision Support System (DSS) to assists tropical forest researchers in making informed decisions. It is expected that developing an integrated decision support system would enable policy makers/managers to better understand the linkages between local, regional and global processes, take effective management decisions and achieve the goal of sustainable development of biodiversity in tropical and subtropical countries, hot spots regions.

ACKNOWLEDGMENTS

The authors would like to thanks the project grant No. (BT/PR/7928/NDB/52/9/2006) funded by Department of Biotechnology, New Delhi, India for supporting this research, research scholars (Dr. Hemen Sarma, Mr. Kitboklang Nagrum, Mr. Souravjyoti Borah, Mr. Amit Kumar Tripathi, Ms. Idaiarilin Lyndogh Synrem and Ms. Mildoona Swer) of Ecosystem Research laboratory, North-Eastern Hill University, Shillong and Assam Forest Department, Government of Assam, Guwahati for providing permission to access the site and field data collection.

REFERENCES

Abbot, J.I.O. and K. Homewood, 1999. A history of change: Causes of miombo woodland decline in a protected area in Malawi. J. Applied Ecol., 36: 422-433.

Abrams, M., 2000. The advanced spaceborne thermal emission and reflection radiometer (ASTER): data products for the high spatial resolution imager on NASA's Terra Platform. Int. J. Remote Sensing, 21: 847-859.

Achard, F., H.D. Eva, A. Glinni, P. Mayaux, T. Richards and H.J. Stibig, 1998. Identification of deforestation hot spot areas in the humid tropics. TREES Series B, Research Report No. 4, EUR 18079 EN, European Commission, Luxembourg, pp: 100.

Achard, F., H.D. Eva and P. Mayaux, 2001. Tropical forest mapping from coarse spatial resolution satellite data: Production and accuracy assessment issues. Int. J. Remote Sensing, 22: 2741-2762.

Achard, F., H.D. Eva, H.J. Stibig, P. Mayaux, F. Galego, T. Richards and J.P. Malingreau, 2002. Determination of deforestation rates of the world's humid tropical forests. Science, 297: 999-1002.

Achard, F., R. DeFries, H. Eva, M. Hansen, P. Mayaux and H.J. Stibig, 2007. Pan-tropical monitoring of deforestation. Environ. Res. Lett., 2: 11-11.

AGO, 2000. Australian greenhouse office. Land Clearing: A Social History. National Carbon Accounting System. Technical Report No. 4, Canberra, Australia. http://www.ieabioenergy-task38.org/softwaretools/ camfor.pdf.

Aksenov, D., D. Dobrynin, M. Dubinin, A. Egorov and A. Isaev *et al.*, 2002. Atlas of Russia's intact forest landscapes. Moscow, http://www.forest.ru/eng/ publications/intact/.

Alves, D.S., 2002. Space-time dynamics of deforestation in Brazilian Amazonia. Int. J. Remote. Sens, 23: 2903-2908.

Arino, O., D. Gross, F. Ranera, D. Gross and P. Bicheron *et al.*, 2007. GlobCover: ESA service for global land cover from MERIS. http://www.gofc-gold.uni-jena.de/ documents/boston/Arino_Globcover_ENVISATSYMPOSIUM.pdf.

Armenteras, D., G. Rudas, N. Rodriguez, S. Sua and M. Romero, 2004. Pattern and cause of deforestation in Colmbian Amazon. Ecol. Indicator, 6: 353-368.

Arvidson, T., S.N. Goward, D.L. Williams and J. Gasch, 2006. Landsat-7 long-term acquisition plan: development and validation. Photogrammetric Eng. Remote Sensing, 72: 1137-1146.

Asner, G.P., 2001. Cloud cover in Landsat observation of the Brazillian Amazon. Int. J. Remote Sensing, 22: 3855-3862.

Barson, M., L. Randall and V. Bordas, 2000. Land Cover Changes in Australia. Bureau of Rural Science, Canberra, Australia.

Bartalev, S., A.S. Belward, D. Erchov and A.S. Isaev, 2003. A new land cover map of Northern Eurasia. Int. J. Remote Sensing, 24: 1977-1982.

Bartholome, E. and A.S. Belword, 2005. GLC 2000: A new approach to global land cover mapping from earth observation data. Int. J. Remote Sensing, 26: 1959-1977.

Billington, C., V. Kapos, M. Edwards, S. Blyth and S. Iremonger, 1996. Estimated Original Forest Cover Map: A First Attempt. World Conservation Monitoring Center, Cambridge.

Bodart, C., R. Beuchle, D. Simonetti, H. Eva and R. Rasi *et al.*, 2009. Global Monitoring of Tropical Forest Cover Changes by Means of a Sample Approach and Object-Based Classification of Multi-Scene Landsat Imagery: Pre-Processing and First Results. Joint Research Centre of the European Commission, Ispra, Italy.

Cohen, W.B. and S.N. Goward, 2004. Landsat role in ecological applications of remote sensing. BioScience, 54: 535-545.

Colwell, R.N., 1983. Manual of Remote Sensing. American Society of Photogrammetry, UK.

DeFries, R., M. Hansen, J.R.G. TownShend, A.C. Janetos and T.R. Loveland, 2000. A new global 1 km datasets of percent tree cover derived from remote sensing. Global Change Biol., 6: 247-254.

DeFries, R.S. and F. Achard, 2002. New estimates of tropical deforestation and terrestrial carbon fluxes: Results of two complementary studies. LUCC Newslett., 8: 7-9.

DeFries, R.S., L. Bounoua and G.J. Collatz, 2002a. Human modification of the landscape and surface climate in the next fifty years. Global Change Biol., 8: 438-458.

DeFries, R.S., R.A. Houghton, M.C. Hansen, C.B. Field, D. Skole and J. Townshend, 2002b. Carbon emissions from tropical deforestation and regrowth based on satellite observations for the 1980s and 1990s. Proc. Natl. Acad. Sci., 99: 14256-14261.

DeFries, R.S., G.P. Asner, F. Achard, C.O. Justice, N. Laporte, K. Price, C. Small and J. Towshend, 2005. Monitoring Tropical Deforestation for Emerging Carbon Markets Tropical Deforestation and Climate Change. In: IPAM and Environmental Defense, Mountinho, P. and S. Schwartzman (Eds.). Amazon Institute for Environmental Research, Brazil, Washington DC., pp: 35-44.

Dewan, A.M. and Y. Yamaguchi, 2009. Using remote sensing and GIS to detect and monitor land use and land cover change in Dhaka metropolitan of Bangladesh during 1960-2005. Environ. Monit. Assess., 150: 237-349.

Eurostat, 2000. REGIO Database: Theme 1, General Statistics. Office for Official Publications of the European Communities, Luxembourg, London.

FAO, 2000. Land Resource Potential and Constraints at Regional and Country Levels. FAO, Rome, pp: 122.

FAO, 2001. Pan-tropical survey of forest cover changes 1980-2000. FRA Working Paper No. 49, http://www.fao.org/docrep/004/y1997e/y1997e1f.htm.

FAO, 2004. FAOSTAT Database Results 2004. FAO, Rome, Itly.

Fearnside, P.M., 2001. Global warming and tropical land-use change: Greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. Climate Change, 46: 115-158.

Flint, E.P. and J.F. Richards, 1991. Historical-analysis of changes in landuse and carbon stock of vegetation in South and Southeast Asia. Can. J. Forest. Res., 21: 91-110.

Foody, G.M., 2003. Remote sensing of tropical forest environments: towards the monitoring of environmental resources for sustainable development. Int. J. Remote Sensing, 24: 4035-4046.

Friedl, M.A., D.K. McIver, J.C.F. Hodges, X.Y. Zhang and D. Muchoney, *et al.*, 2002. Global land cover mapping from MODIS: Algorithms and early results. Remote Sensing Environ., 83: 287-302.

Goward, S.N., J.G. Masek, D.L. Williams, J.R. Irons and R.J. Thompson, 2001. The Landsat 7 mission terrestrial research and applications for the 21st century. Remote Sensing Environ, 78: 3-12.

Hall, G.F., D.E. Strebel and P.J. Sellers, 1988. Linking knowledge among spatial scales: vegetation, atmosphere climate and remote sensing. Landscape Ecol., 2: 3-22.

Hansen, M.C., R.S. DeFries, J.R.G. Townshend, M. Carroll, C. Dimiceli and R.A. Sohlberg, 2003. Global percent tree cover at a spatial resolution of 500 meters: First results of the MODIS vegetation continuous fields algorithm. Earth Interact., 7: 1-15.

Hansen, C.M. and R.S. DeFries, 2004. Detecting long-term global forest change using continuous fields of tree-cover maps from 8-km advanced very high resolution radiometer (AVHRR) data for the years 1982-99. Ecosystems, 7: 695-716.

Hansen, M.C., J.R.G. Townshend, R.S. DeFries and M. Carroll, 2005. Estimation of tree cover using MODIS data at global, continental and regional/local scales. Int. J. Remote Sensing, 26: 4359-4380.

Hansen, M.C., S.V. Stehman and P.V. Potapov, 2010. Quantification of global gross forest cover loss. Proc. Natl. Acad. Sci., 107: 8650-8655.

Heywood, V.H., 1995. Global Biodiversity Assessment. United Nations Environment Programme. Cambridge University Press, Cambridge, UK., ISBN-13: 9780521564816.

Hoffman, T., 1999. Land Degradation in South Africa. National Botanical Institute, Cape Town, South Africa.

Hongchang, W., 1995. Deforestation and Desiccation in China: A Preliminary Study. Chinese Academy of Sciences, Beijing, China.

Houghton, R.A. and J.L. Hackler, 2006. Emissions of carbon from landuse change in Sub-Saharan Africa. J. Geophys. Res., 111: 12-12.

INPE, 2002. Atlas de Remanescentes Florestais. Fundaçao SOS Mata Atlantica and INPE, Sao Paulo, Brazil.

Isaev, A.C., 1990. Forests of the USSR. State Committee of the USSR, Moscow, Russia.

Jepson, W., 2005. A disappearing biome? Reconsidering land-cover change in the Brazilian Savanna. Geographical J., 171: 99-111.

Jiyuan, L., T. Xuyan and X. Jinkai, 1986. Application of Shuttle Imaging Radar data for land use investigations. Remote Sensing Environ, 19: 291-301.

Kilic, S., F. Evrendilek, S. Berberoglu and A. Demirkesen, 2004. Environment monitoring of land-use and land-cover changes in Amik Plain, Turkey. Proceedings of the Geo-Imagery Bridying Continents XXth ISPRS Congress, (GIBCC'04), Istanbul, Turkey, pp: 1-6.

Kimble, G.H.T., 1962. Tropical Africa, (Land and livelihood). Vol. 1. Anchor Books, Doubleday and Co., Garden City, New York.

King, R., 2002. Land cover mapping principles: a return to interpretation fundamentals. Int. J. Remote Sensing, 18: 3525-3545.

Kondratyev, K.Y., 1998. Multidimensional Global Change. Wiely, Chichester.

Kumar, D., S. Borah and U. Shankar, 2010a. Monitoring forest cover change using remote sensing in Amchang Wildlife Sanctuary, Assam, India. Communicated Data.

Kumar, D., S. Borah and U. Shankar, 2010b. Temporal forest cover change monitoring in chakrashila wildlife sanctuary, Assam, India using Remote and GIS. Communicated data.

Kumar, D., S. Borah, H. Sarma and U. Shankar, 2010c. Monitoring and assessment of land use and land cover changes in Kamrup district of Assam, India. Communicated data.

Lambin, E.F. and H.J. Geist, 2006. Land Use and Land Cover Change: Local Process and Global Impacts. Springer, Berlin Heidelberg, New York.

Lele, N. and P.K. Joshi, 2009. Analyzing deforestation rates, spatial forest cover changes and identifying critical areas of forest cover changes in North-East India during 1972-1999. Environ. Monitoring Assess., 156: 159-170.

Liu, J., M. Liu, D. Zhuang, Z. Zhang and X. Deng, 2003. Study on spatial pattern of land-use change in China during 1995-2000. Sci. China Ser. D Earth Sci., 46: 373-378.

Loveland, T.R., Z. Zhu, D.O. Ohlen, J.F. Brown, C. Reed and L. Yang, 1999. An analysis of the IGBP global land-cover characterization process. Photogramm. Eng. Remote Sensing, 65: 1021-1032.

Loveland, T.R., B.C. Reed, J.F. Brown, D.O. Ohlen, Z. Zhu, L. Yang and J.W. Merchant, 2000. Development of a global land cover characteristics database and IGBP DISCover from 1 km AVHRR data. Int. J. Remote Sensing, 21: 1303-1330.

MEA, 2003. Millennium Ecosystem Assessment: Ecosystem and Human Well-Being: A Framework for Assessment. Island Press, Washington D.C., pp: 245.

Mas, J.F., 2005. Monitoring land-cover changes: A comparison of change detection techniques. Int. J. Remote Sens., 20: 139-152.

Mayaux, P., P. Holmgren, F. Achard, H. Eva, H. Stibig and A. Branthomme, 2005. Tropical forest cover change in the 1990s and options for future monitoring. Philosophical Trans. R. Soc., 360: 373-384.

Millington, A.C., X.M. Velez-Liendo and A.V. Bradley, 2003. Scale dependence in multitemporal mapping of forest fragmentation in Bolivia: implications for explaining temporal trends in landscape ecology and applications to biodiversity conservation. ISPRS J. Photogramm, 57: 289-299.

Noss, R.F., 2001. Beyond Kyto: Forest management in a time of rapid climate change. Conserv. Biol., 15: 578-590.

NRCS, 2001. Change in average annual soil erosion by wind and water on Cropland and CPR Land, 1982-1992. Dec. 27, 2004. http://www.nrcs.usda.gov/ technical/NRI/maps/.

Petit, C., T. Scudder and E.F. Lambin, 2001. Quantifying processes of landcover change by remote sensing: Resettlement and rapid landcover changes in South-Eastern Zambia. Int. J. Remote Sensing, 22: 3435-3456.

Preston, B.L. and R.N. Jones, 2006. Climate change impacts on australia and the benefits of early action to reduce global greenhouse gas emissions. A Consultancy Report for the Australian Business Roundtable on Climate Change, http://www.csiro.au/ resources/pfbg.html.

Pyne, S., 1991. Burning Bush: A Fire History of Australia. Henry Holt and Co., New York, pp: 520.

Rahman, M.M. and J.T.S. Sumantyo, 2008. ALOS PALSAR data for tropical forest interpretation and mapping. Int. Arch. Photogrammetry Remote Sensing Spatial Inform. Sci., 37: 185-189.

Ramankutty, N., L. Graumlich, F. Achard, D. Alves and A. Chhabra *et al*., 2006. Global Land-Cover Change: Recent Progress, Remaining Challenges. In: Land-Use and Land-Cover Change: Local Process and Global Impacts, Lambin, E.F. and H.J. Geist (Eds.). Springer, Berlin, Heidelberg, New York, pp: 9-40.

Rao, K.S. and R. Pand, 2001. Land use dynamics and landscape change pattern in a typical micro watershed in the mid elevation zone of central Himalaya, India. Agric. Ecosyst. Environ., 86: 113-124.

Richards, J.F. and E.P. Flint, 1994. Historic land use and carbon estimates for South and Southeast Asia: 1880-1980. ORNL/CDIAC-61, NDP-046, Oak Ridge National Laboratory, pp: 404. http://gcmd.nasa.gov/ records/GCMD_CDIAC_NDP046_LANDUSE.html.

Rignot, E.J.M., C.L. Williams, J. Way and L.A. Viereck, 1994. Mapping of forest types in Alaskan Boreal Forests using SAR imagery. IEEE Geosci. Remote, 32: 1051-1059.

Roughgarden, J., S.W. Running and P.A. Matson, 1991. What does remote sensing do for ecology?. Ecology, 72: 1981-1982.

Saatchi, S., D. Agosti, K. Alger, J. Delabie and J. Musinsky, 2001. Examining fragmentation and loss of primary forest in the southern bahian atlantic forest of Brazil with Radar imagery. Conserv. Biol., 15: 867-875.

Savtchenko, A., D. Ouzounov, S. Ahmad, J. Acker, G. Leptoukh, J. Koziana and D. Nickless, 2004. Terra and Aqua MODIS products available from NASA GES DAAC. Adv. Space Res., 34: 710-714.

SCF, 2004. State of Canada's forests: forest fires 14th Report to Parliament.

Sherbinin, A., D. Carr, S. Cassels and L. Jiang, 2007. Population and environment. Annual Rev. Environ. Resour., 32: 5.1-5.29.

Sierra, R., 2000. Dynamics and patterns of deforestation in the western Amazon the Napo deforestation front 1986-1996. Applied Geography, 20: 1-16.

Skole, D. and C. Tucker, 1993. Tropical deforestation and habitat fragmentation in the Amazon: Satellite data from 1978 to 1988. Science, 260: 1905-1910.

Southworth, J., 2004. An assessment of Landsat TM band 6 thermal data for analysing land cover in tropical dry forest regions. Int. J. Remote Sensing, 25: 689-706.

Steininger, M.K., C.J. Tucker, P. Ersts, T.J. Killeen, Z. Villegas and S.B. Hecht, 2001. Clearance and fragmentation of tropical deciduous forest in the Tierras Bajas, Santa Cruz, Bolivia. Conserv. Biol., 15: 856-866.

Sanchez-Azofeifa, G.A., G.C. Daily, A.S.P. Pfaff and C. Busch, 2003. Integrity and isolation of Costa Rica's national parks and biological reserves: examining the dynamics of land-cover change. Biol. Conserv., 109: 123-135.

Trigg, S.N., L.M. Curran and A.K. McDonald, 2006. Utility of Landsat 7 satellite data for continued monitoring of forest cover change in protected areas in Southeast Asia. Singapore J. Trop. Geo., 27: 49-66.

Tucker, C.J., J.R. Townshend and T.E. Goff, 1985. African land-cover classification using satellite data. Science, 227: 369-375.

Turner, B.L., R.E. Kasperson, P.A. Matson, J.J. McCarthy and R.W. Corell *et al*., 2003. A framework for vulnerability analysis in sustainability science. Proc. Natl. Acad. Sci. USA., 100: 8074-8079.

UNFCCC., 2001. Seventh conference of the parties to the UN framework convention on climate change. Oct. 29-Nov. 9, Marrakesh, Morocco. http://www.iisd.ca/ climate/cop7/mon29.html.

USGS, 2003. United States geological survey. http://www.academicinfo.net/rocksusgs.html.

Wells, K.F., N.H. Wood and P. Laut, 1984. Loss of Forests and Woodlands in Australia: A Summary by State, Based on Rural Local Government Areas, CSIRO Technical Memorandum 84/4. CSIRO, Institute of Resources, Division of Water and Land Resources, Canberra.

Williams, M., 1990. Forests. In: The Earth as Transformed by Human Action, Turner, B.L., W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews and W.B. Meyer (Eds.). Cambridge University Press, New York, pp: 179-201.

Williams, M., 2003. Deforesting the Earth: from Prehistory to Global Crisis. University of Chicago Press, Chicago, pp: 715.

Wilson, E.O. and F.M. Peter, 1988. Biodiversity. National Academy of Sciences Press, Washington, DC.

Zak, M.R. and M. Cabido, 2002. Spatial patterns of the Chaco vegetation of central Argentina: Integration of remote sensing and phytosociology. Applied Veget.ation Sci., 5: 213-226.