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Impact of Coal Mining on landuse/landcover in Singrauli coalfield, Central India: A study using Remote Sensing & GIS

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Abstract

Land use/Land cover change detection has acquired immense significance as part of global environmental change. The necessity on land use/ land cover analysis has gained importance due to large scale environmental impact of mining, besides urban expansion and other related human activities. Remote Sensing (RS) and Geographical Information System (GIS) have widely been employed as modern tools in monitoring and mapping of LU/LC due to mining and other economic activity. Singrauli coal field situated in Central India contributes about 13% of India's coal production through mechanized opencast mining. It produces power grade coal and together with nearby water reservoirs, it offers an excellent location for super thermal power plants (STPS), Aluminium plants, Cement industries etc. The present study utilizes multispectral/multi-temporal Remote Sensing data of 1993, 2001, 2010 and 2020 to assess the impact of coal mining on landuse/landcover in a spatio – temporal scale. Survey of India toposheet (63L/12) on 1: 50,000 scale was used to derive the base map which was superimposed on the FCC for land use/land cover mapping through visual interpretation method. Interpretation of satellite data led to the identification and delineation of 14 land use/land cover classes such as dense forest, open forest, open scrub, cultivated land, uncultivated land, mining pit, overburden dumps, wasteland and settlement/builtup, ash pond, plantation etc. Visual interpretation was supplemented with ground truth verification conducted in key areas. LU/LC cover maps derived from 1993, 2001, 2010 and 2020 satellite data were scanned & digitized in ArcGIS. Various LU/LC were assigned unique IDs in polygon topology. ArcGIS module was used to compute area statistics under each LU/LC category. The comparative analysis of land use/land cover derived from 1993, 2001, 2010 and

2020 data shows that loss of dense forest in the study area has reduced from 80.78 km^2 in 1993 to 29.0 km^2 in 2020 i.e. a reduction of about 51.78 km^2 are due to the expansion of coal mining activity. This analysis suggests large scale changes during the last 27 years as a result of industrialization and expansion of coal mining activities. Significant changes in terms of area have taken place under mining pit, overburden dumps, ash pond, plantation, open forest etc. Coal mining has also affected dense forest, which has reduced by about 51.78 km^2 during 1993-2020, since the expansion of coal mining has taken place in virgin areas. Area under overburden dumps has significantly increased from 34.17 km^2 in 2010 to 51.30 km^2 in 2020 as a result of expansion of coal mining areas, settlement/built up area has also increased from 21.28 km^2 in 2010 to 40.43 km^2 in 2020, area under plantation has increased by about 22.23 km^2 from 1993 to 2020 due to plantation derive undertaken by NCL and Thermal power companies. The drivers for land use/land cover change are mainly coal mining activities and industrial expansion, which have transformed this belt into one of the prominent industrial zone in northern India. It has also been observed that the some areas under overburden dumps have been reclaimed under operation "Green Gold" launched by Northern Coalfield Ltd, through plantation activities.

Keywords: Land use/land cover, Singrauli coal field, Remote Sensing, GIS

Introduction:

The term land use can be referred to human activities which are carried on over land, usually with emphasis on the functional role of land in economic activity. Land use deals with the use of land surface and describes how a parcel of land is involved in forest, agriculture crops, grazing ground, water resources, waste disposal sites, habitation etc. In contrast, land cover is the assemblage of biotic and abiotic component on the earth's surface which describes the material that is present on the earth's surface (Turner et al., 1994). Land cover indicates the visible evidences of land use which include both vegetative and non vegetative features like dense forest, plowed land, grassland, urban structures, parking area, water, snow (Sabins, 2000; Campbell, 2002; Gupta, 2003; Prakasam, 2010). Land use/land cover change has become a central component in current strategies for managing natural resources and monitoring environmental changes (Wilkie and Finn, 1996).

Coal is one of the major energy resources, which provides a key to the energy needs of a developing country, like India. India possesses one of the largest reserves of coal which is suitably exploited to meet the energy demand especially in thermal power generation. India ranks 3rd after China and USA in coal production and coal industry are one of the core sectors of India. However, extracting coal from the earth not only changes the landscape but also deteriorates the environment and ecosystem of the region (Aryee et al. 2003). With passage of time, demand for coal has increased many folds leading to enhanced production from mines which has caused widespread imbalance to the ecosystem. Coal mining in India has resulted in significant changes in land use /land cover in several coal fields of India posing a serious environmental threat including reducing forest cover, contaminating water bodies and aquifers, affecting soil health and crop yield etc. (Khan and Javed, 2012). A detailed study on LU/LC changes in a coal mining area using multitemlporal remote sensing data will lead to assess the impact of coal mining in a time series domain. Therefore, it is important to know the existing land use pattern and the changes that have occurred in the recent past due to coal mining. Remote sensing data with its various spectral and spatial resolutions, offers comprehensive and accurate information for mapping and monitoring of land use/cover over a period of time. The concept, method, and application of land use/land cover studies are introduced to mining area in order to find the land use change and give support to land management and ecological reconstruction (Du et al., 2007). Land use changes are associated with mining of natural resources and coal combustion, significant land area is degraded which replaces existing ecosystem by undesirable waste material in the form of dumps, tailing dams and ash dams (Piha et al., 1995). Some of the recent studies carried out on impact of coal mining on LULC are mentioned herein. Majumdar and Sarkar (1994) carried out a study on Singrauli coalfield suing remote sensing data. Joshi et al., (2006) carried out a study on areas deforested by coal mining activities in Korba, Chattisgarh using satellite data pertaining to 1972, 1990, 1999 and 2004 to evaluate the land cover changes. Du et al., (2007) studied land use/land cover changes in mining area using multi- source remote sensing data in northwest of Xuzhou city, Jiangsu province, Middle and Eastern parts of China. Das et al., (2007) carried out a study on mapping of forest types and land use/land cover of Singrauli coalfield area using remote sensing technique. Patil and Katpatal (2008) studied coal mine impact in Erai watershed of

Chandrapur district, Maharashtra using geoinformatics. Wen-bo et al., (2008) assessed land use change of coal mining area based on the two TM images of 1995 and 2001. Yuan et al., (2008) carried out land cover classification in mining areas using Beijing- 1 small satellite data in northwest of Jiangsu Province, China. Javed (2009) analyzed remote sensing data to monitor land use/land cover changes due to coal mining in Singrauli coalfield. Joshi et al., (2006 and 2009) analysed land use/land cover changes in north Chhattisgarh due to industrialization and coal mining activities using remote sensing and GIS. Chitade and Katyar (2010) carried out a study on impact of open cast coal mines on land use/land cover in Chandrapur district of Maharashtra using remote sensing and GIS technique. Singh et al., (2010) studied impact of coal mining and industrial activities on land use pattern in Angul-Talcher region of Orissa, India. Panwar et al., (2011) carried out a study on time sequential surface change analysis of Talcher- Angul region of Orissa using remote sensing and GIS. Chang and Xiao, (2011) carried out a study on land use change and analyzed driving forces in Luan mining area in southeast of Shanxi Province, China. Khan et. al (2013) carried out a study on physico-chemical analysis of surface and ground water around Singrauli Coal Field, M,P. India. Debashiri and Narayana (2018) carried out a study on land use/land cover changes in the mining area of Godavari coal fields, of Southern India. More recently, Ranjan et al (2020) carried out a study on land transformation due to coal mining in Jharsuguda area of Odhisa, India using remote sensing data.

Singrauli region of late has emerged as one of the important industrial hub, as several well known industrial houses have established their units during the last few decade. The availability of good quality of coal at their door steps is one of the key factors that attract industrial houses to establish their units. With the rapid industrial development, the demand for coal has also gone up in the region substantially, which has resulted in the expansion of coal mining in virgin areas. Hence it is imperative to assess the impact of expansion of coal mining on LU/LC in this important coal rich region. The present study utilizes remotely sensed data of 1993, 2001, 2010 and 2020 to assess the change in the land use /land cover due to coal mining activities. The study also utilizes GIS for data input, data analysis, spatial analysis, overlay and computations. GPS has been used in the ground truth verification for recoding coordinates and validation of the feature classes of and use/land cover.

Study Area:

The study area is a part of Singrauli coalfield in Central India falling in Singrauli district in Madhya Pradesh, bounded by the coordinates $24^0$00 to $24^0$15 N latitudes and $82^0$15 to $82^0$45 E longitudes, falling in Survey of India toposheets No. 63L/12 and covers about 438 km^2. It is characterized by tropical monsoonal climate with extreme temperatures ranging from 47.2^0 C to 2^0 C during summer and winter, respectively. Annual average rainfall in the study area is 1,119.65 mm. The study area is part of the Son-Rihand basin and the major streams draining the area are Kachan, Mayar, Matwani, Mehrauli, Baliya nala, and Bijul.

Singrauli is considered India's energy capital since it comprises of one of the most important coalfields in India both in terms of reserves and production. 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).

Singrauli Coalfield managed by Northern coalfield Ltd (NCL) is spread over 2202 Sq. Km, comprising of two basins, viz. Moher Sub-basin (312 Sq. Km.) and Singrauli Main basin (1890 Sq. Km.). NCL has total coal reserves of 10.06 BT (6.83 BT in Moher Sub-basin and 3.23 BT in Main Basin). Out of this reserve, the industry has extracted 1.7 BT of coal from Moher Sub-basin till March 2019. Major part of the Moher sub-basin lies in the Singrauli district of Madhya Pradesh and a small part lies in the Sonebhadra district of Uttar Pradesh. Coal mining operations are at present concentrated in Moher Sub-basin through ten numbers of highly mechanized opencast mines. Singrauli main basin lies in the western part of the coalfield and is largely unexplored. NCL produced 101.50 MT in 2018-19, about 14% of the total coal production in India, The targets for coal production in 2019-20 and 2020-21 are 106.25 and 110.50. The development of the Singrauli area began during the year 1950s with the construction of two dams on the Rihand River. These reservoirs were mainly built for irrigation purpose, but 400 MW of hydropower has also been generated. Before the Coal mining and other industrial activities the region was densely covered with tropical deciduous forests. Coal mining operation on large scale has significantly changed the landscape of the region. Besides coal mining the surrounding industrialization also has an adverse impact on land use/land cover, air and water quality of the study area.

The geological sequence of the area is represented by series of formations that have been recognized on broad lithic characteristics within the Gondwana rocks of Singrauli coal field. In ascending order they are Talchir, Barakar, Barren Measure, Raniganj, Precambrian, and Mahadeva. However only four Precambrian, Talchir, Barakar, Barren Measure has been reported from study area. The most dominant geological formation in the area is Barakar formation covering 515.18 km^2 followed by Talchir covering 118.94 km^2 , Precambrian covering 57.63 km^2 and Barren Measure covering 16.89 km^2 respectively. The area is occupied by structural hills on the northern part with elevation ranging between 270 m - 620 m, formed of resistant Precambrian rocks.

The structural plateau is made up of coal-bearing Gondwana rocks. Low lying flats characterized by gentle-undulating topography in the central part of the area where most of the agricultural activities have been noticed. Fig. 1 shows the location map of the area

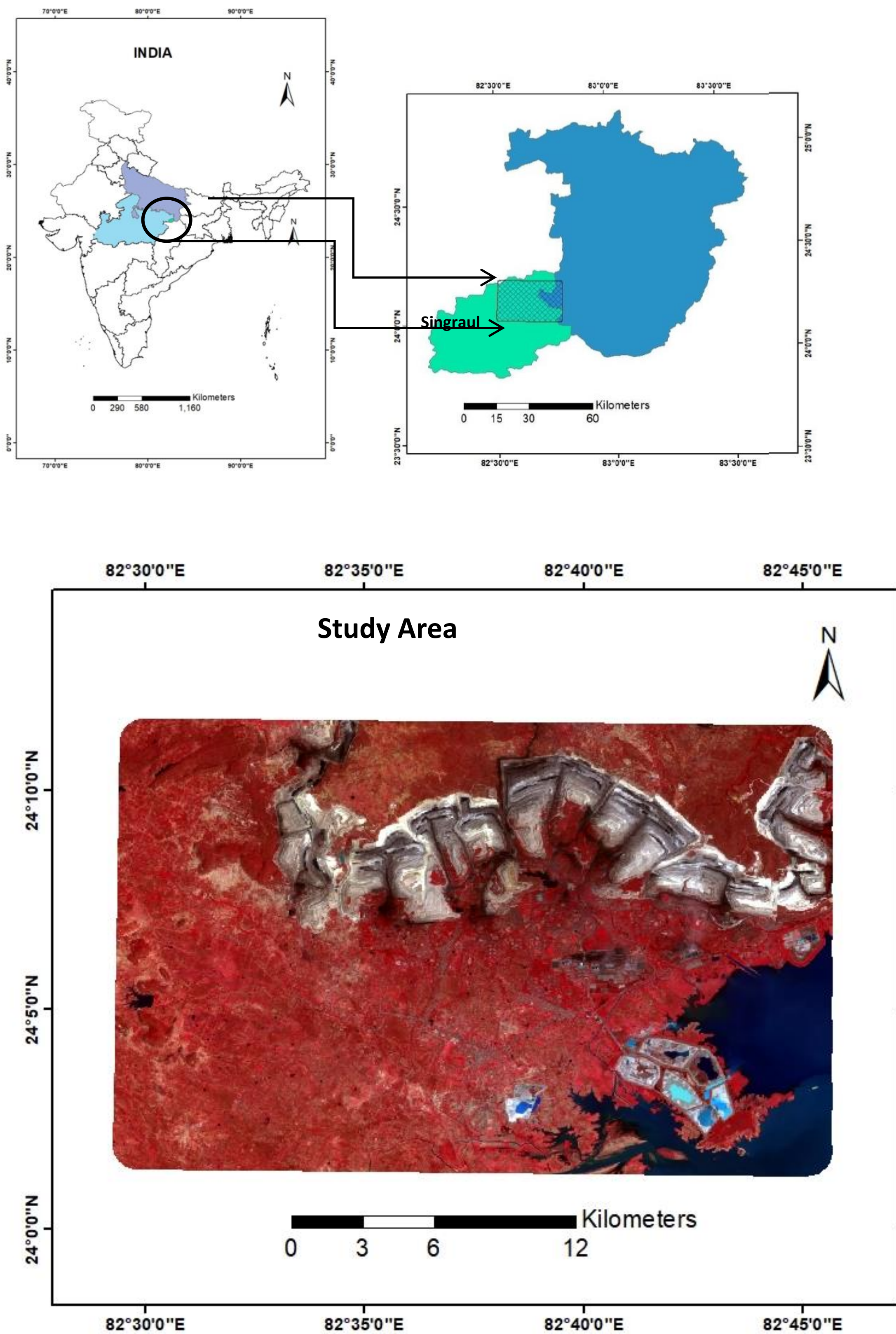

Figure : 1 Location map of the study area

Data Sources and Methodology:

The study has been carried out using both primary and secondary data sources. Remote sensing data of IRS IB LISS II of 4th May 1993, IRS LISS III 8th May 2001, IRS P6 LISS III of 4th May 2010 and Landsat 8 data of 29th April 2020 have been utilized for the present study (Fig.2). Survey of India toposheet No. 63 L/12 on 1:50,000 scale has been used for base map preparation and extracting basic information about the area. Secondary data from Northern Coal field Ltd, district census handbook, published reports besides the data in public domain has also been collected, consulted and collated wherever required. Ground truth verification was one of the key inputs in the analysis. The satellite data pertaining to 1993, 2001, 2010 and data was geometrically corrected using ortho-rectified Landsat imagery as reference and were geo-referenced to the UTM coordinate system (Zone 44), WGS84 datum. The four times period rectified scenes were clipped based on study window using AOI tool in *ERDAS* imagine software.

Since 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 color composite) were generated for land use mapping (Prakash & Gupta 1998). The satellite data of 1993, 2001, 2010 and 2020 were visually interpreted onscreen and classified using unsupervised classification (ISODATA technique) in *ERDAS* software. Ground truth verification was carried out and 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).

Visual interpretation method using photographic elements was followed to delineate various LU/LC categories based on tone, texture, size, shape, pattern, association and field knowledge etc. Fourteen LU/LC categories namely dense forest, open forest, open-scrub, cultivated land, uncultivated land, mining pit, overburden dumps, wasteland, plantation settlement/built up, ash pond, water body, thermal power plant and dry river were mapped and delineated on the satellite data.

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 resampled to similar spatial resolution (30 m) to minimize the effect of varying spatial resolution on area statistics and change matrices. The maps were then digitized and the data base of land use map has been created using ArcGIS 10 software for land use change analysis. The steps followed for analysis are (a) Digitization of land use map, (b) Creation of polygon topology assigning unique identity (id) for each polygon in the attribute table and (c) Editing. Area statistics of land use categories have been calculated in ArcGIS 10 in sq. km as well as in percentage. The change in the spatial extent of different land use categories during 1993- 2001, 2001-2010 and for 2010 – 2020 analyzed and computed.

Results & Discussion:

Interpretation of remotely sensed data led to the identification and delineation of the following LU/LC categories

- Dense forest
- Open forest
- Open-scrub
- Cultivated land
- Uncultivated land
- Mining pit
- Overburden dumps
- Wasteland
- Plantation
- Settlement/built-up
- Ash pond
- Water body
- Thermal Power plant
- Dry river

The land use/land cover maps of 1993, 2001, 2010 and 2020 (Fig.3 a-d) were derived from four datasets, the changes under each LU/LC category in terms of their area & extent as assessed through the satellite data are discussed as under.

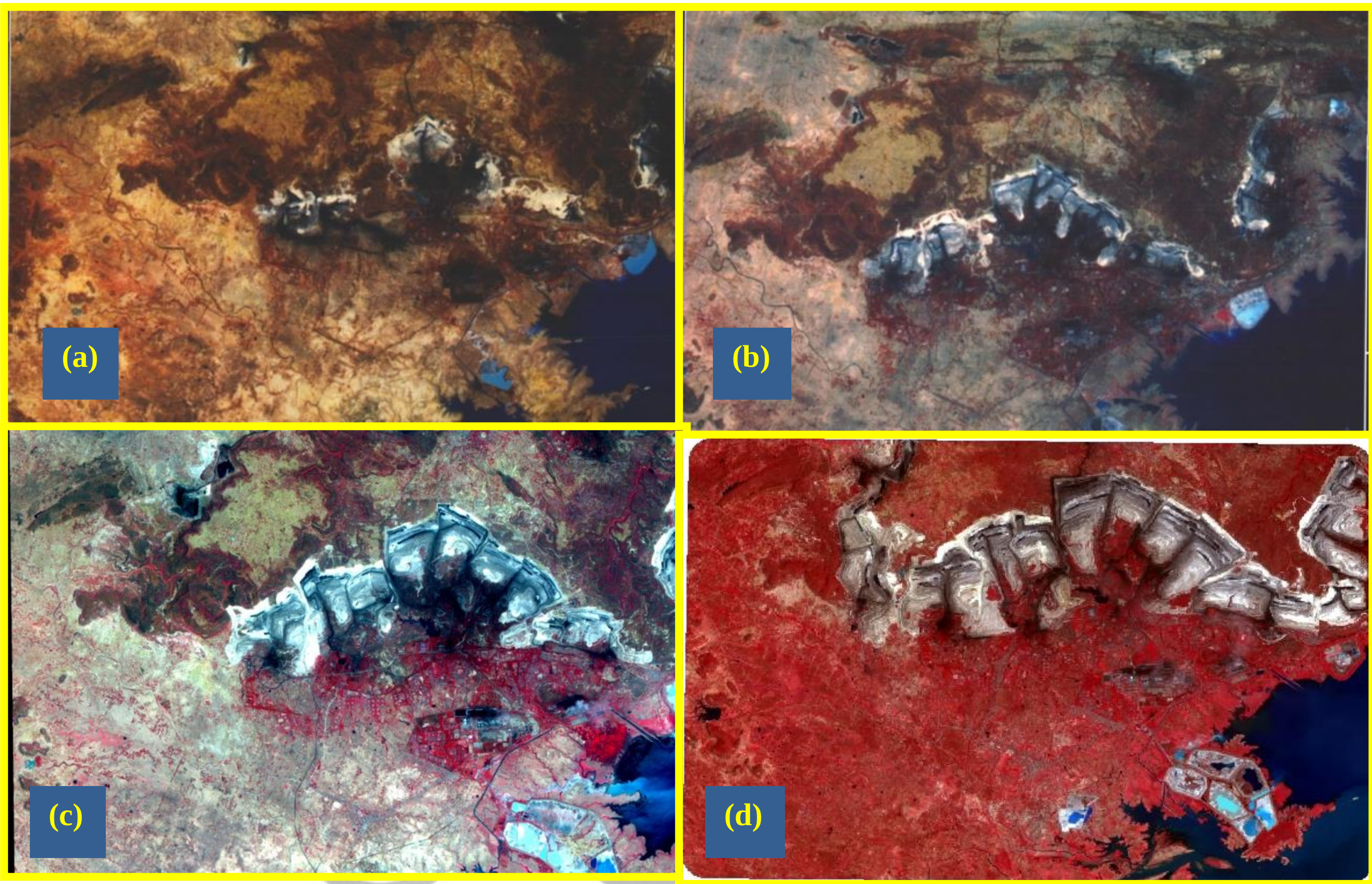

Figure: 2 Multi temporal satellite data used for the study (a) IRS LISS II, 1993 (b) IRS LISS III, 2001 (c) IRS LISS III, 2010 and (d) Landsat TM, 2020

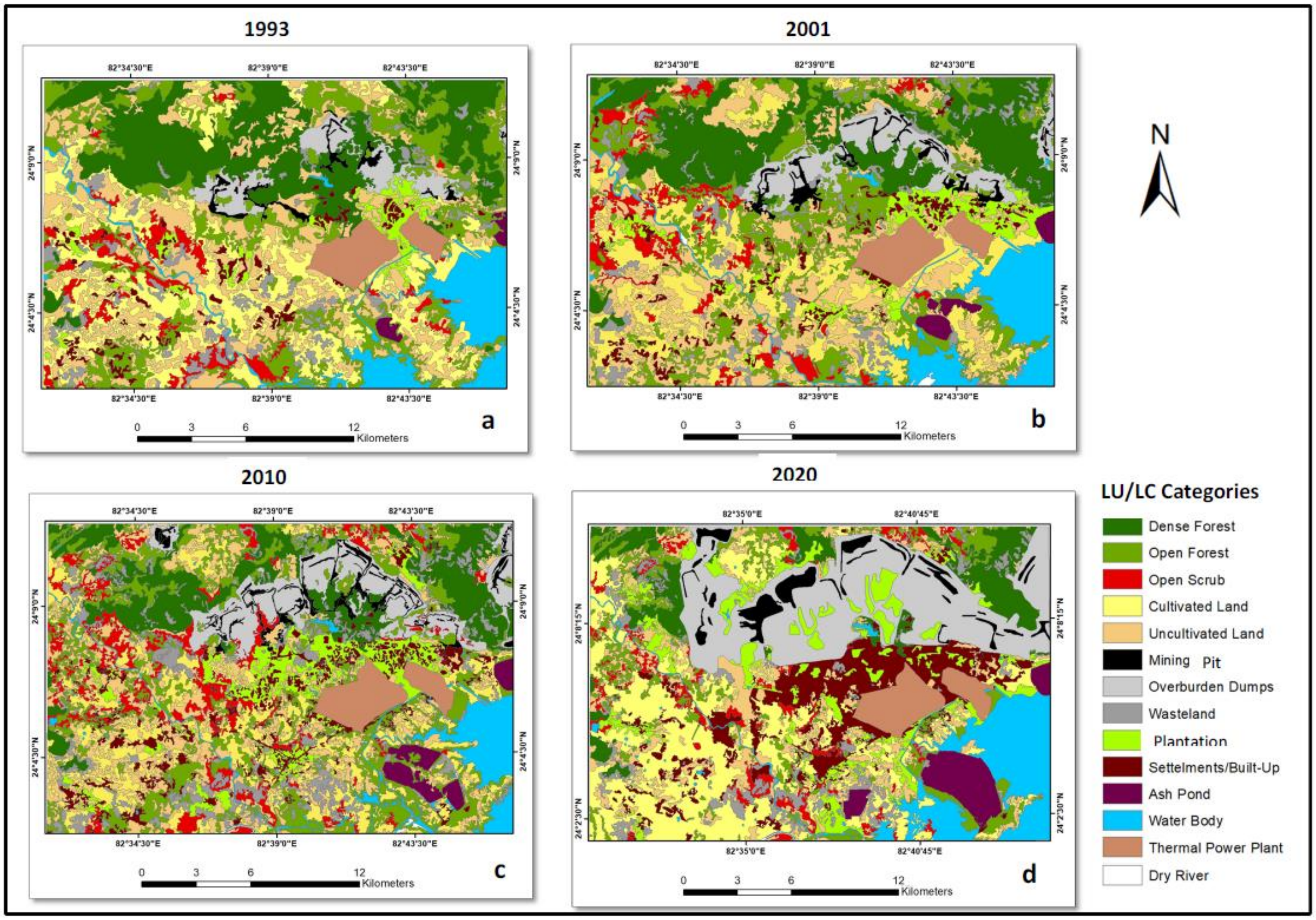

Figure 3: Land use/Land cover maps of Singrauli area based on (a) IRS LISS II 1993 FCC (b) IRS 1B LISS II 2001 FCC (c) IRS P6 LISS III 2010 FCC and (d) Landsat TM FCC data

Dense forest:

It is the most dominant land cover category in the region. Dense forest is recognized by its dark red tone, course to medium texture, contiguous pattern, and irregular boundary outline and is generally associated with high relief. The LU/LC analysis of the satellite data suggests that the dense forest covers an area of 80.78 km^2 in 1993, which is spread in northern, and north west parts of the study area. In 2001, dense forest has reduced and covers an area of 71.78.km^2, suggesting expansion of coal mining into the forest. 2010 satellite data analysis finds that the dense forest has further reduced and covers about 49.73 km^2 area confined to northern parts of the study area. The most recent satellite data (2020) analysis suggest that the dense forest has further shrunk in its extent and only covers 29.0 km^2 area mainly in north west part. The continuous decline /reduction in dense forest from 1993 to 2020 is mainly attributed to the expansion of coal mining in virgin areas and associated overburden dumps. The expansion of coal mining has drastically reduced the green cover in the region, as there has been a significant reduction in dense forest from 1993 (80.78 km^2) to 2020 (29.0 km^2). The temporal variation in dense forest during 1993-2001 is 8.99 km^2 (2.05%), during 2001-2010 is 22.06 km^2 (5.04 %) and during 2010 – 2020 is 20.73 km^2 whereas overall reduction from 1993 to 2020 is 51.78 km^2 (Table 1).

Open forest:

Open forest is identified on FCC by its light red - greenish colour, smooth - medium texture, contiguous to non contiguous pattern with irregular outline. LU/LC analysis of satellite data suggests that Open forest covers an area of 73.71 km^2 (16.83 %) in 1993, 71.94 km^2 (16.42 %) in 2001, 74.70 km^2 (17.05 %) in 2010 which has significantly reduced to 30.51 km^2 (6.96%) in 2020. The study suggests that there has been significant reduction in area under open forest from 73.71 km^2 in 1993 to 30.51 km^2 in 2020 which is mainly attributed to coal mining and its associated activities.

Open scrub:

Open scrub on FCC can be identified by its pink - light yellow tone, coarse to medium texture scattered pattern and irregular outline boundary and its association with uncultivated land. Open scrubs are mainly reported on the plain area and along the south western part of the study area. It covers 17.18 km^2 (3.92 %) in 1993, 20.55 km^2 (4.69 %) in 2001, 29.80 km^2 (6.80 %) in 2010 and, 14.51 km^2 (3.31 %) in 2020 (Table 1). The LU/LC analysis suggests that there has been no significant change in area under open scrub during 1993-2020 period, however it saw an increase in area during 2001-2010 period but again during 2010-2020 period it has reduce and occupies only 14.51 km^2

Cultivated land:

It is the second most dominant LU category in the study area. Cultivated land is recognized on FCC by its red - light greenish tone, smooth - medium texture having non contiguous pattern with regular - sub regular outline shape. The analysis of satellite data also suggests that cultivated land covers 76.19 km^2 (17.39%) in 1993, 62.58 km^2 (17.75%) in 2001, which has further reduced to 52.24 km^2 (14.60 %) in 2010. However there has been an increase in area under cultivated land in 2020 where it covers to 79.30 km^2 (18.10 %). The gain is attributed to uncultivated land being converted into cultivated land. An additional area of 15.33 km^2 (6.18%) has been added to cultivated land during 2010 to 2020, since uncultivated land has been brought under cultivation, probably due to normal/ good monsoon years.

Uncultivated land:

Uncultivated land on FCC is recognized by its light brown to light yellow tone, medium to smooth texture having non-contiguous pattern with irregular outline, and association with cultivated land The area under uncultivated land covers 82.58 km^2 (18.8%) in 1993 but slightly reduced to 77.75 km^2 (17.75 %) in 2001. LULC statistics suggest that it has further decreased to 63.97 km^2 (14.60 %) in 2010 and has substantially come down to 40.46 km^2 (9.23 %) in 2020 (Table 1). The continuous decline in area under uncultivated land is attributed to increase in area under cultivated land particularly during 2010-2020 period. Moreover, uncultivated has also been converted into wasteland at scattered places, especially during 2001-2010 period.

Mining pit:

Coal mining is a significant economic activity, which is confined to central and eastern parts of the study area. Mine pits are interpreted on FCC by its dark tone, smooth texture having linear to curvilinear pattern and irregular shape, sharp contact with overburden dumps. Mine pits together form a curvilinear or arcuate pattern as a whole and represent sign of human activity (Fig 4a). LU/LC statistics derived from remotely sensed data suggests that mine pit covers an area of only 4.69 km^2 (1.07 %) in 1993, which has slightly increased to 7.29 km^2 (1.66 %) in 2001. Mine pits cover 10.15 km^2 (2.32 %) in 2010 but it has further expanded in other areas as covers 12.34 km^2 (2.82 %) in 2020. There has been a three times increase in area under mining pits from 1993-2020 suggesting expansion of coal mining in virgin areas (Fig. 3).

Overburden dumps:

Overburden dumps show bright tone, smooth texture, and irregular outline and are closely associated with mine pits and active coal mine areas. Overburden dumps are generally country rocks which are dumped while extracting the coal/ore. In the study area shale is generally associated with coal, and is dumped while extracting the coal (Fig 4b). Overburden dumps cover 15.82 km^2 area (3.61%) in 1993, which has increased to 24.52 km^2 (5.60 %) in 2001. From 2001 to 2010 it covers 34.17 km^2 (7.80 %) area showing 9.65 km^2 increase. The increase in area under overburden dumps is attributed to expansion of coal mining in new areas. In 2020, overburden dumps occupy a substantial area of 74.94 km^2 (17.10 %), as coal mining has expanded to virgin areas (Fig 3). Hence from a mere 15.82 km^2 area in 1993, the overburden dumps occupy 74.94 km^2 in 2020, a five time increase in its area, suggesting accelerated coal mining in the region, which led to quantum jump in area under overburden dumps (Fig 5).

Figure: 4 Field photographs of (a) Mine pit (b) Overburden dumps (c) Ash pond, and (d) Plantation

Wasteland:

Wasteland is identified by its bright tone, smooth texture, scattered pattern, irregular boundary outline and its association with cultivated land & uncultivated land. Wasteland covers an area of 18.71 km^2 (4.27%) in 1993, and 20.12 km^2 (4.59%) in 2001. However in 2010 it is spread in a significant area and covers about 32.15 km^2 (7.34 %), but in 2020 it has substantially reduced from 32.18 km^2 to 18.71 km^2 (4.27 %), area, which might be attributed to expansion of built up area, plantation, land brought to cultivation etc. There has been a net decrease in wasteland by 13.44 km^2 (3.07 %) from 2010 to 2020, suggesting some reclamation measures. However, from 1993 to 2020 its area remains almost same.

Settlement/ Built up:

The settlement/builtup area is reported mostly from the central and south western part in the plain area. It is identified on FCC by its Cyan - light grey tone, coarse texture, scattered pattern and sharp boundary outline and association with rail/road and industry. It occupies an area of 10.10 km^2 (2.31%) in 1993, which has increased to 11.72 km^2 (2.68%) in 2001, 22.35 km^2 (5.10 %) in 2010 and further 40.43 km^2 (9.23%) in 2020 (Fig 5). The sharp increase in area under settlement/built up is due to the establishment of industrial units which requires residential colonies, industrial buildings, schools, community halls etc and increased demand for labour. The area has attracted people from other states, districts to settle in this industrial belt resulting in expansion of villages, towns and cities. Between 2010 and 2020 the built up area has expanded significantly from 22.35 km^2 (5.10 %) to 40.43 km^2 in 2020 (Table 1).

Ash pond:

Ash generated during burning of coal in power production is disposed of in especially designed area normally called ash pond (Fig 4c). Ash pond is recognized on FCC by its light blue color, smooth texture well shaped structure and sharp outline and its vicinity with the water body. Ash pond is seen in the area in the south eastern part near the GB Pant reservoir. Thermal power plants generate fly ash which is disposed through pipelines to the ash pond which has increased in numbers along the boundary of the GBP Sagar reservoir. The area under ash pond was 2.30 km^2 (0.53%) in 1993 which has increased to 5.01 km^2 (1.14%)

in 2001. In 2010 it covers 7.97 km^2 (1.82 %) and further to 13.85 km^2 to (5.01 %) in 2020. An increase in area of ash pond of 5.89 km^2 (1.34 %) has been observed during 2010 to 2020. which mostly encroaches cultivated land, and open scrub areas in the south (Fig 3d). The increase in area and number of ash ponds suggests enhanced power generation in the power plants resulting in higher quantity of ash being generated as part of coal consumption in power plants.

Water body:

Water body is the easiest to be is identified on FCC due to its blue to dark tone, smooth texture sharp contact and irregular shape. The water body occupied an area of 31.13 km^2 (7.11%) in 1993 and 33.72 km^2 (7.70%) 2001, but has seen a sharp decrease in 2010 to 21.34 km^2 (4.87 %). However it regain its area and covers about 36.45 km^2 (8.32%) in 2020. The most prominent water body in the study area is the GB Pant reservoir in the south east of the study area which is formed as a result of Rihand dam (not lying in the study area). There has been a significant reduction in area under water body from 2001 to 2010, from 33.72 km^2 to 21.34 $km^{2.}$ However from 2010 to 2020 the water body has increased in area from 21.34 km^2 to 36.45 km^2

Dry River:

It is easily recognized by its bright tone, linear pattern, smooth texture with irregular outline on the FCC image. The dry river occupied an insignificant area of 0.43 km^2 (0.10%) in 2010 and 0.15 km^2 (0.03 %) in 2020. There is no significant change in area under dry river during the study period.

Thermal power plants:

Thermal power plants are located in the south east part of the study area, east of near G.B.P Sagar reservoir where from water is pumped for the thermal power plants and open cast coal mines. It is identified on the FCC by its dark tone, smooth and coarse texture, well-shaped and regular boundary outline and signs of human activity. The area occupied by thermal power plants is about 14.28 km^2 (3.26 %). The study area has two power plants one each owned by National Thermal Power Corporation (NTPC) at Shaktinagar, and Vindhyachal Thermal Power Station in the south east part of the study area owned by the Provincial government.

Plantation:

Plantation started from 1985 onwards under different schemes on the overburden dumps and residential colonies of NCL and NTPC. The area under plantation has registered an increase of 12.6 km^2 (1.74 %) during 1993 – 2010. Plantation occupies an area of 10.78 km^2 (1.48 %) in 1993 which rose to 16.49 km^2 (2.29 %) in 2001, showing an increase of 5.90 km^2 (0.81 %). It has further increased to 24.76 km^2 (3.22 %) in 2010 registering an increase of 8.69 km^2 (1.19 %) from 2001 to 2010 (Fig 5). It has been further increased in 2020 and covers an area of 33.08 km^2 (7.67), mostly seen in Dasauti, Garda, Jayant colony, Jaipur, Diyapahar and Ranibari villages which are now parts of NTPC and NCL residential complexes and on overburden dumps around mining blocks of Jayant, Nigahi, and Amlori open cast mines (Fig 4d). The plantation was carried out under the scheme "Operation Green Gold" by NCL and under social forestry scheme by NTPC. Fig 4(d) shows plantation on overburden dumps near Jayant open cast mine.

Table: 1 Details of land use/land cover and its changes during 1993-2001-2010-2020 period.

	1993		2001		2010		2020		Net Change 1993-2001		Net Change 2001-2010		Net Change 2010-2020		Net Change 1993-2020	
	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Net change (Km^2)	Net change (%)	Net change (Km^2)	Net change (%)	Net change (Km^2)	Net change (%)	Net change (Km^2)	Net change (%)
Dense forest	80.78	18.44	71.78	16.39	49.73	11.35	29.00	6.62	-8.99	-2.05	-22.06	-5.04	-20.73	-4.73	-51.78	-11.82
Open forest	73.71	16.83	71.94	16.42	74.70	17.05	30.51	6.96	-1.77	-0.40	2.76	0.63	-44.19	-10.09	-43.20	-9.86
Open scrub	17.18	3.92	20.55	4.69	29.80	6.80	14.51	3.31	3.37	0.77	9.24	2.11	-15.28	-3.49	-2.67	-0.61
Cultivated land	76.19	17.39	62.58	14.29	52.24	11.93	79.30	18.11	-13.61	-3.11	-10.34	-2.36	27.06	6.18	3.11	0.71
Uncultivated land	82.58	18.85	77.75	17.75	63.97	14.60	40.46	9.24	-4.83	-1.10	-13.78	-3.15	-23.51	-5.37	-42.12	-9.62
Mining Pit	4.69	1.07	7.29	1.66	10.15	2.32	12.34	2.82	2.59	0.59	2.86	0.65	2.19	0.50	7.65	1.75
Overburden dumps	15.82	3.61	24.52	5.60	34.17	7.80	74.94	17.11	8.70	1.99	9.65	2.20	40.76	9.31	59.11	13.50
Wasteland	18.71	4.27	20.12	4.59	32.15	7.34	18.71	4.27	1.42	0.32	12.03	2.75	-13.44	-3.07	0.01	0.00
Plantation	10.76	2.46	16.49	3.77	24.76	5.65	33.08	7.55	5.73	1.31	8.27	1.89	8.32	1.90	22.32	5.10
Settlement/ Built-up	10.10	2.31	11.72	2.68	22.35	5.10	40.43	9.23	1.62	0.37	10.63	2.43	18.08	4.13	30.33	6.92
Ash pond	2.30	0.53	5.01	1.14	7.97	1.82	13.85	3.16	2.71	0.62	2.95	0.67	5.89	1.34	11.55	2.64
Water body	31.13	7.11	33.72	7.70	21.34	4.87	36.45	8.32	2.59	0.59	-12.38	-2.83	15.11	3.45	5.32	1.21
Thermal Power plant	14.02	3.20	14.01	3.20	14.28	3.26	14.48	3.31	-0.01	0.00	0.27	0.06	0.20	0.05	0.46	0.11
Dry river	0.03	0.01	0.53	0.12	0.43	0.10	0.15	0.03	0.50	0.11	-0.09	-0.02	-0.29	-0.07	0.12	0.03
	438.00	100.00	**438.00**	100.00	**438.00**	100.01	**438.00**	100.00								

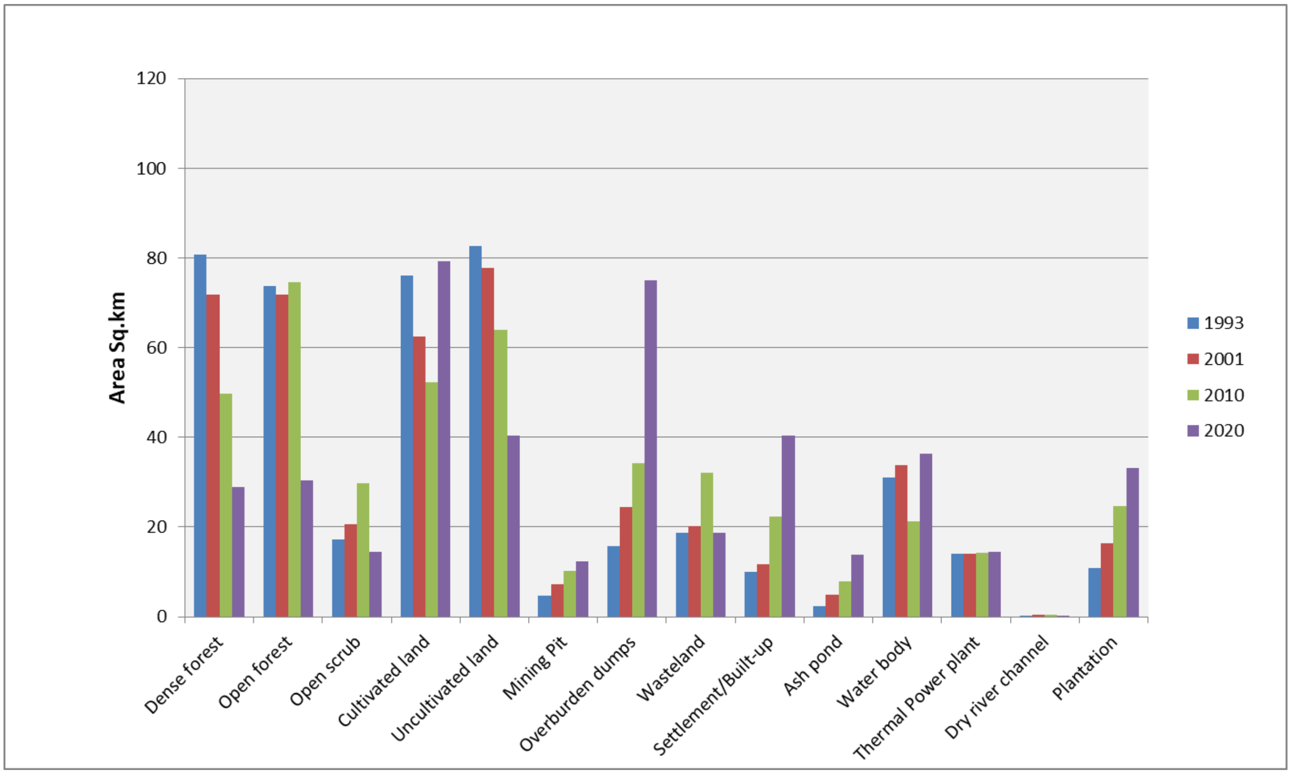

Fig 5: Changes in area under land use/land cover categories from 1993 to 2020.

Conclusion:

The present study demonstrates the utility of RS data to monitor and assess the LULC changes due to coal mining. The study highlights widespread changes in terms of reduction in area under dense forest, from 80.78 sq km in 1993 to 29.0 sq km in 2020 which is mainly attributed to the expansion of coal mining. This study reveals major land use/land cover categories that have undergone major changes in the study area are open forest, cultivated land, uncultivated land, mining pit, overburden dumps, plantation, settlement/builtup, ash pond, water body. It may be concluded that the land use/land cover change in the Singrauli coal field has resulted due to the rapid expansion of coal mining and associated industrial activity especially during 2010 - 2020 period.

On the basis of 1993, 2001, 2010 and 2020 satellite data analysis, it is found that during 1993 – 2001 an area of 27.46 km^2 (6.27 %) has seen a change in land use/land cover category, whereas during 2001 – 2010, 58.66 km^2 (13.39 %) area reported change in land use/land cover category and during 2010-2020, 117.61 km^2 (26.85%) area reported change in land use/land cover category. The overall change during 1993 – 2020 period is 139.98 km^2 (31.96 %) which suggests the dynamic land use of the study area, where area has changed from one land use/land cover to another land use/land cover category. This analysis suggests that the area has seen rapid changes during the last 27 years as a result of industrialization and expansion of coal mining activities. The coal mining in the study area has a significant impact on LU/LC, as the analysis suggests that mine pit, overburden dumps, ash pond have seen a significant increase in their areas from 1993 to 2020 viz. 7.65 km^2 , 59.11 km^2 and 11.55 km^2 respectively . Coal mining has also affected dense forest, which has reduced by about 51.78 km^2 during 1993-2020, since the expansion of coal mining has taken place in virgin areas. The other notable change is in area of plantation which has increased by about 22.23 km^2 from 1993 to 2020 due to plantation derive undertaken by NCL and Thermal power companies.

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