Tropical Ecology **54**(2): 239-250, 2013 ISSN 0564-3295

www.tropecol.com

Land use/land cover change dynamics analysis in mining areas of Singrauli district in Madhya Pradesh, India

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Abstract: This paper presents results of the study on the dynamics in land use/land cover (LULC), resulting from mining related activities, in Singrauli district of Madhya Pradesh. The availability of large coal reserves and the construction of Gobind Ballabh Pant Sagar reservoir in Rihand river have provided the necessary impetus to industrial development in the district. Mapping of LULC change is an important activity of land management and monitoring. The changes were mapped using remotely-sensed multi-date satellite in a Geographic Information System (GIS). Spatial and temporal changes in the land use/land cover were quantified using Landscape metrics. In addition, Markov transition matrix and change rate were also calculated for each of the LULC classes. The transitions from one class to the other were depicted with the help of change matrices. The analysis suggests that the vegetation cover is undergoing continuous negative change in terms of composition and extent. The rate of deforestation and forest fragmentation has also increased while built up and mining areas have registered a positive change.

Resumen: Este artículo presenta los resultados de un estudio de la dinámica en la cubierta del uso del suelo/cobertura del suelo (LULC, siglas en inglés) como resultado de actividades relacionadas con la minería en el Distrito Singrauli, Madhya Pradesh. La disponibilidad de grandes reservas de carbón y la construcción de la presa Gobind Ballabh Pant Sagar en el río Rihand han brindado el ímpetu necesario al desarrollo industrial en el distrito. El mapeo del cambio de LULC es una actividad importante de manejo y monitoreo del territorio. Los cambios fueron mapeados con información satelital multitemporal obtenida por percepción remota en un Sistema de Información Geográfica. Los cambios espaciales y temporales en LULC fueron cuantificados usando métricas de paisaje. Además, también se calcularon matrices markovianas de transiciones y tasas de cambio para cada clase de LULC. Las transiciones de una clase a otra fueron representadas por medio de matrices de cambio. El análisis sugiere que la cobertura vegetal está sufriendo un cambio negativo continuo en términos de composición y extensión. Las tasas de deforestación y de fragmentación del bosque también se han incrementado, mientras que las áreas urbanizadas y de minería han registrado un cambio positivo.

Resumo: Este trabalho apresenta resultados do estudo sobre a dinâmica do uso / cobertura solo (LULC), resultante das atividades relacionadas com a mineração, em Singrauli distrito de Madhya Pradesh. A disponibilidade de grandes reservas de carvão e a construção da barragem Gobind Sagar Ballabh Pant em Rihand rio deram o impulso necessário para o desenvolvimento industrial no distrito. O mapeamento da mudança LULC é uma atividade importante para a gestão do solo e o seu monitoramento. As mudanças foram mapeados usando detecção remota

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multi-data por satélite com um Sistema de Informação Geográfica (SIG). As alterações espaciais e temporais na uso / cobertura do solo foram quantificadas através de métricas da paisagem. Além disso, a matriz de transição de Markov e taxa de mudança foram também calculadas para cada uma das classes LULC. As transições de uma classe para a outra foram retratadas com a ajuda das matrizes de mudança. As análises sugerem que a cobertura vegetal está passando por uma mudança negativa contínua em termos de composição e extensão. A taxa de desmatamento e fragmentação florestal também tem aumentado, enquanto a área construída e as áreas de mineração têm registado uma mudança positiva.

Key words: Change analysis, fragmentation, landscape metrics, land use and land cover (LULC), Markov transition matrix, mining.

Introduction

Globally, the need to meet the increasing energy requirement has had adverse impact on the environment and more so in the developing countries, like India which are striving to achieve economic growth for sustaining an ever-growing human population. This has resulted in over exploitation of natural resources due to activities like deforestation, overgrazing, cultivation of marginal lands, mining and industrialization for meeting the increasing demand for food, fuel and fibre. Globally, 1964.4 million ha of land are affected by human-induced degradation (Dwivedi 2002). India is endowed with a rich variety of mineral resources and hence mining industry is one of the key industries of the country (Mehta 2002). The presence of large mineral deposits in ecologically sensitive areas threatens India's already vulnerable forests. The total forested area in the 50 major mineral producing districts in India accounts for 18 % of the country's total forest cover. The government estimates indicate diversion of 95003 ha forested land for mining between 1980 and 2005 while CSE puts it to 164,610 ha (CSE 2009; Greenpeace 2011).

However, lack of environment friendly technology has led to hosts of undesirable effects on the ecosystem. Mining operations, which involve mineral extraction from the earth's crust, tends to make a notable impact on the environment, landscape and biological communities of the earth (Bell *et al.* 2001).The impacts can be seen in the form of deforestation, water and air pollution, changing pattern of rainfall and the local climate, depleting water balance and many others (Mehta 2002; Reddy 1993). Large areas of the country are disturbed by mining and other anthropogenic activities involving industrial production, transportation and urban growth (Pandey 2005; Reddy 1993).

Singrauli, India's energy capital comprises of one of the most important coalfields in India both in terms of reserves and productions. Large scale mining activities has generated a great deal of environmental stress not only on the LULC but also on ecosystems in this region (Greenpeace 2011; Singh *et al.* 1997). The on-going exploitation of the area for surface water, ground water, coal, building material, unsafe industrial waste disposal have singled it out as an environmentally-sensitive zone (Singh *et al.* 2003). Mining activity has resulted in huge dumps of overburden known as mine spoil, which is physically, nutritionally and microbiologically an impoverished habitat. This drastically disturbed system is highly prone to erosion and could cause contamination of rivers and adjoining agricultural lands with harmful substances that can leach out through rainwater (Singh 2007). Moreover, quarrying for limestone, the establishment of thermal power stations, cement factory and the construction of Gobind Ballabh Pant Sagar Reservoir in the 1960s have resulted in the rapid increase of human population, the displacement of the native population, deforestation and conversion of natural forest ecosystems into grassland and marginal croplands. The converted ecosystems are under immense biotic stresses. Rainfall is meagre and erratic, the soils are highly weathered and impoverished, and consequently the natural forests, as well as the derived ecosystems are fragile. The signs of desertification are widespread (Singh *et al.* 1991).

Therefore, it is essential to analyze these impacts in terms of spatial and temporal domain and with time, the significance of mapping and monitoring the changes in LULC has been widely

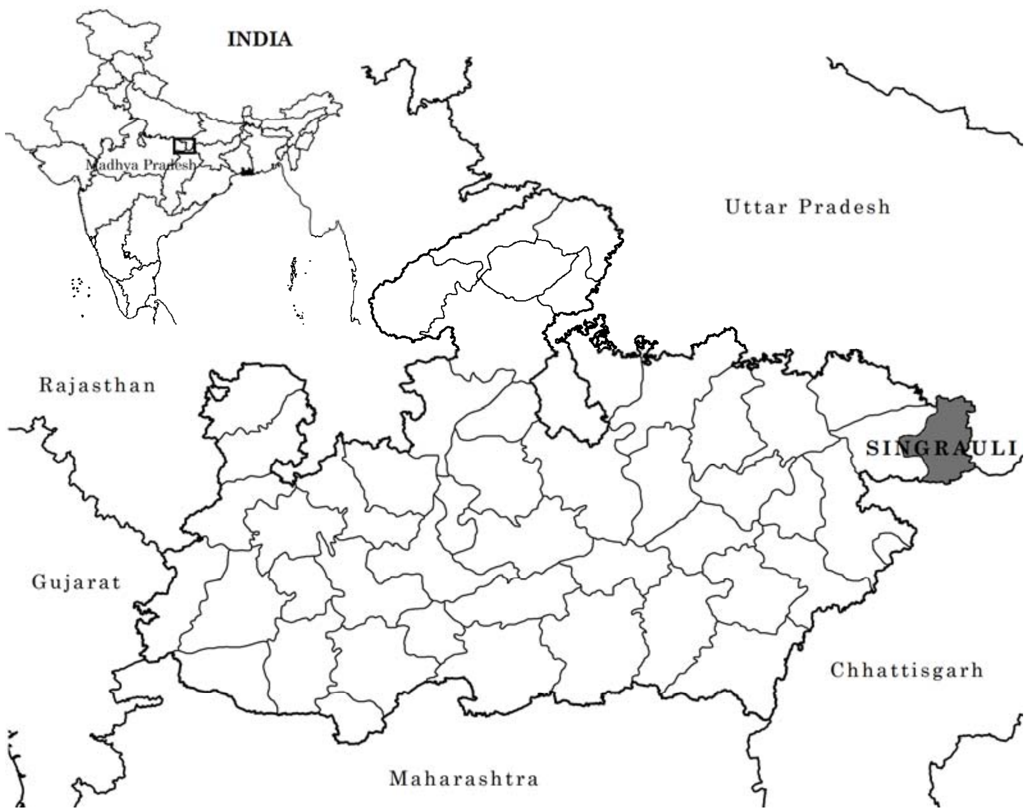

Fig. 1. Location map of Singrauli district, Madhya Pradesh.

recognised by the scientific community. Remote sensing and geographic information systems (GIS) are important tools for assessing and monitoring environmental impacts due to synoptic coverage and repetitive coverage of space borne imagery to detect the changes at various resolutions and thereby generating information on LULC change dynamics for sound planning and a cost-effective decision making (Giriraj *et al.* 2008; Joshi *et al.* 2006; Navalgund *et al.* 2007; Prakash & Gupta 1998; Ricketts 1992).

Keeping the above in view, an attempt was made to map the spatial distribution of the mining activities with the help of LULC and quantify changes over time in Singrauli district, Madhya Pradesh using multi-date satellite images for three time periods, i.e., 1978, 1991 and 2010. Effort was also made to analyse the impact of LULC change on the impact of landscape using Markov transition probability and landscape metrics.

Study area

The district of Singrauli came into existence on 24th May 2008, as the 50th district of the state of Madhya Pradesh, with its headquarters at Waidhan. It has been formed by separating three tehsils of the erstwhile Sidhi district, viz., Singrauli, Deosar and Chitrangi (http://en.wiki-pedia.org/wiki/Singrauli_district; http://singrauli. nic.in/abtsing.htm). Singrauli is the easternmost district of the state of Madhya Pradesh and is bordered by the state of Uttar Pradesh in the north and eastern part, Chhattisgarh in the south and the western part is bordered by the neighbouring district of Sidhi, Madhya Pradesh (Fig. 1). The district covers an area of 5672 km^2 and has human population of 1.18 million according to the 2011 census. The decadal (2001 - 2011) population growth rate was estimated to be 28.03 % (http://en.wikipedia.org /wiki/Singrauli_district).

The climate is tropical monsoonal with temperature reaching up to 48 °C during June and going down to 6 °C in January. Rainfall varies from 90 - 100 cm, 90 % of which occurs between June and September (Singh 2007). The area comprises two distinct geomorphological units, the plateau region comprising the area covered by the mining block in the northern part and the plain below the plateau are formed mainly by the valleys of the Rihand River and its tributaries. The undulating topography has given rise to different types of soils at different elevation. It varies from loamy sand to clay. Colour of these soils varies from red to yellow (Das *et al*. 2007). The place earlier known as Shringavali, named after the sage Shringi, was once upon a time covered by moderate to good density dry deciduous forests with many wild animals (http://singrauli.nic.in/abtsing.htm). The tract bears the heavy pressure of grazing as well as firewood collection by the local people (Singh 2007). The forest types recorded in the study area are Dry Peninsular Sal forest, Northern Dry Mixed Deciduous forest, *Boswellia* forest and Southern Dry Mixed deciduous forest (Das *et al*. 2007). Some of the main species in these forests are *Acacia catechu*, *Anogeissus latifolia*, *Butea monosperma*, *Diospyros melanoxylon*, *Bassia latifolia*, *Lagerstroemia parviflora*, *Terminalia bellirica*, *Boswellia serrata*, *Holarrhena antidysenterica* and *Dendrocalamus strictus* (Singh 2007).

The area in the eastern part of Madhya Pradesh and the adjoining southern part of Sonebhadra district in of Uttar Pradesh is collectively known as Singrauli. It has India's largest coal reserves. The landscape of Singrauli is thus characterized by G. B. Pant Sagar or Rihand Reservoir and extensive coal mines, several super thermal power plants and a good number of industries (Pandey 2005).

Materials and methods

Satellite imagery

For land use change analysis satellite imagery from Landsat MSS, TM and IRS LISS-III for the three time period were used. Landsat series (MSS and TM) data available with the Global Land Cover Network (GLCN) were used for mapping the LULC of 1978 and 1991 respectively. The recent changes were mapped using IRS P6 LISS III data of 2010, procured from National Remote Sensing Centre (NRSC), Hyderabad. The IRS P6 LISS III imagery of 2010 was geometrically corrected using ortho-rectified Landsat series imagery as reference and was geo-referenced to the UTM coordinate system (Zone 44), WGS84 datum. The three time period rectified scenes were clipped based on the district boundary using AOI tool in *ERDAS*.

Land use/land cover classification

Since the spatial and spectral resolutions of different sensors vary significantly, the ability to discriminate the land cover also varies greatly (Zhou *et al.* 2004). To eliminate the effect of varying spectral resolution of the input images, standard FCCs (false colour composite) were generated for land use mapping (Prakash & Gupta 1998). The satellite images of 1978, 1991 and 2010 were on-screen visually interpreted and classified using unsupervised classification (ISODATA technique) in *ERDAS* software. The classified images were cleaned using recode process. Settlements, water body and rivers were captured separately using AOI tools and subsequently recoded (Areendran *et al*. 2011). Field verification of the final output was carried out to calculate the accuracy of current LULC of 2010 and for better understanding of the change dynamics. Field survey was carried out in the post monsoon season. Random points were selected and at each location the existing land use pattern and the coordinate information was noted down with the help of Global Position System (GPS).

Change analysis

Post-classification comparison method, which is the most common approach in change detection studies (Araya 2009; Miller *et al*. 1998; Zhou *et al.* 2004), has been applied in this study. The LULC maps were re-sampled to similar spatial resolution (57 m) to minimize the effect of varying spatial resolution on area statistics and change matrices. The changes in LULC were analysed firstly between 1978 - 1991 and secondly for 1991 - 2010. Change matrices were generated for the mentioned time periods to analyse the changes in area under different LULC classes. This was done by comparing the number of pixels falling into each category of LULC in one time period with the categorization of the same pixels in the same/different class in the previous time period (Munsi *et al*. 2009). The generated matrix was further re-arranged to prepare the change matrix. Change maps were also prepared to depict the spatial extent and locations of forest cover changes. The maps were prepared by overlaying LULC maps of two successive time periods. The data obtained from change matrices was further used to calculate rate of change in each LULC class using the following formula as the changes were not linear to the timeline (Puyravaud 2003).

$$r = [1/(t_1 - t_2)] \times [ln(A_2/A_1)] \quad (1)$$

where, r is the rate of LULC change, and A_1 and A_2 are the forest cover at time t_1 and t_2, respectively.

Transition probabilities used extensively for analysis and modelling of LULC change (Brown *et al.*

2000; Weng 2002) were computed using MARKOV function available in the *IDRISI Andes* software (Eastman 2006). The central mechanism behind Markov chain is a probability p_{ij} which refers to the likelihood of transition or movement from a state i to a state j in a given time interval, where, i and j are either locations or locationally relevant classes (Brown 1970). The Markovian model analyzes two qualitative LULC images from different dates and produces a transition matrix, which determines the likelihood for a cell or pixel to change from a LULC class to every other category from time 1 to time 2 (Eastman 2006; Houet & Hubert-Moy 2006). From the resulting matrixes, a number of characteristics of the LULC classes and their relationship to one another may be identified (Brown 1970).

Landscape metrics analysis

Landscape pattern analysis at class level was done using Fragstats (Kabba & Li 2011). For this LULC images were converted to signed layers. The landscape metrics were selected and the process was run. The following metrics (Fragstats 2008) were quantified:

(a) Number of Patches (NP): It measures the extent of subdivision or fragmentation of the patch type; measures the extent of fragmentation of the entire landscape.

$$NP = n_i \qquad (2)$$

where, n_i = number of patches

(b) Patch Density (PD): Its basic utility is same as that of number of patches, but it expresses the number of patches on a per unit area basis and thus, facilitates comparisons among landscapes of varying sizes.

$$PD = \frac{n_i}{A} \times 10{,}000 \times 100 \qquad (3)$$

where, A = area of landscape; n_i = number of patches.

(c) Perimeter to area ratio (PARA): It measures the shape complexity, but without standardization to a standard euclidean shape (square).

$$PARA = \frac{p_{ij}}{a_{ij}} \qquad (4)$$

where, p_{ij} = perimeter of the patch ij; a_{ij} = area of patch ij

(d) Shape index (SHAPE): It measures the complexity of patch shape compared to a standard shape (square or almost square) of the same size.

$$SHAPE = \frac{p_{ij}}{min\, p_{ij}} \qquad (5)$$

where, p_{ij} = perimeter of the patch; $min\ p_{ij}$ = minimum perimeter of the patch ij in terms of number of cell surfaces.

Though landscape metrics were computed for all the LULC classes, forest cover classes were emphasized.

Results and discussion

Land use/land cover mapping

The LULC maps depicting nine LULC classes (Fig. 2) were prepared for the three period viz. 1978, 1991 and 2010. The area covered under each of the classes and the changes in area is given in Table 1. Three forest classes viz., dense forest (canopy density more than 40 %), open forest (canopy density between 10 and 40 %) and scrub (canopy density less than 10 %) (FSI 2010) were derived based on satellite image interpretation and ground truth. It was found that higher ridge areas were mainly covered by dense or open forests while scrub land were found in the low lying areas. The plains and the lowlands were dominated by cropland and fallow land. Built up areas were well distributed in the entire area, most of them occurring in the vicinity of agricultural lands.

In between 1978 and 2010 the area under both dense and open forests have decreased, while scrubland increased during 1978 and 1991 and then decreased between 1991 and 2010. This change can be largely attributed to deforestation and degradation initially but depletion during the last decade. The natural vegetation in Singrauli area has suffered great loss due to coal mines, feeding the thermal power units and also because of adverse impacts on vegetation due to particulate deposition etc. and environmentally difficult situation for survival (Pandey 2005). Area under cropland and built-up areas witnessed a constant increase over the years. The area under mining increased significantly from 4.82 km^2 in 1978 to an area of 33.29 km^2 in 2010. Increase in mining activities led to growth of human population with a corresponding increase in built-up areas and cropland. Establishment of super thermal power projects (Sharma & Singh 2009; Singh *et al.* 1997) resulted in substantial increase in human populations (Pandey 2005; Singh *et al.* 1991) due to migration from adjoining and far off places (Pandey 2005).

The field data were used to calculate the accuracy of the LULC map of 2010 using the common 'confusion matrix' method (Zhou *et al.* 2004). The overall accuracy of the map was 78.92 % with a Kappa coefficient of 0.73.

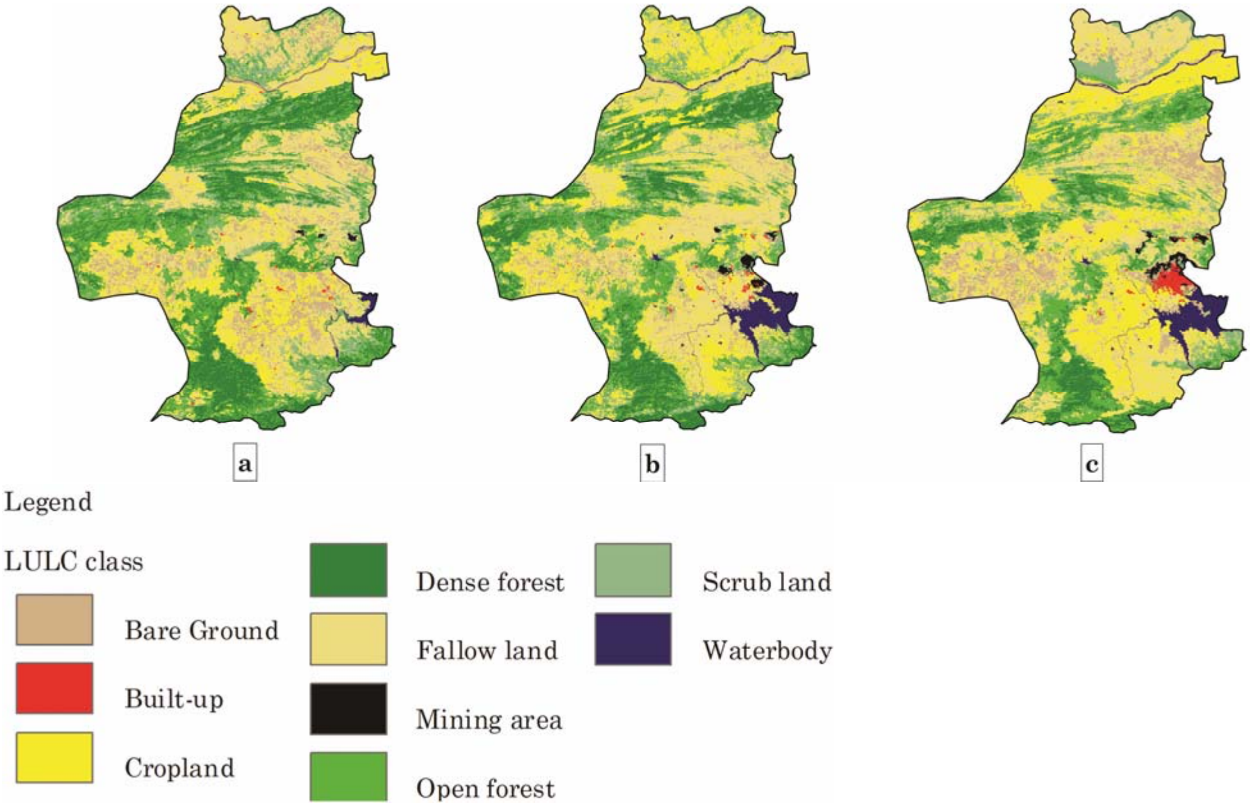

Fig. 2. Land-use/land–cover map 1978 (a), 1991 (b), and 2010 (c).

Table 1. Area distribution under land use/land cover classes.

LULC class	1978		1991		2010	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area(%)
Waterbody	30.88	0.65	142.00	2.99	149.59	3.15
Dense forest	773.37	16.26	575.89	12.11	334.72	7.04
Open forest	957.37	20.13	777.02	16.34	709.29	14.92
Scrubland	582.01	12.24	718.15	15.10	608.14	12.79
Cropland	734.49	15.45	1152.99	24.24	1259.59	26.49
Fallow land	1266.53	26.63	1184.28	24.90	1262.65	26.55
Bare ground	396.10	8.33	170.71	3.59	354.77	7.46
Built up area	9.63	0.20	12.02	0.25	43.39	0.91
Mining area	4.82	0.10	22.91	0.48	33.29	0.70

Change analysis

Change matrix (Tables 2 & 3) shows the change area from one LULC class to another. The diagonal cells of the matrix represent the area that has remained same in both the time periods. Other cell values represent the area that has changed from one class to another class.

An area of 367.54 km^2 dense forest got transformed into open forest, 165.88 km^2 into scrubland and 16.79 km^2 into cropland during 1978 - 1991. Area under open forest also got converted to scrubland and cropland. Similarly, change matrix of 1991 - 2010 showed increasing conversion of forests to non forest LULC classes. Almost all the coal blocks that are currently being allocated for mining are located in forest areas. According to estimates, nearly, 58.72 km^2 of forests from the Singrauli region have been officially diverted for non-forest use since the initiation of the Forest Conservation Act in 1980. However, it does not include the several instances of encroachment on forest land that may have occurred as a result of the existing and proposed industrial

Table 2. Change matrix for 1978 - 1991 (area in km²).

1978	1991								
	WB	DF	OF	SL	CL	FL	BG	BA	MN
WB	26.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DF	3.57	575.80	367.54	165.88	16.79	5.87	0.31	0.07	2.84
OF	2.61	0.00	409.48	330.42	101.28	24.87	0.75	0.29	4.29
SL	14.79	0.00	0.00	220.34	190.37	75.18	1.80	0.55	3.10
CL	18.25	0.00	0.00	0.00	386.33	278.97	16.00	1.50	3.40
FL	51.83	0.00	0.00	0.00	456.68	798.24	41.40	2.57	3.45
BG	23.31	0.00	0.00	0.00	0.59	0.24	109.74	0.88	3.56
BA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.14	0.00
MN	0.00	0.00	0.00	1.51	0.00	0.00	0.67	0.13	2.16

WB - waterbody; DF - dense forest; OF - open forest; SL - scrubland; CL - cropland; FL - fallow land; BG - bare ground; BA - built up area; MN - mining area.

Table 3. Change matrix for 1991 - 2010 (area in km²).

1991	2010								
	WT	DF	OF	SL	CL	FL	BG	BA	MN
WB	149.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DF	0.00	334.60	377.97	44.23	5.02	2.32	0.19	0.00	0.54
OF	0.00	0.00	331.69	307.89	74.37	51.20	2.77	0.43	3.96
SL	0.00	0.00	0.00	251.00	188.43	199.75	14.59	3.97	8.12
CL	0.00	0.00	0.00	0.00	466.85	506.22	81.27	8.22	4.24
FL	0.00	0.00	0.00	0.00	523.77	500.67	152.22	12.88	5.15
BG	0.00	0.00	0.00	1.81	0.33	0.38	100.79	2.31	1.59
BA	0.00	0.00	0.00	0.00	0.31	0.30	0.00	15.58	0.00
MN	0.00	0.00	0.00	3.60	0.10	1.27	2.89	0.00	9.66

WB - waterbody; DF - dense forest; OF - open forest; SL - scrubland; CL - cropland; FL - fallow land; BG - bare ground; BA - built up area; MN - mining area.

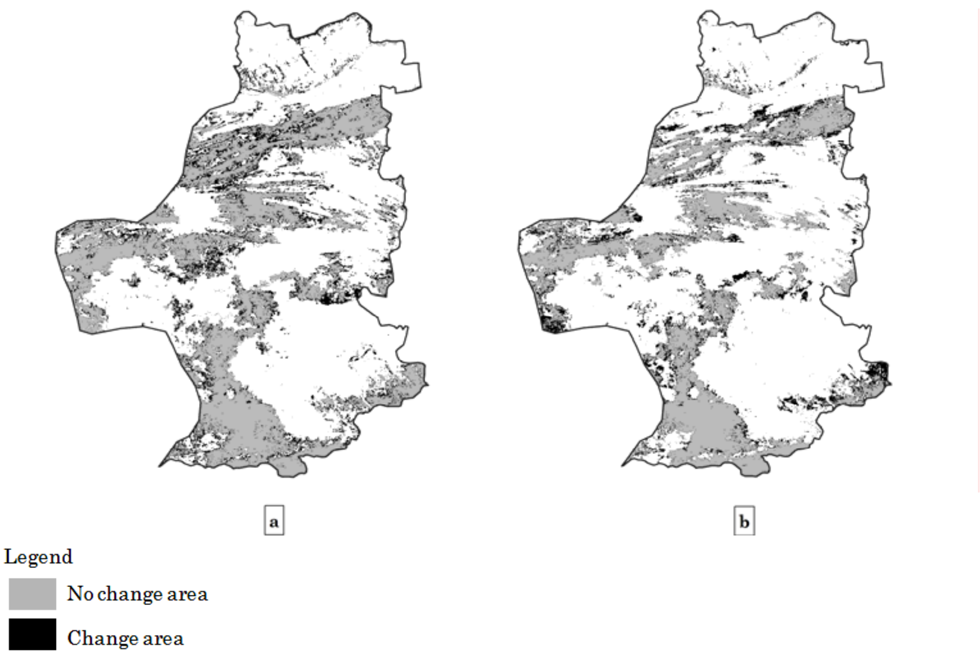

Fig. 3. Change in forest cover 1978-1991 (a) and 1991-2010 (b).

operations (Greenpeace 2011) and conversion of natural forest ecosystems into croplands (Singh *et al.* 1991). Areas that have undergone transformation in dense and open forest cover have been highlighted in Fig. 3. Though changes have taken place throughout the district area, major losses in forest cover were witnessed around reservoir and the mining areas (Bose & Leitmann 1996).

Table 4. Rate of land use/land cover change.

LULC class	Rate of change	
	1978 - 1991	1991 - 2010
Waterbody	5.10	0.25
Dense forest	-0.99	-2.62
Open forest	-0.70	-0.44
Scrubland	0.70	-0.80
Cropland	1.51	0.43
Fallow land	-0.22	0.31
Bare ground	-2.81	3.53
Built up area	0.74	6.19
Mining area	5.21	1.80

Cropland and fallow land got converted to mining area, built-up area and bare ground during both the study period. This can be attributed to extension of mining areas (Bose & Leitmann 1996), development of infrastructure and residential complexes of mining industry and thermal power plants (Singh *et al.* 1997). Built-up areas have also developed from bare ground. The conversion of mining area into scrubland during 1978 - 1991 and 1991 - 2010 was due to efforts in greening the mined out area by putting plantation on overburden dumps (Bose & Leitmann 1996; Singh *et al.* 1997). However, in such programs often exotic plant species like *Prosopis juliflora*, are also used along with native tree species. After plantation these species tend to monopolize the mine spoil, as result of which other plant species fail to flourish (Singh 2007).

Table 4 shows that the loss in dense forest was highest in 1991 - 2010 while open forest witnessed maximum loss during 1978 - 1991. Setting up of mega thermal power and coal mining projects in the region during 1980s (Sharma & Singh 2009) led to increase in deforestation activities since the late 80s (Singh *et al.* 1991; Singh *et al.* 1997). The higher rate of loss in dense forest cover during 1991 - 2010 can be largely attributed to this factor. Built-up area was increasing continuously while after initial growth, mining area increased at a much slower growth rate (1.80 km^2 $year^{-1}$). With progressive discovery of large coal reserves in the 1970s (Bose 1996), the land use patterns started to change radically as evident from the increase in built-up and mining areas at a positive rate and the large-scale decrease in open forest. The process of urbanisation got impetus in the late 1980s and early 90s as coal mining activity and the power industry (Singh *et al.* 1997) begun to flourish in the region which led to significant growth in built-up areas during 1991 - 2010. Availability of water and abundance of power grade coal at shallow depth in the coalfields (Sharma & Singh 2009) have offered an excellent location for mining activities and mining industries in the vicinity of the reservoir, which is located in the eastern margin of the district (Bose & Leitmann 1996; Singh *et al.* 1997)

Land use/land cover transition probability

The transition matrices show that the probability of dense forest changing to open forest has increased (Tables 5 & 6) from 0.34 in 1978 - 1991 to 0.52 in 1991 - 2010. The probability of open forest changing to scrubland has also increased (0.26 in 1978 -1991 to 0.28 in 1991 - 2010). In order to accommodate the growing industrial development more and more forest land are likely to get diverted. Development of the Singrauli area has transformed the land-use and the environmental profile of the region into a rapidly industrializing, urbanizing and growing economy (Bose & Leitmann 1996). The entry of private sector in the last decade (since 2000) to tap the area's coal reserves for large-scale power generation is likely to bring about significant changes to the landscape (Greenpeace 2011). As the Divisional Forest Office estimates, 32.29 km^2 of forest are awaiting approval for diversion in Singrauli (Greenpeace 2011). Similar increasing trend can be seen in the probability of scrubland changing to cropland and fallow land. Over time the probability of cropland being converted to built-up areas also show an increasing trend (0.03 in 1978 - 1991 to 0.20 in 1991 - 2010). Growing population, as a result of economic growth has necessitated development of built-up areas, which has and is likely to result in conversion of cropland to developmental activities (Bose & Leitmann 1996; Pandey 2005; Singh *et al.* 1997). Probability of mining areas remaining the same has also increased from 0.25 in 1978 - 1991 to 0.42 in 1991 - 2010.

Table 5. Transition matrix 1978 - 1991.

1978	1991								
	WB	DF	OF	SL	CL	FL	BG	BA	MN
WB	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DF	0.00	0.52	0.34	0.10	0.02	0.00	0.00	0.00	0.00
OF	0.00	0.00	0.43	0.26	0.11	0.03	0.00	0.00	0.00
SL	0.00	0.00	0.00	0.36	0.33	0.13	0.00	0.00	0.01
CL	0.00	0.00	0.00	0.00	0.41	0.38	0.00	0.03	0.00
FL	0.00	0.00	0.00	0.00	0.36	0.49	0.00	0.00	0.00
BG	0.00	0.00	0.00	0.02	0.00	0.00	0.27	0.00	0.01
BA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00
MN	0.00	0.00	0.00	0.31	0.00	0.00	0.14	0.00	0.25

WB - waterbody; DF - dense forest; OF - open forest; SL - scrubland; CL - cropland; FL - fallow land; BG - bare ground; BA - built up area; MN - mining area.

Table 6. Transition matrix 1991- 2010.

1991	2010								
	WB	DF	OF	SL	CL	FL	BG	BA	MN
WB	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DF	0.00	0.38	0.52	0.08	0.01	0.00	0.00	0.00	0.00
OF	0.00	0.00	0.41	0.28	0.10	0.07	0.00	0.00	0.01
SL	0.00	0.00	0.00	0.31	0.26	0.28	0.02	0.01	0.01
CL	0.00	0.00	0.00	0.00	0.39	0.44	0.00	0.20	0.00
FL	0.00	0.00	0.00	0.00	0.44	0.38	0.00	0.01	0.00
BG	0.00	0.00	0.00	0.01	0.00	0.00	0.59	0.01	0.01
BA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.01
MN	0.00	0.00	0.00	0.16	0.00	0.00	0.13	0.00	0.42

WB - waterbody; DF - dense forest; OF - open forest; SL - scrubland; CL - cropland; FL - fallow land; BG - bare ground; BA - built up area; MN - mining area.

Landscape metrics analysis

Landscape metrics helped in quantification of landscape structures and conveys the extent of changes and their effects. Area/density metrics were used to study the extent of fragmentation in the area. Both number of patches and patch density (area/density metrics) show that the numbers of patches have increased for dense forests (Table 7) although the area under dense forest decreased (Table 1). This indicates that fragmentation with respect to dense forests strengthened during the study period, giving rise to patches of isolated forests. Since 1960s people of Singrauli have witnessed series of development induced displacement as land was appropriated for dams, reservoirs, coal mines, power plants and waste disposal areas (Bose & Leitmann 1996; Greenpeace 2011; Sharma & Singh 2009). Many of the people who were displaced but not resettled found shelter in forested areas or were allotted forested lands. Those unable to find employment in agriculture or industry turned to tree cutting because of high wood fuel prices and strong demand (Bose & Leitmann 1996; Greenpeace 2011). The human pressure coupled with land conversion (Bose & Leitmann 1996; Das *et al.* 2007) led to fragmentation of forests. However, the number patches have decreased for open forests which could be the result of complete conversion of forest patches to other LULC classes. For cropland and fallow land, the patches have decreased probably due to aggregation of smaller fields into larger ones, by clearing and putting under cultivation more forest patches existing between the plots, as was observed during field survey. The number of patches for built-up and mining areas has also increased over study period due to growing urbanisation and mining activities (Bose & Leitmann 1996; Singh *et al.* 1991; Singh *et al.* 1997).

Table 7. Landscape matrix.

LULC	Number of Patches (NP)			Patch Density (PD)		
	1978	1991	2010	1978	1991	2010
WB	4971	5108	3718	0.60	0.61	0.45
DF	73	392	404	0.01	0.05	0.05
OF	3614	2731	2420	0.43	0.33	0.29
SL	7005	7813	7354	0.84	0.94	0.88
CL	10776	10415	9244	1.29	1.25	1.11
FL	5268	6973	5846	0.63	0.84	0.70
BG	2787	2791	2732	0.33	0.34	0.33
BA	34	50	73	0.00	0.01	0.01
MN	6	36	51	0.00	0.00	0.01

Table 8. Landscape matrix.

LULC	Perimeter to area ratio (PARA)			Shape index (SHAPE)		
	1978	1991	2010	1978	1991	2010
WB	429.24	445.21	463.21	1.43	1.42	1.34
DF	423.87	513.23	475.90	1.46	1.45	1.50
OF	400.90	436.21	437.42	1.30	1.33	1.30
SL	474.74	473.48	478.27	1.35	1.42	1.38
CL	483.02	477.24	488.91	1.30	1.33	1.31
FL	446.88	467.58	445.43	1.39	1.29	1.34
BG	333.36	426.05	403.76	1.28	1.24	1.27
BA	187.41	313.75	405.24	2.12	1.96	1.65
MN	139.74	416.23	436.12	2.05	1.48	1.50

Both the shape indices (SHAPE and PARA) show that patch shape complexity has increased for forest cover (Table 8). Thus, the patches are becoming more vulnerable to undesirable changes due to edge effects. The increase in PARA for built up areas is due to rapid expansion of human settlements and it indicates that in future the area will expand more.

Conclusions

The present study analysed the distribution of different LULC classes in Singrauli district, changes in LULC and probabilities of changes from 1978 to 2010. The results of the study indicate that during the period between 1978 and 2010, the distribution of individual LULC classes has changed drastically (Bose & Leitmann 1996). The result of change detection show that area under forest cover has reduced considerably as more and more forested lands are being converted to cropland, built-up area (Das *et al*. 2007; Singh *et al*. 1991) and mining (Greenpeace 2011; Singh *et al*. 1991; Singh *et al*. 1997). As a result the areas under cropland, built-up and mining have witnessed increase in area. The transition matrices suggest that the forested areas are most prone to future transformation (Greenpeace 2011). Also increasing human pressure (Bose & Leitmann 1996; Das *et al*. 2007) has made the forest classes more vulnerable to fragmentation. Thus, it can be concluded from the study that there is a strong relationship between loss in forest cover and growth in mining areas.

The study highlights the capability of remote sensing and GIS in analysing the change dynamics of LULC. A study like this one would help in planning, management and utilization of land and other natural resources and related future impacts of mining. It can form potential tool at research level, policy formulation level and policy implementation level, which will help in proper management of landscapes and natural resources, thus leading to sustainable development and use of non-renewable resources.

Acknowledgements

The authors are grateful to Mr. Ravi Singh, CEO & Secretary General, WWF-India and Dr. Sejal Worah, Programme Director, WWF-India for their support to the project. The authors are also thankful to Ms. Shruti Shukla, former Sr. Programme Officer, Climate Change and Energy Programme, WWF-India, for her valuable inputs in the course of the project work. Authors also express their sincere thanks to the staff members of IGCMC Division, WWF-India, for their continuous support and help in carrying out the work.

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(Received on 31.01.2012 and accepted after revisions, on 18.06.2012)