Land use and land cover change in India: A remote sensing & GIS prespective

P. S. Roy[1] *AND Arijit Roy*[2]

Abstract | Land use and land cover change have been among the most important perceptible changes taking place around us. Although perceptible, the magnitude, variety and the spatial variability of the changes taking place has made the quantification and assessment of land use and land cover changes a challenge to scientists. Furthermore, since most of the land use and land cover changes are directly influenced by human activities, they rarely follow standard ecological theories. The Remote Sensing and Geographic Information System has proved to be very important in assessing and analyzing land use and land cover changes. Satellite-based Remote Sensing, by virtue of its ability to provide synoptic information of land use and land cover at a particular time and location, has revolutionized the study of land use and land cover change. The temporal information on land use and land cover helps identify the areas of change in a region. The use of Geoinformatics has enabled us to assign spatial connotations to land use land cover changes, namely, population pressure, climate, terrain, etc which drive these changes. This has helped scientists to quantify these tools and to predict various scenarios. This article gives a overview of the current trends in land use and land cover changes along with two case studies on the same subject, one case study on geospatial LULC change modeling and one on agent based land use and land cover change modeling.

[1] *Dean, Indian Institute of Remote Sensing and Associate Director (NRSC), ISRO, 4, Kalidas Road, Dehradun*
[2] *Scientist, National Remote Sensing Centre, ISRO, Balanagar, Hyderabad*
psroy13@gmail.com
arijitroy13@gmail.com

Keywords: Drivers of change, LULC change modeling, Remote Sensing, GIS.

Introduction

Human beings have been altering the face of the earth for the last few centuries but with the introduction of machines, the land cover of the earth has changed drastically in the last three centuries. The debate about the relationship between human population dynamics and the availability of natural resources dates back to more than 200 years when Malthus (1798) put forward his argument that population growth would eventually outstrip the production capacity of the land. It was only in the second half of the 20th century when the probability of the Malthusian projection seemed to be a reality, that sincere efforts to study the human population–environment relation were undertaken. The Scientific study and analysis of land use and land cover change involves a quantitative estimation of land use and land cover at a particular location and time. In this regard, remote sensing plays a major role in giving a synoptic view of the spatial extent of land use and land cover at a particular point of time.

The Human use of land resources gives rise to "land use" which varies with the purpose it serves, whether it be food production, provision of shelter, recreation, extraction and processing of materials, and the biophysical characteristics of the land itself. Tropical ecosystems are under continuous threat by organic and chemical pollution from agriculture and industries and the resultant degradation of the natural resources has taken on an alarming aspect (Benidick, 1999). In the developing countries, due to population pressure and in a bid to extract the maximum output from the available sources, the impact of degradation can be worse than in other countries and adversely affect the land cover of the region.

Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil and/or artificial structures (Ellis, 2007). Land use, on the other hand, has a more complicated aspect as it involves social sciences and management principles and is defined as the social and economic purposes and contexts for and within which lands are managed. Although land use and land cover are frequently used together, there is a very clear difference between the two. While land cover signifies the spatial distribution of the different land cover classes on the earth's surface, and can be directly estimated qualitatively as well as quantitatively by remote sensing, land use and its changes require the integration of natural and social scientific methods to determine which human activities are occurring in different parts of the landscape, even when the land cover appears to be same (Lambin et al., 2001).

Land use and land cover change are perhaps the most prominent form of global environmental change since they occur at spatial and temporal scales immediately relevant to our daily existence (CCSP, 2003). Technically, land use and land cover change mean quantitative changes in areal extent (increase or decrease) of a given type of land use and land cover respectively. Land use and land cover change are a manifestation of forces both anthropogenic and environmental – climate driven factors (Liu et al, 2009). The changes in land use in various spatial and temporal domains are the material expressions, and also indicate environmental and human dynamics and their interactions mediated by land availability (Lambin et al., 2003).

Spatial data on land use and land cover in a region is a prerequisite to determining the qualitative and quantitative changes in land use and land cover. Advances in remote sensing over the past few decades now enable repeated observations of the earth's surface (NAP, 2008). With the increase in sensor capability in terms of spatial resolution, spectral variability and temporal frequency, the minute changes on the earth's surface can be estimated fairly accurately.

Land use and land cover changes, apart from changing the physical dimension of the spatial extent of the land use and land cover classes, also influence many of the secondary processes which lead to the eventual degradation of the ecosystems of the earth (Dregne and Chow, 1992). First and foremost, the impact of land use and land cover changes is the reduction of vegetation cover. The loss of a vegetation cover, in turn, leads to many other deleterious effects on the environment, namely, loss of biodiversity, climate change, changes in radiative forcing, pollution of other natural ecosystems with a reduction in their quality, changes in hydrological regimes, and the list continues (Niyogi, et al. 2009). The secondary impact of land use and land cover changes initiates a cascade of effects on the environment and this works in a loop to further influence land use and land cover changes.

To further understand the influence of human beings on the ecosystems of the world, we need to understand the concept of the ecological footprint of the human population. An Ecological footprint or the amount of earth we use for maintaining the standard of our living has a tremendous implication (Dietz et al., 2007). "Ecological Footprint" a term coined by Wackernagel and Rees (1996) is the land area necessary to sustain current levels of resource consumption and waste discharge by that population. Assuming that ecosystems are '*autopoietic*' i.e. self producing to the extent that each living species participate in the production of the other species, there are constant fluxes in the ecosystem in terms of energy flow, food webs and nutrient cycling. The dynamic nature of ecosystems is manifested in the form of ecosystem development and evolution (succession) involving recycling between producers and consumers and highlighting the interdependence among the ecosystem components. This resource analysis tool helps in understanding underlying questions of sustainability. It measures the extent to which humanity is using the nature's resources. When humanity's ecological resource demand exceeds what nature can continuously supply, we move into what is termed as ecological overshoot (Wakrangal et al., 2002). It is the ecological overshoot which leads to land use and land cover change which reflects irreversible change to ecosystems. This leads to changes in one form of land cover naturalized over time to a particular ecological formation.

Remote sensing as a tool for land use and land cover change

In this regard, satellite remote sensing has immense potential in ensuring a synoptic view of the landscape at all levels right from the local level to the global level. Furthermore, satellite-based remote sensing sensors can capture the electromagnetic spectrum in ranges other than the visible region and can split the complete electromagnetic spectrum into various bands. This enables the extraction of information about the variability of the earth's surface due to the reflective property of the earth's surface to the different electromagnetic wavelengths (Lillisand and Kiefer, 2006). GIS, which can depict information on natural as well as anthropogenic induced resources in spatial domains enables the proper planning and execution of policies.

Remote sensing is an essential tool of land-change science because it facilitates observations across larger extents of Earth's surface than is possible by ground-based observations. This is accomplished by the use of cameras, multi-spectral scanners, RADAR and LiDAR sensors mounted on air- and space-borne platforms yielding aerial photographs, satellite imagery, and RADAR and LiDAR datasets. Data available from remote sensing vary from the very high-resolution datasets produced irregularly over extents no larger than a single state or province (by aerial photography, imaging, LiDAR, and by high resolution satellite sensors such as CartoSat, IKONOS and Quickbird), to regional datasets produced at regular intervals from satellites (e.g.,LISS III, Landsat, SPOT), to lower-resolution (>250 m) datasets now produced across the entire Earth on a daily basis (e.g., MODIS).

The temporal dynamics of the synoptic view of the earth's surface by satellite assisted data capture has given us an important tool to study the variations in land use and land cover over a period of time. The changes in the land use and land cover manifested as a function of the changes either natural or manmade, have a bearing on the reflectance patterns of incidence radiation due to the changes in the vegetative cover, soil moisture or the various modifications of the earth's surface (Navalgund, 2001). Since the changes in land use and land cover are more or less unidirectional, without much oscillation, it is safe to extrapolate the changes in spatial extents and also calculate the rate of changes. A very important tool in this regard is the Geographical Information System (GIS).

The Geographic Information System is a powerful tool in which spatial information can be stored, organized, and retrieved in a user-friendly environment. The Conjunction of satellite remote sensing data and ancillary data in a GIS environment combined with the Global positioning system (GPS) data is a potential tool to environment management. By Combining the GIS and Information technology (IT), a new word has been coined, namely, Geoinformatics. The three major objectives of Geoinformatics include: Organization/development and management of geospatial data; spatial modeling and data analysis; development and integration of computer tools for visualization and analysis of real time geospatial problems in decision making processes.

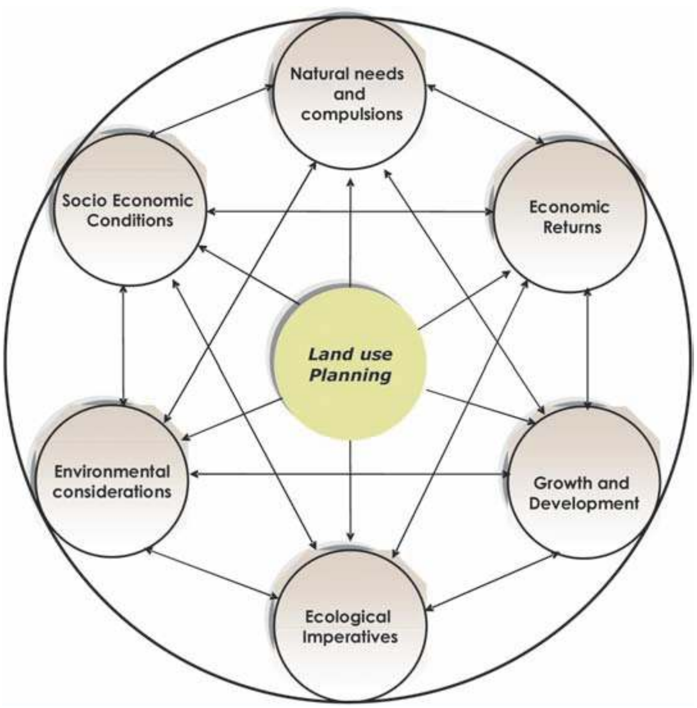
Need for estimation of land use and land cover change

For inclusive growth and development in various spheres and sectors, food and water security for the growing population needs to be met and issues emerging from climate change, need to be addressed (Ramakrishna, 1998). Recognizing these multifunctional requirements of land, the various dimensions and relationships of different sectors of the society need to be recognised. In this context, land use planning and management are considered an interwoven complex web system (figure 1).

In view of this, due attention has been given in India to developing national policies of various sectors of land management. Although India has only 2.3 % of terrestrial land area, it harbours 17% of the global population and 11% of the global livestock. The pressure on the Indian land mass is almost 4–6 times the global average. In the last 40 years the area under crop has almost remained constant at around 140±2.0 Mha (Roy and Murthy, 2009). To sustain the bursting population, in India there is intensive agriculture, which annually withdraws around $2000–2500 \times 10^6$ m^3 of water. India's urban population has grown phenomenally over the past five decades with about 7–8 million people being added to the urban population each year. Considering the rate of urbanization as a parameter to indicate the growth of a city, it is found that eleven cities in India are amongst the 100 fastest growing cities of the world (TOI, 2007).

Although the urban regions of India have some modern technologies for planning and development, it is rural India, which constitutes around 72% of the total population in the country, which needs scientific and technical inputs in overall socioeconomic development (Rao, 2008). Nearly three-fourth of the households in the country accounting for one third of total primary energy consumption are in rural areas with little access to energy sources other than biomass. Water security will be one of the major concerns in the coming decades with a projected water demand of over

Figure 1: Land Use Planning – An Interwoven Web (adapted from Roy & Murthy, 2009).



980 billion cubic meters by 2050. India, being a agrarian community, must ensure that water security is addressed in the coming decades to maintain economic development as well as to feed its ever-increasing population. There is a need to develop sustainable management of the ground water as well as effective utilization of surface water for maintaining the water security in the country

Furthermore, India has reasons to be concerned about the impact of climate change. Its large population depends on climate-sensitive sectors like agriculture and forestry for livelihoods. India has a very long coastline. The coastal zone of India is densely populated and stretches over 7500 km with the Arabian Sea in the west and the Indian Ocean/Bay of Bengal in the east. The total area occupied by coastal districts is around 379,610 km^2 with an average population density of 445 persons per km^2 (about 1.5 times the national average; Earth Trend, 2003). Recent studies on the potential impact of a one meter sea level rise along the Indian coast suggest that the total area of 5763 km^2 along the Coastal States of India i.e., 0.41% could be inundated and almost 7.1 million i.e., 4.6 % of the coastal population could be directly affected (TERI, 1996). These and other associated impacts of climate change will threaten food security and cause a dieback of natural ecosystems including species that sustain food production.

National LULC databases

In the last decade, there has been a tremendous increase in the quality and extent of spatial database generation of land use and land cover in India. The Concentrated effort of various governmental and non-governmental organizations/agencies has resulted in the generation of thematic information on the various aspects of land use and land cover. The department of Space has been at the forefront of the effort and has taken a lead role in the generation of land use and land cover information at various resolutions. Some of the major achievements in this regard have been discussed already.

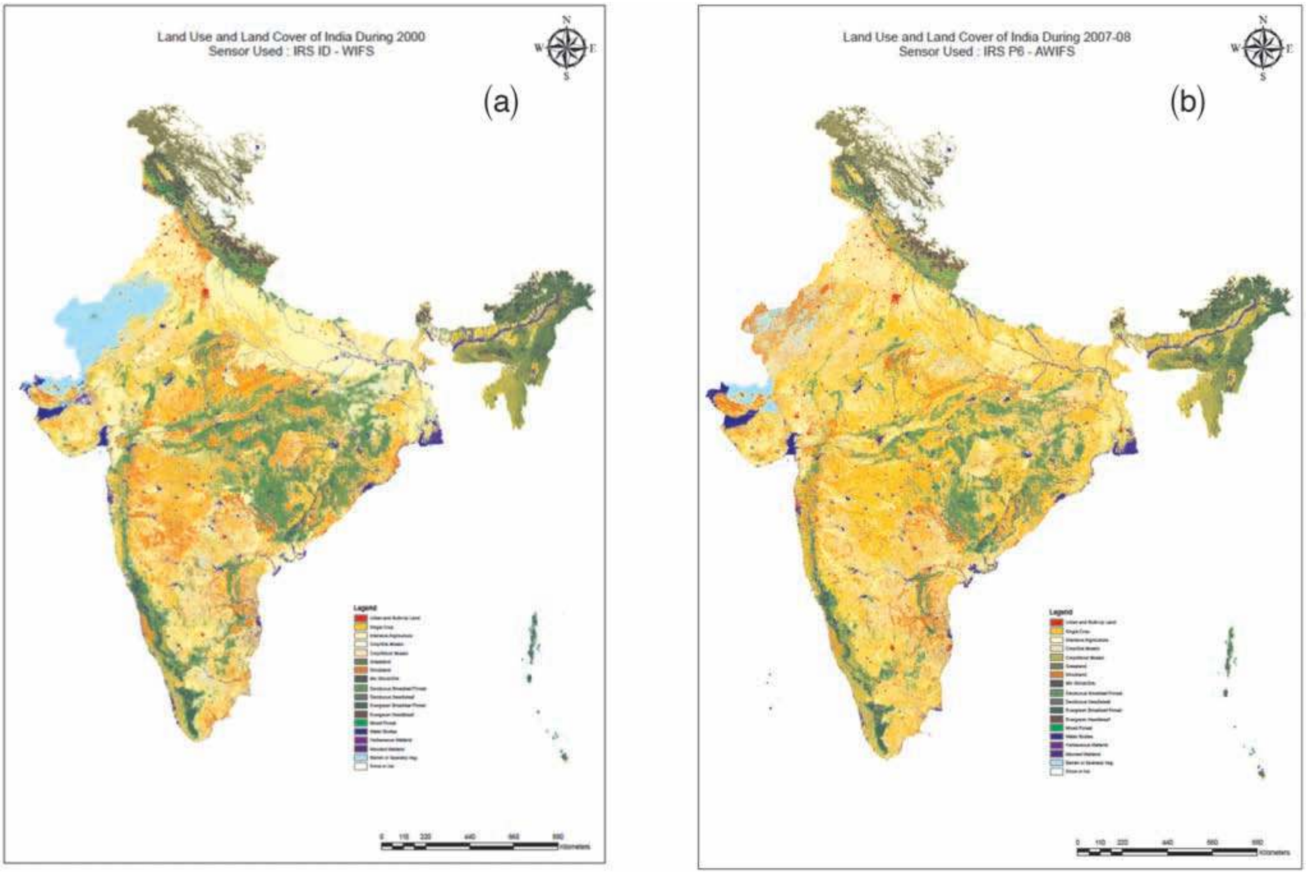
One of the first National Level surveys on the land use and land cover of India was generated as part of Biome level mapping using IRS 1D WiFS data (180m) at 1:1M. The data base has been used for Global land cover mapping 2000. The database has been generated using the premise that vegetation is a function of climatic and environmental conditions prevalent in a particular area. This database is one of the baseline databases of land use and land cover in India (Fig. 2a) and helped in the formulation and effective implementation of the National Level Biodiversity Characterization at Landscape Level Project.

Of the major land use and land cover databases available is the annual land use and land cover map at 1:250K using AWiFS data (56 m) (Fig. 2b). The project has resulted in the generation of a cropped area for all the three cropping seasons (Kharif, Rabi and Zaid). Already 5 cycles of database generation for the years 2004–05, 05–06, 06–07, 07–08 and 08–09 have been completed. Currently, the sixth cycle of the project (09–10) is in progress.

All three cycles of the LULC database, seasonal snow and water are organized in conjunction with ancillary information on roads, settlements and socioeconomics in the geospatial domain to serve as a Web-enabled LULC information system "Bhoosampada" to facilitate value-added data query, utilization and dissemination. The information system is organized to serve 1:1 million scale products for wider use as a primary information product and 1:250,000 scale products viz., maps, statistics and digital databases to facilitate advanced analysis and integration. The facility on query and integrated analysis of the 3 cycles' data in conjunction with socio economic information adds an additional dimension to data value and utilization.

Understanding the spatial dynamics of land use and land cover change (LULCC), has been a challenge for geospatial scientists and until now date there has not been a single robust model which can capture the land use and land cover dynamics of a

Figure 2: Land use and land cover maps of India during 2000 (a) and 2007 (b) (*resampled* to 200 m × 200 m).



region. In view of the importance of understanding the influence of the human, physical and climatic determinants in LULCC, this project envisions the study of their impact on the LULCC in the country. To facilitate the study, the entire country has been divided into 14 river basins owing to the intrinsic variability in topography, hydrology, climate and anthropogenic influence in each basin. This leads to unique drivers and properties for each river basin. The project will spatially identify the future land LULC scenario with respect to region-specific drivers of LULCC.

Land use and land cover change modeling

First and foremost in land use and land cover change modeling is the generation of scenarios. This is because the relationship of the people with the land has the same origin as their evolution – the ability to modify their surroundings to suit themselves. Land use change is a locally pervasive and globally significant ecological trend. On a global scale, nearly 1.2 million km^2 of forest have been converted to other uses during the last three centuries (Ramanakutty and Foley, 1999) while cropland has increased by 12 million km^2 during the same period. Currently, humans have transformed significant portions of the earth's land surface: 10–15% is dominated by agriculture or urban-industrial areas and 6–8% is pasture (Vitousek et al., 1997). These changes in land use have important implications for future changes in the earth's climate and, in turn, greater implications for subsequent land use and land cover change. The surface heat and moisture budgets depend very much on land use and land cover which, in turn, affect atmospheric instability. Simulations of the plausible human-influenced landscape changes following different scenarios may reveal strategic policies that should be modified to improve the environment.

Understanding the spatial dynamics of land use and land cover change has been a challenge for geospatial scientists and until now there is not a single robust model which can capture the land use and land cover dynamics of a region. Historical land use patterns coupled with current trends in a region are used to model future land use. Land use change models include trend analyses of historical data like GEOMOD (Pontius et al., 2001) or CA-Markof which predicts the rate and spatial pattern of land conversion based on past land use change or agent-based change models where the drivers define the change in land use.

Numerous models have been used to build scenarios of the future: narrative method models and hybrid methods using both qualitative and quantitative methods (Jones 2005). Agrawal et al. (2002) have provided an exhaustive study on the various available land use and land cover change models. Most land use/change models incorporate three critical dimensions. Time and space are the first two dimensions and provide a common setting in which all bio-physical and human processes operate. The third dimension is the human process or the human decision-making dimension. The three dimensions of land use change models (space, time and human decision-making) and the two distinct attributes for each dimension (scale and complexity) are the foundations of the land use change models (fig. 3).

Vegetation dynamics over three decades in Mangroves of Godavari Delta

Coastal locations have been the favorite destinations of populations in movement for defense, commercial and other economic reasons. About 20% of the population of India lives in coastal areas, a larger percentage of this being in coastal cities, such as Mumbai, Chennai and Calcutta. One of the major factors responsible for the degradation of coastal ecosystems is the growth in human population that requires space for settlement and other resources like soil and water.

Recent work by Reddy and Roy (2007) has shown that coastal ecosystems are dynamic ecosystem and are extensively influenced by anthropogenic factors and policies. The study was carried out using four time period satellite data (1977, 1988, 2000 and 2005) of the Kakinada bay. Using the supervised digital classification method (maximum likelihood classifier), the mangroves and their surrounding LULC classes (5 km buffer from the mangroves) have been identified. On running change analysis among the nine LULC classes, it was observed that the various classes had different trends of change through the four decades as shown in Table 1.

The change matrix generated shows that mangrove vegetation had a negative change during 1977-1988 due mainly to encroachment of the natural mangroves by agriculture and aquaculture during the 1980s which led to extensive degradation of the mangrove vegetation in the Kakinada Bay. But after the Coringa Wild life sanctuary was established, the mangrove vegetation in the Kakinada bay has shown a positive increment (Fig. 4). Reddy & Roy have also observed that the majority of positive changes in the region are due to the active involvement of the government in the form of protection of natural areas and plantation efforts (Table 1).

Figure 3: Three dimensional frame work for land use change models.

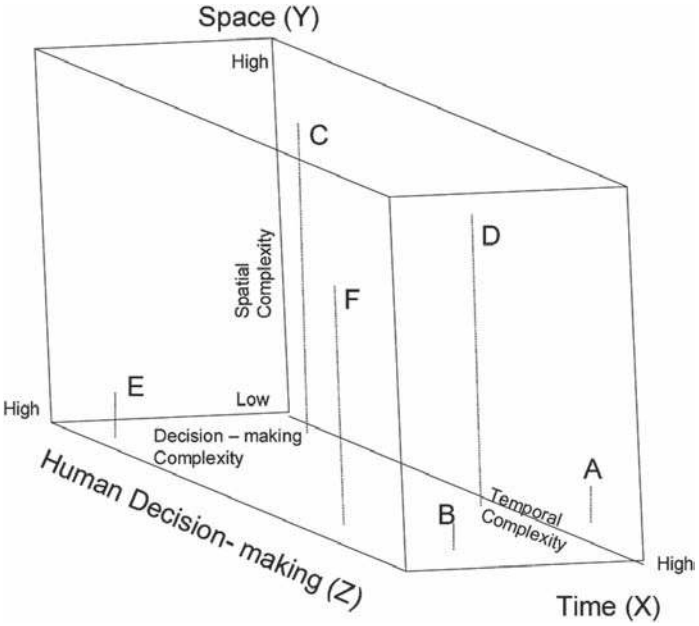
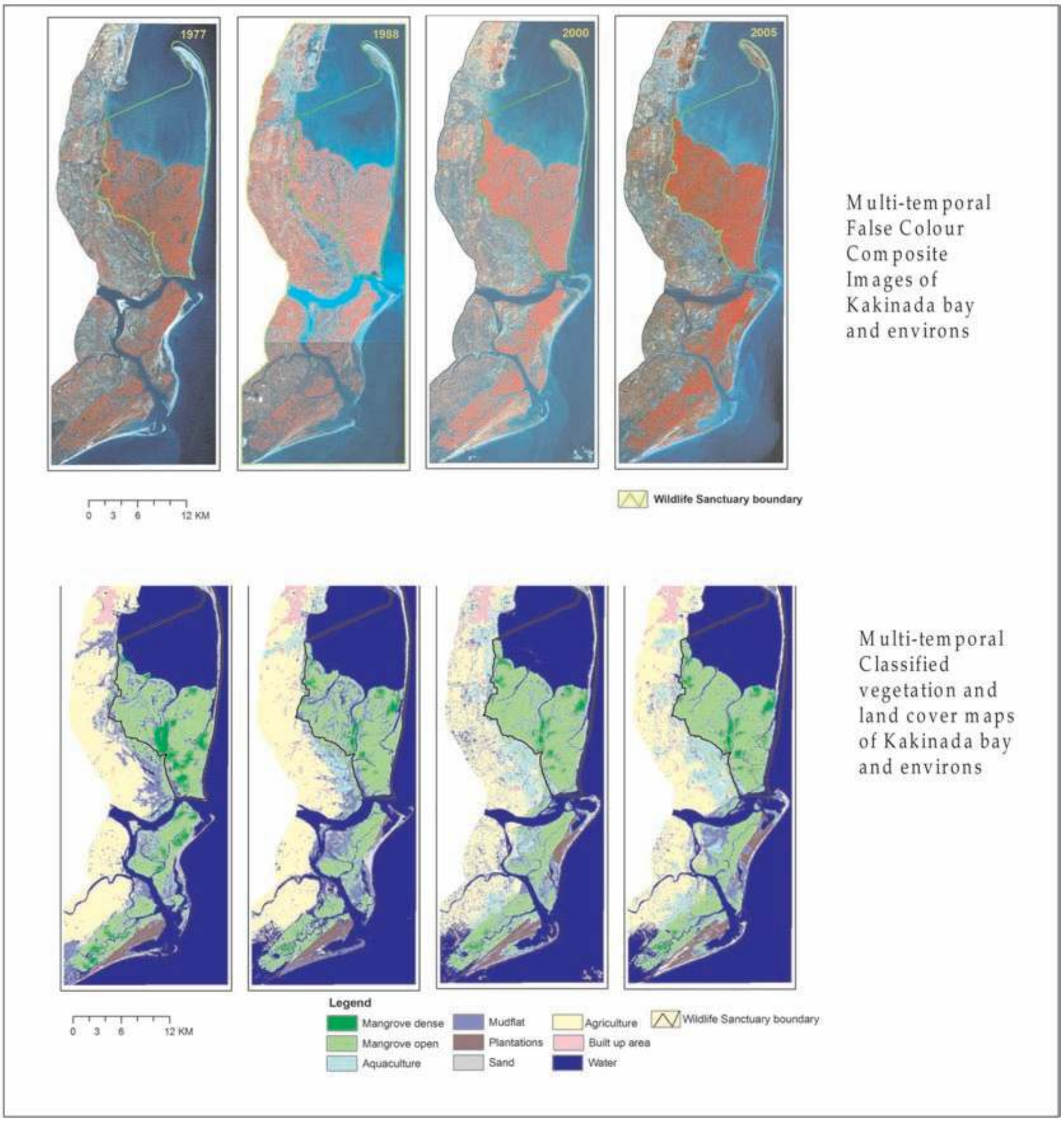


Table 1: Change area matrix of vegetation and other land cover in the Godavari mangroves and its environs (Source Reddy and Roy, 2007).

1977/2005	Dense Mangrove	Open Mangrove	Plantations	Agriculture	Built uparea	Aquaculture	Water	Mudflat	Sand	Total
Dense Mangrove	4.3	14.9	0.0	0.0	0.0	0.0	1.0	0.3	0.0	20.6
Open Mangrove	5.8	124.7	0.7	5.0	0.0	8.2	14.2	14.5	1.2	174.2
Plantations	0.0	0.4	7.1	0.0	0.0	0.2	0.3	1.2	1.4	10.6
Agriculture	0.0	0.8	0.1	164.2	8.3	18.8	6.6	9.4	0.6	208.8
Built up area	0.0	0.0	0.0	0.7	13.5	0.0	0.0	0.0	0.0	14.2
Aquaculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.1	12.5	5.1	8.3	0.1	1.9	388.1	15.1	7.2	438.2
Mudflat	0.2	21.1	1.4	17.4	0.5	17.4	12.3	14.5	0.7	85.5
Sand	0.0	1.2	3.9	0.7	0.0	0.1	6.3	5.0	2.5	19.8
Grand total	10.3	175.7	18.2	196.2	22.4	46.5	428.8	60.1	13.6	972

Figure 4: Changes in vegetation and land cover in Kakinada Bay over 3 decades (Source Reddy & Roy 2007).



Land use and land cover change analysis in the Pennar River Basin: a case study

The Pennar Basin extends over nearly 1.7 % of the total geographical area of the country. The basin lies in the states of Andhra Pradesh and Karnataka. The Pennar River rises from the Chenna Kesava hills of the Nandi ranges of Karnataka and flows for about 597 km before falling into the Bay of Bengal. An average annual surface water potential of 6.3 Km^3 has been assessed in this basin, which is completely utilizable. The cultivable area in the basin is about 20.3 m ha, which is about 10.4 % of the total cultivable land of the country.

A Temporal land use and land cover map of

Figure 5: Methodology for temporal LULC mapping in the Pennar River Basin.

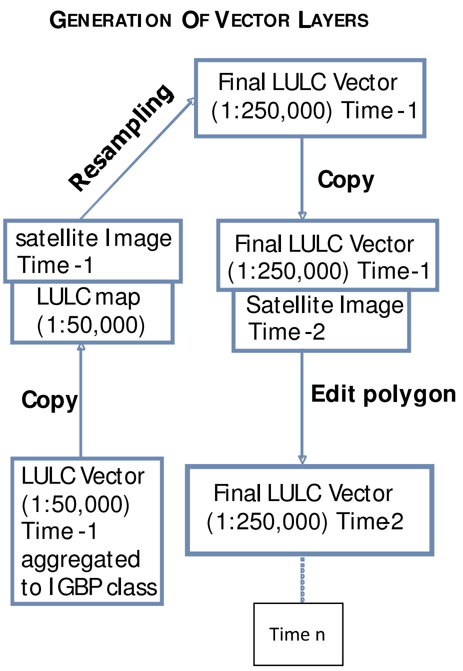


Figure 6: Temporal LULC map of the Pennar River Basin.

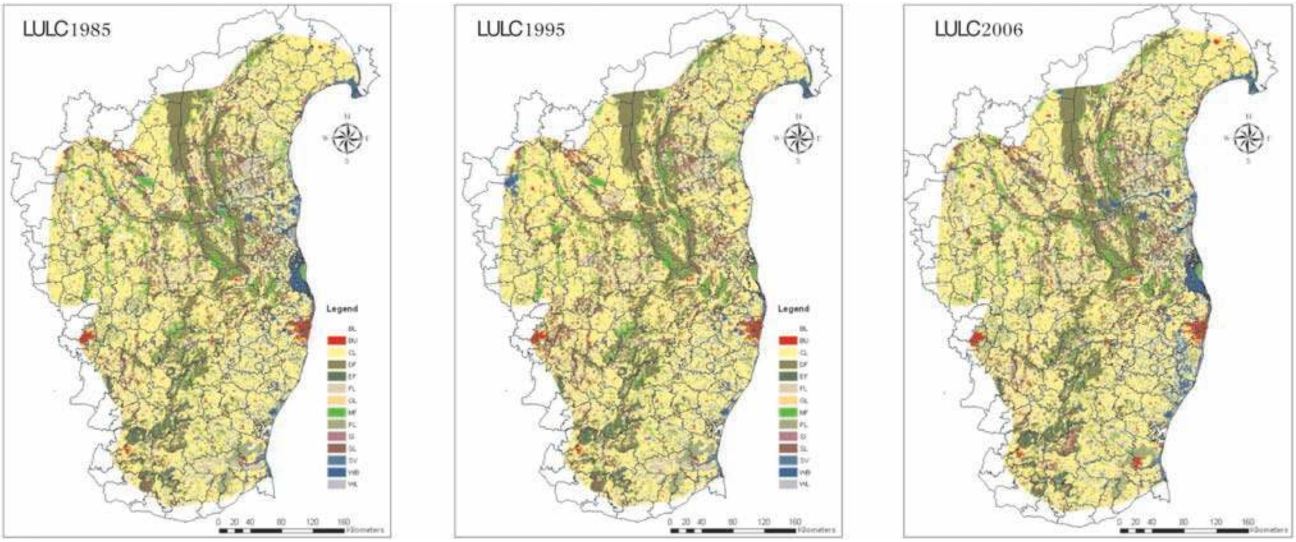
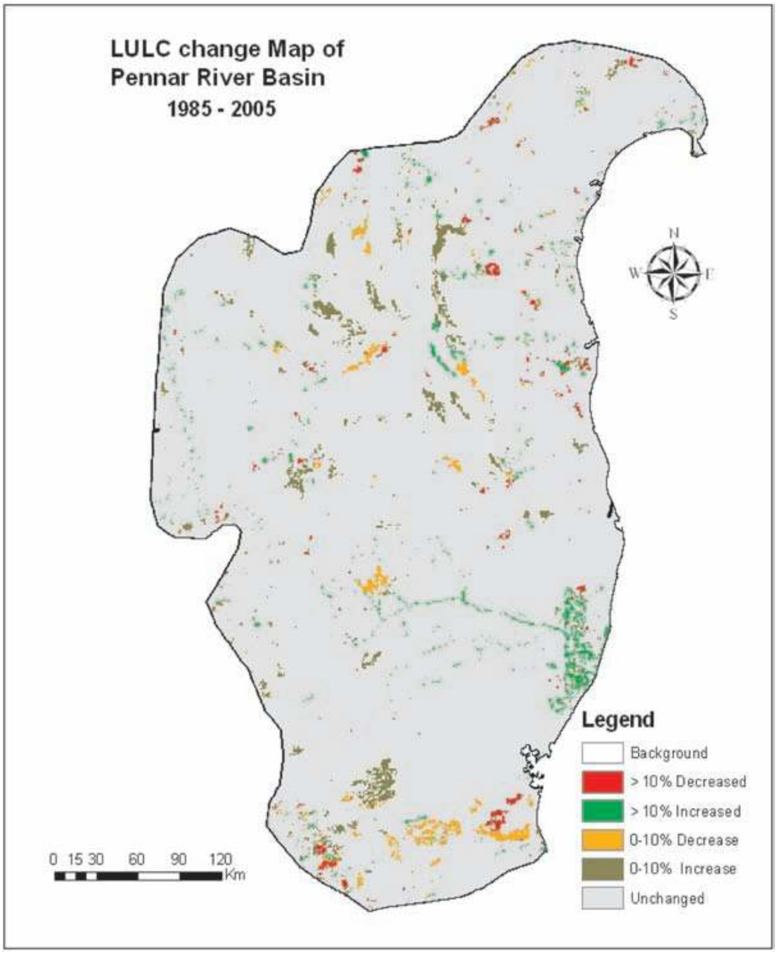


Figure 7: Change map of the Pennar river basin (1985–2005).



the Pennar river basin was prepared for the years 1985, 1995 and 2005 and covered two decades. The methodology followed for the land use map is given in figure 5.

Using the three time period data (Fig. 6) a change map was generated using ERDAS imagine software. The change map is shown in figure 7.

It has been observed that the land use and land cover change in the region is mainly driven by the socio-economic changes in the region. The wetland of the region has increased greatly and has been mostly converted from crop lands. This is due to the sudden spurt in aquaculture practice during the early part of the 1990s.

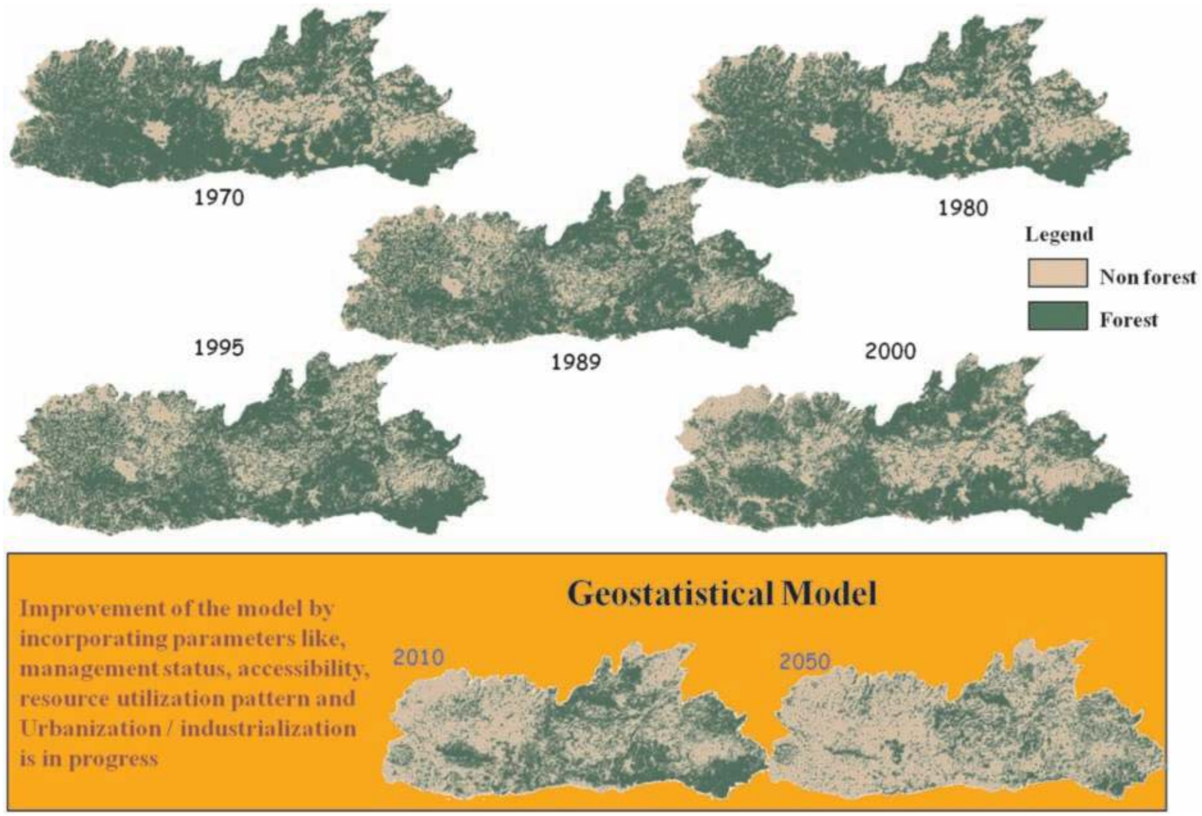
Geostatistical modeling of Land cover change in Meghalaya

A case has been described here for land use and land cover change simulation. The North Eastern (NE) Region of India harbours an 83.5% forest cover and is dominated by varied forest types and associated land use. Indigenous shifting cultivation has long been practised in all parts of the NE region over the past several decades and has impacted land use patterns and compositional and structural changes in the forests. In view of this, a predictive analysis of forest cover changes in Meghalaya state of the NE region was conducted. The trends in LULC changes were analyzed based on remote sensing based LULC maps generated for 1980, 1989, 1995 and were used to develop a predictive forest cover for these years (Roy and Tomar,2001; Singh et al, 2001) (Fig. 8) This work has been one of the first efforts in change modeling in the country.

Table 2: Change area matrix of Pennar River Basin (1985–2005)

1985/2005	Built up	Crop land	Fallow Land	Plantation	Evergreen Forest	Deciduous Forest	Mixed Forest	Scrub land	Grass land	Barren Land	Waste land	Water Body
Built up	1782.20	5.05	0.00	1.58	0.00	0.00	0.66	0.00	0.00	0.00	0.45	3.13
Crop land	122.64	78110	567.86	28.90	4.85	19.93	58.21	154.82	0.00	19.84	1.57	1421.30
Fallow Land	8.63	912.29	8079.49	6.43	0.00	4.90	4.95	62.13	0.00	22.36	0.01	117.53
Plantation	107.51	19.11	0.64	4566.14	0.00	0.76	0.95	0.42	0.00	0.63	0.62	21.27
Evergreen Forest	0.00	3.47	0.00	0.00	1636.10	122.50	46.79	9.22	0.00	0.00	0.00	0.12
Deciduous Forest	0.00	22.66	6.29	14.13	39.37	14373.69	695.17	742.22	0.00	6.89	0.00	30.13
Mixed Forest	3.27	77.05	21.18	4.81	7.91	387.58	8162.5	341.03	0.00	22.66	0.00	59.79
Scrub land	0.45	191.16	92.46	4.24	5.84	44.06	80.07	10504.12	0.00	25.55	0.02	74.44
Grassland	0.00	1.67	1.22	0.18	0.00	0.00	0.00	0.00	8.10	0.00	0.02	0.00
Barren Land	1.62	16.14	21.20	43.41	0.00	0.00	2.70	4.37	0.00	811.90	0.00	0.11
Wasteland	0.00	4.22	0.00	1.06	0.00	0.00	0.01	0.72	0.00	0.00	804.47	1.20
Water Body	2.00	263.46	4.87	3.62	0.00	1.73	25.81	12.24	0.00	2.71	2.43	7591.69

Figure 8: Land cover change simulation in Meghalaya (Roy & Tomar 2001).



Land use and land cover modeling in the Indian scenario: a case study in Goa

Human influence on natural ecosystems in association with biogeography has been changing land cover through the ages. But in recent times, due to an ever-increasing demand for agricultural space and resources as a result of increasing population, there rapid changes in the land cover of most of the regions of India with Goa being no exception. Understanding the spatial dynamics of land use and land cover change has been a challenge for geospatial scientists and until now date there has not been a single robust model which can capture the land use and land cover dynamics of a region. Here, it may be noted that the population expansion in a region is intrinsically related to topographical and climatic impedances. This results in the colonization of areas with less topographical variability and moderate climates.

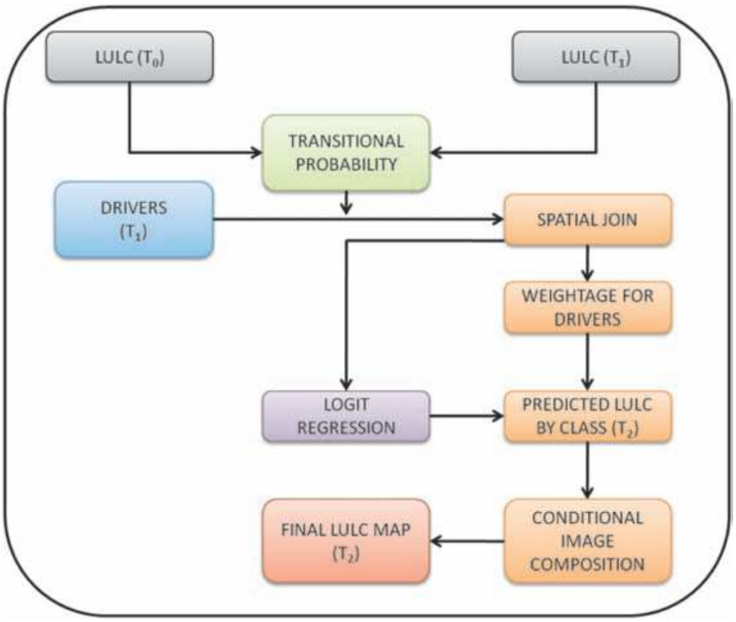
An agent-based land use and land cover change model has been developed to understand the land use and land cover dynamics in Goa (Roy et al., 2010). The model used Markovian probability in association with Cellular Automata to allocate spatially the trends defined by the drivers of change. This is a open-ended model where the drivers can be defined based on local/regional specific characteristics. In the present study the drivers used were population density, terrain (elevation and slope) and rainfall. Using the multiple regression method, the impact of the drivers was calibrated and fed into the model.

The three time period data has been used to model land use change in Goa. The 1985 and 1994 data have been used to model land use and land cover change. The land use change model used was the CA-Markof model which gives a Markof's probabilistic model of probable land use change in the second time frame data, the cellular automata is used to weed out the outliers and give the optimized output.

Identification of drivers

The land use change from 1985 to 2006 has been a result of various anthropogenic and climatic factors. Until now there has been little work on the quantitative assessment of the various drivers of land use change. Since the assessment of the various socio-economic factors is qualitative, there has been an attempt to select the drivers which will lend

Figure 9: Schematic diagram of the Agent Based Change Model.



themselves to statistical evaluation. After extensive statistical analysis, we have identified three drivers, namely, population density, rainfall, and terrain (slope and elevation). A brief methodology of the work flow is given in fig. 9.

The land use and land cover changes as well as the ongoing changes which have occurred in Goa are influenced mainly by two drivers, anthropogenic and the bio-geo-climatic. Since the bio-geo-climatic drivers are at a very coarse spatial scale when we take into account the spatial extent of a state like Goa, it is the anthropogenic drivers which play a major role in the spatial variability in the land use and land cover changes in the region. This does not mean that the bio-geo-chemical factors are non-existent; in fact, bio-geochemical factors in association with anthropogenic factors are solely responsible for the changes in land use and land cover in the region.

Using the three time period data, two for computation and one for validation, the land use and land cover data were modeled for the state of Goa with a kappa accuracy of 85% which gives a estimate of the errors of omission as well as errors of commission with respect to the actual changes. The roles of the drivers in the LULC changes have been different for different drivers with the terrain playing a major role followed by rainfall and finally population density. The land use and land cover change scenario of 2027 shows that the most dynamic land use class is fallow land followed by degraded forests.

A Comparison between the modeled value and the satellite derived value of 2006 shows a mixed level of performance for the different classes. The variation is more prominent in classes managed by

Figure 10: Comparison between actual Image and the modelled Image.

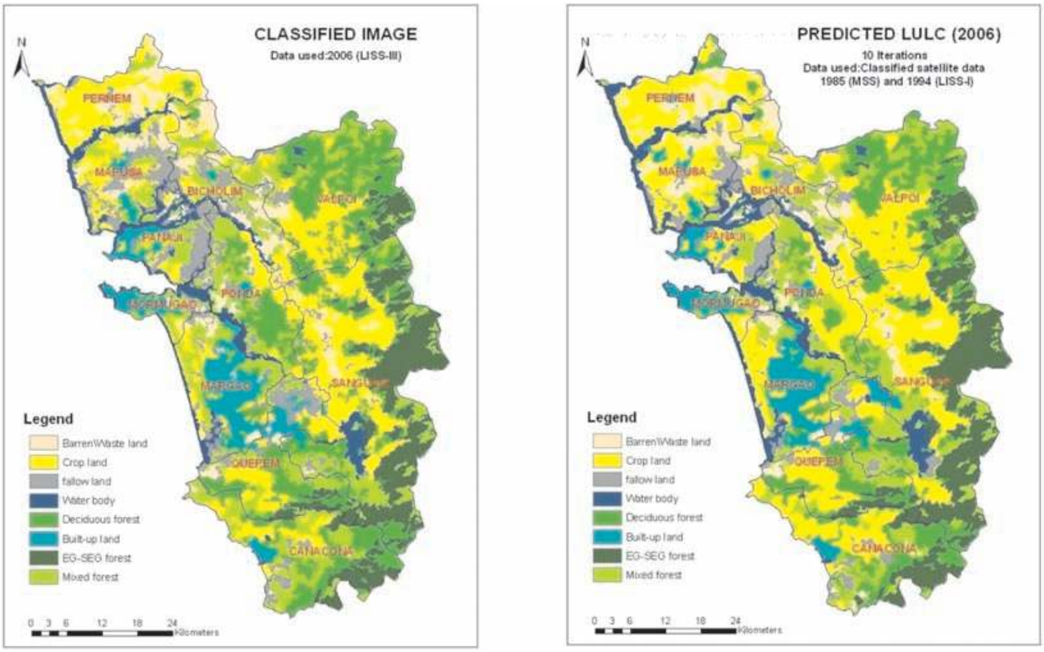
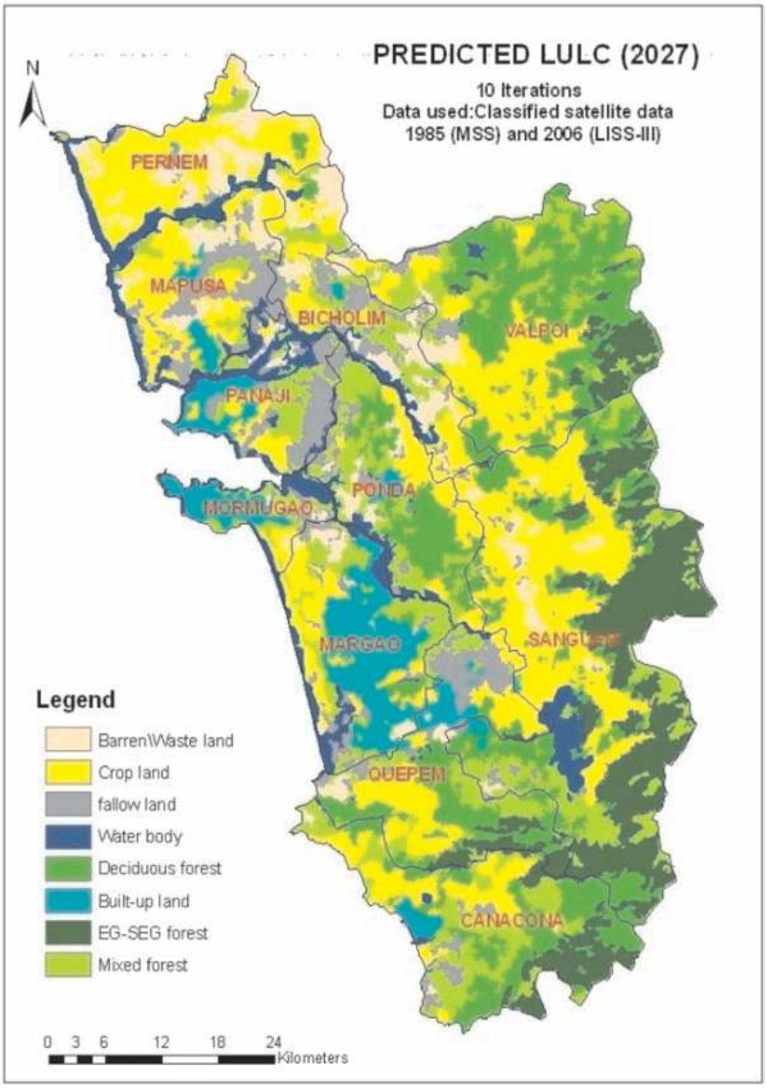


Table 3: Variations between the modeled values and satellite derived values for different land use and land cover classes.

Class	Variation (%)
Barren Land/Wasteland	−2.45
Crop Land	30.42
Fallow Land	−31.64
Water Body	26.56
Deciduous Forest	−21.28
Built Up	−0.82
Semi-Evergreen	9.32
Mixed forest	−10.72

Figure 11: Modelled Land use and land cover map of Goa for the year 2027.



human activity like cropland, fallow-land, water bodies (due to construction of reservoirs) and the natural classes which are considerably influenced by human activities, such as deciduous forests and mixed forests (Table 3). This variation is due to the influence of different land use and land cover drivers. It has been further observed that the variation in the natural land cover classes are most pronounced in the areas which are close to major settlements (Fig. 10).

The model after validation has been used to project a future land use and land cover change scenario for 2027 (Fig. 11). The predicted map of the land use and land cover change scenario when compared with the 2006 classified land use and land cover map shows that most of the small forest patches have disappeared and croplands have invaded the area.

The roles of the drivers in the LULC changes have been varied for different drivers with the terrain playing a major role followed by rainfall and finally population density. The land use and land cover change scenario of 2027 shows that the most dynamic land use class is fallow land followed by degraded forests.

Conclusion

Spatial land use and land cover change is a reflection of the impact of biotic drivers as well as abiotic drivers on the prevalent land use and land cover of the region. The force of the drivers as well as the changes in driver composition leads to changes in the prevalent land use and land cover of a region. Both the terrain and climatic factors also play a major role in influencing the intensity as well as the rate of land use and land cover change. GIS-based analysis of the RS derived temporal data of the land use and land cover of a region can identify the potentially vulnerable areas to change as a result of the different driving forces. A Geographic understanding of land use change processes can be achieved by analyzing a temporal database for spatial patterns, rates of change and trends. The analysis requires understanding a region's land use history involving population data, timelines of historical events and related information. Spatio-temporal analysis of past historical events aid in understanding and subsequently modeling the issues that influence the development in a region in association with topography, climate and adequate supply of water and other natural resources.

The human footprint is how touching more pristine and relatively natural areas. The structural and functional changes in ecological processes as a result of the extending and the consolidation of the human footprint are continuously leading to changes in land use and land cover on the earth's surface. The land use and land cover change taking place today has very serious implications for ecological sustainability as well as climate change. It is imperative that the changes in land use and land cover be assessed for spatial extent as well as intensity and magnitude to understand the cause behind this irreversible change. Furthermore, the various drivers of land use and land cover change until now date have been mostly qualitative. There is a need to quantify the drivers of land use and land cover change for estimating and quantifying their consequences. Numerical modeling of land use and land cover change gives us a tool to understand and quantify the processes involved in this alteration and will enable us to take the necessary steps to arrest the various land use and land cover changes taking place.

Acknowledgement

The authors thank the Director NRSC, for his encouragement and support. The various project teams are duly acknowledged.

Received 27 October 2010.

References

1. Agarwal, C., G. M. Green, J. M. Grove, T. P. Evans, and C. M. Schweik. 2002. A Review and Assessment of Land-Use Change Models: Dynamics of Space, Time, and Human Choice. General Technical Report NE-297. Newtown Square, Pennsylvania: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 61 pp.
2. Benedick, R.E., 1999. Tomorrow's environment is global. Futures, 31(9-10), 937–947.
3. CCSP,2003. Strategic Plan for the U.S. Climate Change Science Program. Final report.
4. Dietz T., Rosa E.A., York R. 2007. Driving the human ecological footprint. Frontiers in Ecology and Environment, 5(1): 13–18
5. Dregne, H.E. and Chou, N.-T. 1992. Global desertification dimensions and costs. In: Degradation and restoration of arid lands. Lubbock: Texas Tech. University.
6. Earth Trend (2003) http://earthtrends.wri.org
7. Ellis E., 2007. Land use and land cover change. Encyclopedia of Earth.
8. Jones, R. 2005. A Review of Land Use/Land Cover and Agricultural Change Models. Stratus Consulting Inc. for the California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2005-056.
9. Lambin, E.F., Turner II, B.L., Geist, H., Agbola, S., Angelsen, A., Bruce, J.W., Coomes, O., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skånes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T., Vogel, C., Xu, J., 2001. Our emerging understanding of the causes of land-use and land-cover change. Global Environ. Change, 11, 261–269.
10. Lambin E.F., Geist H, Lepers E. 2003. Dynamics of land use and cover change in tropical regions. Annual Review of Environment and Resources 28: 205–241.
11. Lillesand, T.M. and Kiefer, R.1993. Remote Sensing and Image Interpretation. Fifth Edition John Willey, New York.
12. Liu M., Hu Y., Chang Y., He X., and Zhang W. 2009. Land Use and Land Cover Change Analysis and Prediction in the Upper Reaches of the Minjiang River, China. Environmental Management, 43(5), 899–907.
13. Navalgund R.R. 2001. Remote Sensing. Resonance. 6(12), 51–60.
14. NAP, 2008. Earth Observation from Space. www.nap.edu.
15. Niyogi D., Mahmood R. and Adegoke, J.O. 2009. Land-Use/Land-Cover Change and Its Impacts on Weather and Climate. Boundary Layer Meterology. 133(3), 297-298.
16. Pontius, R.G., Cornell, J. and Hall, C.H. (2001) Modeling the spatial pattern of land-use change with GEOMOD2: application and validation for Costa Rica. Agriculture, Ecosystems & Environment 85(1–3) pp. 191–203.
17. Ramakrishna P.S., 1998. Sustainable Development, Climate Change and Tropical Rain Forest Landscape. Climatic Change 39(2–3), 583–600.
18. Ramankutty, N. and Foley, J.A. 1999. Estimating historical changes in global land cover: croplands from 1700 to 1992. Global Biogeochemical Cycles. 13(4): 997–1028.
19. Rao, S.S. 2008. Social development in Indian rural communities: Adoption of telecentres. International Journal of Information Management, 28(6), 474–482.
20. Reddy, C.S. and Roy, Arijit (2007). Assessment of three decades of vegetation dynamics in mangroves of Godavari delta, India using multitemporal satellite data and GIS. Research Journal of Environmental Science, 2(2), 108–115.
21. Robbins, J. 2001. The food revolution: how your diet can save your life and our world. Barnes and Noble, Berkley California, pp 450.
22. Roy P.S. and Murthy M.S.R. 2009. Efficient Land Use Planning And Policies Using Geospatial Inputs: An Indian Experience. In: Land Use Policy. Editors: A.C. Denman, O.M. Penrod, Nova Science Publishers, Inc.
23. Roy P.S., Srivastava, V.K., Roy A., Mehtab A., Sampath K., Suresh J.R., Sharma A. and Dwivedi R.S. 2010. Agent Based Land use and land cover change modeling. *Unpublished.*
24. Roy P.S., and Tomar S. 2001. Landscape cover dynamics pattern in Meghalaya. International Journal of Remote of Remote Sensing, Vol. 22 No. 18, pp 3813–3825.
25. Singh S., Porwal, M.C., Jeganathan, C., Talukdar G. and Roy, P.S., 2001. Vegetation Cover Mapping using Hybrid Approach in Digital Classification. Asian Journal of Geoinformatics Vol. 2 No. 2, pp 37–45.
26. TERI (1996): The economic impact of one meter sea level rise on Indian coastline-Methods and case studies, Report submitted to the Ford Foundation.
27. TOI 2007. 11 Indian Cities among worlds fastest growing. Times of India. http://timesofindia.indiatimes.com/articleshow/2481744.cms
28. Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M. 1997. Human domination of Earth's ecosystems. Science. 277: 494–499.
29. Wackernagel M. and Rees W.E. 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. ISBN 086571312X, 9780865713123, New Society Publishers, 160p.
30. Wackernagel M., Schulz N.B., Deumling D, Linares A.C., Jenkins M., Kapos V., Monfreda C., Loh J., Myers N., Norgaard R., and Randers J. 2002. Tracking the ecological overshoot of the human economy Proceedings of National Academy of Sciences USA, 99(14). 9266–9271.

Dr. PS Roy is the Outstanding Scientist, ISRO, Associate Director (Capacity Building), National Remote Sensing Centre, Dean, IIRS and also Director, Centre for Space Science and Technology Education in Asia and the Pacific (affiliated to the United Nations), Dehradun (India) for international Capacity Building. He is Ph.D. in Ecology and has contributed significantly in Satellite Remote Sensing and Geoinformatics Science for Natural Resources and Disaster Management. Presently he is Lead for National Biodiversity Characterisation at Landscape Level and Landuse Land Cover Change Dynamics in the Indian River Basins projects of ISRO.

Dr Arijit Roy is presently working as a Scientist in National Remote Sensing Centre, Indian Space Research Organization, Hyderabad. He has obtained his graduation, post-graduation and Ph.D. in Botany from Banaras Hindu University. He was previouly associated with Computer Center, Banaras Hindu University, where he was working as a post-doctoral fellow. Dr Arijit Roy is working in the field of Ecological Modeling, Geospatial land-use land-cover change modeling and modeling biological diversity and its change and has published a number of papers in this field. He is a team member of the Landuse Land Cover Change Dynamics in the Indian River Basins.