FRAGMENTED LANDSCAPES OF EAST BOKARO COALFIELDS: A REMOTE SENSING BASED APPROACH HIGHLIGHTING FORESTLAND DYNAMICS

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Abstract. Due to massive mining practices and subsequent spurt of human habitation, the East Bokaro coalfield region of Jharkhand in India has faced enormous changes in the landscape. This article aims to study the land cover changes and fragmentation dynamics of the landscape especially forests from 1972 to 2016. Remote sensing based satellite images combined with spatial analysis were used to derive the land cover and fragmentation dynamics over the last 44 years. The results reveal the existence of six primary land cover types namely agriculture, forest, water bodies, mining, settlement and barren land/scrubland. Agriculture and forest which are the dominant categories decreased while mining, settlements and barren lands increased at the expense of forests and agriculture. Fragmentation analysis brings out significant trends in landscape changes that have occurred from 1972 to 2016. The most prominent fragmentation metrics were observed for forests and agriculture classes. Agricultural land has continuously been converted and fragmented into other classes. The forests also show strong fragmentation during 1972-2001 period but in 2016 the level of fragmentation is not very high. This study is a preliminary step towards evaluating the long term impact of mining and its related activities on the landscapestructure.
Keywords: *land cover, coal mining, fragmentation, landscape metrics, forests*

Introduction

A landscape refers to all the visible features of a region of land and their integration with the man made features. Landscape is mostly studied on the basis of composition and configuration of the spatial arrangements of different ecosystems that it is composed of (Tolessa et al., 2016). Composition refers to all the land cover attributes or habitats while configuration refers to the various levels of fragmentation of those habitats. Changes in the composition and configuration of landscapes form the basis of landscape dynamics and fragmentation studies. Fragmentation studies integrated with land cover analysis paves the way for detecting and understanding the spatial patterns of landscape changes (Jansen et al., 2002). There is a lot of research to support that most of the changes in landscapes are brought about by the anthropogenic activities and fragmented landscapes are an indicator of this conspicuous interplay between mankind and the environment (Dupin et al., 2013).

Forests are a very important constituent of the landscape due to their critical role in maintaining biodiversity, regulating climate and providing essential ecological resources. Hence the loss of forest cover from the land raises global concerns on biodiversity, climate change and ecosystem services. However, losing forest cover is not the only concern. Traditional methods document the area of forest lost but the crucial part that needs to be studied is the spatial distribution and fragmentation of the forests and the way these fragmented forests affect the functioning of the ecosystem. Studies on the forest and human health impacts of coal mining are very poorly represented in literature (Upgupta and Singh, 2017). There are a lot of international level studies which have done landscape level fragmentation work for example, Southworth et al. (2002), Armenteras et al. (2003), Millington (2003), Echeverria (2006), Dupin et al. (2013), Tolessa et al. (2016). According to Ritters et al. (2002), fragmentation not only deals with the quantity of habitat loss but also the spatial connection between patches of the habitat. Landscape fragmentation research has mostly been conducted on forests (Cakir et al., 2007) and the majority of forest fragmentation studies have a prime focus on the wildlife habitat as compared to the trees. Various scientists in India have studied forest fragmentation and its impacts on the species diversity like Roy and Tomar (2000) in northeastern India; Jha et al. (2005) in the Vindhyas; Malaviya et al. (2010) in Central India; Behera (2010) in the eastern Himalayas. Roy and Joshi (2001) used remote sensing to study the fragmented landscapes of northeast Indian Himalayan Region. The study emphasized the importance of shape, richness and diversity indices in evaluating spatial distribution of land cover and concluded that fragmentation has led to the lapsed connectivity, corridors and vanishing ecotones as well as meta-populations. De and Tiwari (2008) did research on the Rajaji-Corbett National Parks using LISS III datasets and remote sensing software. They estimated the patchiness of different forest types in the national Parks. The forests of Himalayan foothills were studied by Munsi et al. (2010) using satellite remote sensing and fragmentation analysis. They quantified the landscape structure using landscape based metrics. Giriraj et al. in 2010 used fragmentation to study the forests communities of Southern Western Ghats. The developmental activities like building roads for better connectivity and increasing resource utilization for economic upliftment of local people leads to fragmentation. Therefore fragmentation studies are very important when evaluating changes in forested habitats over a period of time.

Numerous tools are available to estimate a number of fragmentation metrics from remote sensing classified data on land and forest cover. Fragmentation metrics can be computed using different software platforms e.g., FRAGSTAT, SPLAM and Landscape Fragmentation Tool. One of the most widely used and applied tool is the FRAGSTAT which was developed by McGarigal and Marks (1995) to quantify fragmentation. FRAGSTAT gives elaborate statistical information of a variety of landscape levels. Spatial Landscape Modeling (SPLAM) gives landscape parameters like patchiness, interspersion, porosity, juxtaposition, fragmentation and landscape modeling. Landscape Fragmentation Tool maps the types of fragmentation present in a specified land cover type (i.e. forest). It also creates value-added map layers that can be used to quantify and assess the amount and type of fragmentation present in a landscape and runs on ArcToolbox through a Python script. Metrics can be computed at the class level, patch level as well as the landscape level for the whole study area. However class-level metrics are most frequently used in ecological studies as they measure the distribution of one particular habitat within a landscape.

The East Bokaro coalfield region is a predominantly mining area with coal as the major mineral resource being mined. The area was rich in biodiversity and had a large

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forest cover with fertile cultivable patches. With the advent of coal mining and industrialization, the region witnessed rapid increase in population, economic growth and urbanization. Due to this the original land cover and its rich vegetation cover underwent rapid degradation and the region is subjected to high levels of disturbance and environmental degradation. The goal of this research is to study the changes in land cover during 1972 to 2016 and to assess as how coal mining triggered development and urbanization are driving the fragmentation of the landscape especially forests.

Materials and Methods

Study area

The study area is located in the Bokaro district of the Indian sub-continent. It lies between 23^0 45' to 23^0 50' N latitude and 85^0 30' to 86^0 03' E longitude (*Figure 1*). It covers an area of 259 sq. km with elevation ranging from 230-300m above mean sea level (MSL). The general slope of the area is from west to east and the area is marked by Lugu Hill (1070m) which is a prominent landmark and also the separation point between the East and West Bokaro coalfields. Tenughat reservoir in the southern part is a tourist attraction. Bokaro thermal power plant is the major industrial set up. This coalfield is in the form of a long narrow strip extending for about 64 km in an east-west direction with a maximum width of about 11 km in the north-south direction.

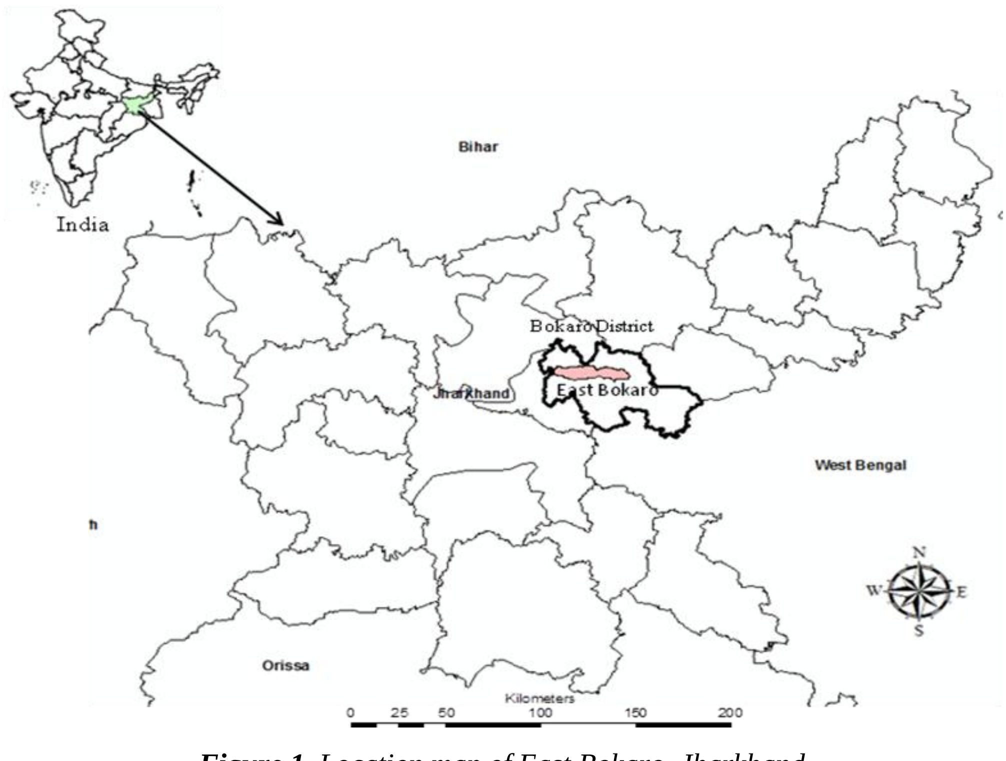

Figure 1. *Location map of East Bokaro, Jharkhand*

The Barkar Formation is the chief coal bearing horizon. Damodar and Bokaro are the primary rivers draining the landscape from north to south. Geologically, the northern part of the area is composed of massive sandstone formation which has resulted in a

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rugged topography. The East Bokaro is a source of medium coking coal in India. Coal is produced in East Bokaro by underground as well as opencast mining methods by Central Coal Field limited (CCL) a subsidiary of Coal India Limited. The important coal seams found in the coalfield include Jarangdih seam, Kargali seam, Bermo seam and Karo seam.

Climatically, the area has an average temperature of 30 °C during summer season while 20 °C during the winter season. During summer, the maximum temperature rises up to 44 °C while during winter the minimum temperature comes down to 2°C. On an average, the area receives about 1200 mm of rainfall with the bulk of rainfall occurring around the July-September period.

Currently 28.1% of the total geographical area of East Bokaro is under forest cover. Majority of these forests belong to the Tropical Dry Deciduous forest type group. There is 16.6 sq.km, 36.9 sq. km and 21.6 sq.km of the forests having very dense (>70% canopy density), moderately dense (40–70% canopy density) and open forests (10–40% canopy density), respectively [FSI, 2013]. The Bermo subdivision of the area is comparatively rich in forest wealth and the forests are replete with Sal (*Shorea robusta*) along with other trees like mango (*Mangifera indica*, Shisham (*Dalbergia sissoo*, jackfruit (*Artocarpus heterophyllus*) and kendu (*Diospyros melanoxylon*).

Data used

Multi-temporal satellite images of different time periods representing long term and discernible changes were acquired for this analysis. For land cover mapping moderate spatial resolution Landsat images of three time periods 1972 (Landsat 1 reprocessed, Multi-Spectral Scanner), 2001 (Landsat 7, Enhanced Thematic Mapper plus) and 2016 (Landsat 8, Operational Land Imager) at 57m, 28.5m and 30m were used. These images were downloaded from the Earth Explorer USGS image database (Landsat Imagery Archive). The images were chosen based on their availability for the study area, the defined time periods, clarity of data and the season of data capture. Cloud free images were collected for the same season for the month of November 2016. Landsat images are already geo-referenced and were subjected to appropriate atmospheric corrections in the next level of image preprocessing steps to bring out more clarity in the interpretation of the land cover features.

Methods

All the analyses were performed in ArcMap environment. The data for the three time periods were extracted for the study area using the Clip tool in ArcMap 10.2. The delimiting boundary of the East Bokaro coalfield was acquired from the Central Coalfields Limited. FRAGSTAT 4.2 was employed to carry out fragmentation analysis and estimate the various class level metrics.

Land cover classification

Supervised Maximum Likelihood Classifier (MLC) approach was used for land cover classification followed by cleaning of the classified images using majority filters. Six classes namely agriculture, forest, water bodies, mining, settlement and barren/scrub were identified. These classes were based on the land cover classification system developed by National Remote Sensing Centre, Hyderabad in the Manual of Nationwide Land Use/ Land Cover Mapping Using Satellite Imagery" (NRSC, 2006). Majority

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filters were used to get rid of very small group of pixels below a threshold value of 10 pixels. Ground verification was conducted in the same season as that of satellite image collection. Random points were generated and for every point the existing class in the ground and the corresponding land cover type in the classified image were noted. Accuracy assessment of the classified map of 2016 was performed in Arc Map 10.2 using pivot tables.

Fragmentation analysis

Classified land cover raster datasets were first converted to tiff file format and then used as the inputs into the fragmentation analysis. FRAGSTAT4.2 was used to carry out fragmentation analysis and estimate the various landscape and class level metrics. Landscape metrics were computed at the class level for all the mapped land cover classes of agriculture, forest, water bodies, mining, settlement and barren/scrub. Based on the recently reviewed literature and forest fragmentation studies, the following twelve landscape metrics (*Table 1*) were selected for quantification and comparison.

Table 1. *Landscape metrics used in the analysis*

Level of Analysis	Metric Name	Abbreviation	Description	Valid Range	Units
Class Level	Percentage of landscape	PLAND	Percentage of total landscape area occupied by the largest-sized patch	0 < PLAND < 100	%
	Patch Density	PD	Number of patches on a per unit area		-
	Number of Patches	NP	Total number of patches in the class	N ≥ 1	-
	Largest patch Index	LPI	Percentage of total landscape area occupied by the largest-sized patch of each class	0 < LPI < 100	%
	Mean Patch Size	AREA_AM	Average of patch size in hectares		m2
	Edge Density	ED	Sum of length of all edge segments for the class, divided by total landscape area	ED ≥ 0	m/ha
	Euclidean nearest neighbor	ENN_AM	Mean of minimum edge-to-edge distances to the nearest neighboring patch of the same type of a certain class	ENN ≥ 0	m
	Shape Index	SHAPE	Measures the complexity of patch shape of a particular class	SHAPE≥1	-
	Perimeter to area ratio	PARA	Measure of patch shape	SHAPE≥1	-
	Fractal Dimension	FRAC_AM	Index of the complexity of shapes on the landscape	1 ≤ FRAC ≤ 2	-
	Aggregation Index	AI	Percentage of neighboring pixel of the same class, based on single-count method	0 ≤ AI ≤ 100	%
	Interspersion Juxtaposition Index	IJI	Measure of evenness of patch adjacencies		

These metrics have been widely applied and are the best for the evaluation of spatial properties of fragmented landscapes. Although the analytical outputs were reported for all the land cover classes, forest category was specially emphasized on the spatio-temporal pattern of forest fragmentation during 1972-2016.

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Results

Land cover dynamics

The land cover maps representing the spatial pattern of the six identified cover classes of East Bokaro coalfields for the different time periods that is 1972, 2001 and 2016 are shown in *Figure 2*. The area statistics for all the identified classes and for three time periods are shown in *Table 2*. The accuracy assessment for the classified map of 2016 using the ground verification points yielded an overall accuracy of 81% and kappa co-efficient of 0.7. The error matrix for accuracy assessment is shown in *Table 3*.

Table 2. *Comparison of areas and change statistics of Land cover classes between 1972 and 2016*

Sl. No.	Land Cover	1972		2001		2016		Change (1972 to 2016)		Rate of change
		Area (sq.km)	Area (%)	Area (sq.km)	Area (%)	Area (sq.km)	Area (%)	Area (sq.km	Area (%)	(ha/yr)
1	Agriculture	121.48	46.89	114.02	44.08	87.04	33.59	-34.44	-28.35	-78
2	Forest	95.48	36.86	85.46	33.04	92.49	35.70	-2.99	-3.13	-7
3	Water Body	14.02	5.41	13.28	5.13	13.72	5.29	-0.3	-2.14	-1
4	Mining	9.64	3.72	13.36	5.16	19.23	7.42	9.59	99.48	22
5	Settlement	7.74	2.99	20.39	7.88	27.71	10.70	19.97	258.01	45
6	Barren/Scrub	10.69	4.13	12.18	4.71	18.90	7.30	8.21	76.80	19
	Total	259	100	259	100	259	100			

It can be observed from the statistics provided in *Table 2* that in the year 1972, 36.86% of the land was covered by forests and this decreased to 33.04% in the year 2001. But the next decade of 2016 is marked by an increase in forest cover to 35.70%.

Since 1972 to 2016 there is an overall decline of 3.13% in the total forested areas. Similar trend is observed in the water bodies but the change observed is not very significant (*Table 2*). Water bodies also show a decrease in coverage followed by a slight increase. The overall decrease stands at 2.14% since 1972 to 2016.

Table 3. *Error matrix of* overall *accuracy*

Classification	Ground Truth Classes								
	Agriculture	**Forest**	**Water Bodies**	**Mining**	**Settlement**	**Barren/Rocky**	**Sum Total**	**Commission**	**User Accuracy**
Agriculture	26	1	0	0	2	8	37	33.33%	66.67%
Forest	0	37	0	1	0	0	38	2.6%	97.40%
Water Bodies	0	0	4	0	0	3	7	42.9%	57.10%
Mining	0	1	0	3	0	1	5	40%	60%
Settlement	0	0	0	0	5	0	5	0%	100%
Barren/Rocky	0	0	0	0	0	8	8	0%	100%
Sum Total	26	39	4	4	7	20	100		
Omission	0%	8%	0%	25%	43%	60%			
Producer Accuracy	100%	92%	100%	75%	57%	40%			

* Overall Accuracy: 81%, Kappa classification: 0.74

The agriculture category however depicts a completely different picture. There has been a constant declining trend observed in the agricultural lands from 1972 to 2016 (*Table 2*) indicating land cover transformations from agriculture to other classes like

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mining, human settlements and barren lands (*Fig. 2*). The decrease accounts for 28.35% reduction in the total area of agricultural lands. Agriculture covered 46.89% of the study area in 1972 which decreased to 44.08% in 2001 and this is followed by a further decrease in 2016 to 33.59% (*Table 2*).

The fourth category of land cover class that is mining has doubled in the last 44 years. The area statistics shows a noticeable increase of 3.72% in 1972 to 5.16% in 2001 and a further increase to 7.42% in 2016 (*Table 2*). There is an overall increase of 99.48% in the total mining sites. *Fig. 2* shows that although few mining sites have been abandoned and reclaimed, there are new sites within the forested areas which have been leased out to the mining companies. There is also expansion of some existing mining projects into bigger mines and into the forested areas.

The remaining classes of settlement and barren lands show an increasing trend in their areas from 1972 to 2016. Most massive increase is in the human settlement areas which increased from 2.99% in 1972 and 7.88% in 2001 to 10.70 in 2016 with an overall increase of more than 200%. The barren lands also show more than 50% increase in their representation.

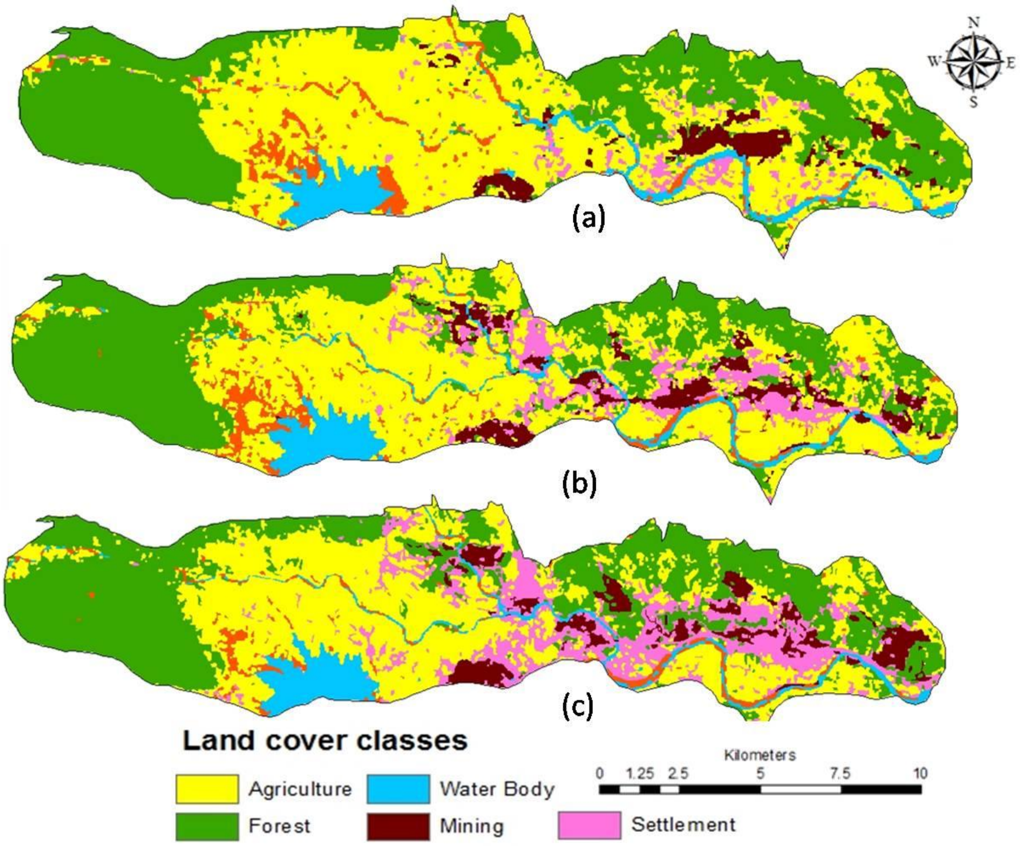

Figure 2. *Land Cover map 1972 (a), 2001 (b) and 2016 (c)*

Fragmentation dynamics

The fragmentation metrics calculated from the classified images assisted in quantifying the landscape structure and imparted thorough information regarding the configuration changes as well as its impact on the landscape. The analysis revealed that

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there have been major changes in the density, number, size and the distance between the spatially distributed fragments. The analysis at class level also confirmed that different land cover classes exhibited different patterns of changes. The values estimated for 12 class metrics for the East Bokaro coalfields are represented in *Table 4*. The temporal variations in the class metrics for nine selected class metrics are depicted graphically in *Figure 3* for agriculture and forest classes. The detailed dynamics for each category is discussed below.

Table 4. *Dynamics of class metrics for all the land cover classes for 1972, 2001 and 2016*

	Area-Edge				Shape			Aggregation				
Year/Land Cover	NP	PD	LPI	ED	AREA_AM	SHAPE	FRAC	PARA	PAFRAC	ENN	IJI	AI
1972												
Agriculture	123	0.47	29.96	27.88	5103.97	6.80	1.21	62.99	1.42	95.48	89.52	93.62
Forest	121	0.47	18.00	13.53	3270.57	3.92	1.15	43.44	1.33	94.77	36.47	95.77
Water Bodies	22	0.08	2.97	4.56	632.74	4.88	1.18	91.31	1.48	245.15	74.02	91.28
Mining	44	0.17	1.75	3.61	251.34	2.20	1.11	99.67	1.28	189.74	55.31	90.59
Settlement	157	0.61	0.35	7.03	27.71	1.90	1.10	235.37	1.42	250.09	37.91	75.97
Barren Lands	104	0.40	0.60	7.11	59.26	2.24	1.12	174.94	1.45	249.02	45.51	82.36
2001												
Agriculture	303	1.17	23.42	33.41	3338.00	6.51	1.19	79.94	1.39	66.58	88.65	94.56
Forest	152	0.59	19.73	17.78	3393.65	4.24	1.16	59.55	1.37	80.14	48.79	96.05
Water Bodies	32	0.12	3.25	6.13	537.06	3.50	1.16	116.11	1.50	93.27	78.18	92.42
Mining	48	0.19	0.85	6.77	130.77	2.85	1.14	126.96	1.38	278.18	77.81	91.65
Settlement	165	0.64	1.16	12.44	120.95	3.03	1.15	175.45	1.43	124.71	69.24	88.08
Barren Lands	152	0.59	1.51	9.31	151.85	3.49	1.16	232.00	1.50	198.71	54.80	84.21
2016												
Agriculture	284	1.10	22.52	27.82	3556.75	6.05	1.19	78.25	1.39	73.64	79.58	94.42
Forest	127	0.49	18.86	18.13	3202.28	4.63	1.18	57.73	1.41	72.95	64.32	95.97
Water Bodies	41	0.16	3.51	6.30	598.93	3.17	1.15	120.86	1.47	86.86	84.59	91.66
Mining	48	0.19	0.90	6.32	119.47	2.18	1.11	113.22	1.31	227.90	61.08	92.23
Settlement	142	0.55	5.60	19.50	773.38	7.20	1.23	149.19	1.55	92.74	77.97	89.27
Barren Lands	89	0.34	0.41	6.21	38.58	2.47	1.14	241.93	1.55	312.11	69.86	82.81

*Note: Please refer Table 1 for units and abbreviations.

Agriculture

Agriculture is the dominant land cover category in the study area and it shows significant decrease during the entire study period from 1972 to 2016 (*Table 4*). Among the twelve fragmentation metrics displayed in *Table 4* the parameters that are very important to note are the number of patches, patch density and the largest patch index. Increase in the number of patches signifies that an area of land is continuously being broken into smaller pieces or fragments. The agriculture lands show a very steep rise in the number of patches from 1972 to 2001 followed by a slight decrease. Similar trend was observed for the patch density also wherein the patch density increased highly from 1972 to 2001. The large patch index decreased successively from 29.96 in 1972 to 22.52 in 2016 although the shape complexity has decreased in the agriculture lands over time. The Interspersion and Juxtaposition Index signifies that there was a decrease in patch mixing over time for the agriculture as it changed from 89.52 to 79.58.

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Forest

The period from 1972 to 2001 has also seen an increase in the number of patches as well as patch density for the forest lands (*Figure 3*). The largest patch index shows continuous decline for agriculture category from 1972 to 2016, however the forests depict a slightly improved large patch index (*Figure 3*). The shape indices like SHAPE and PARA show that the patch shape complexity of the forested class has also increased over time (*Table 4*) indicating that the patches are becoming more vulnerable to disturbances. On the other hand the forests show an overall increase in the IJI indicating that the forest patches have mixed over time which explains the increase in the large patch index as well as mean patch size. The mean Eucliden Nearest Neighbour distance of forests decreased continously from 94.77 in 1972 to 72.95 in 2016.

Water bodies

The water bodies have undergone very little changes in their total area within the landscape but their fragmentation metrics have changes significantly. There is a steady increase in the number of patches from 22 in 1972 to 41 in 2016 and the patch density from 0.08 in 1972 to 0.16 in 2016 (*Table 4*). The large patch index improved over time with the index being 2.97 in 1972 to 3.51 in 2016 (*Table 4*). This is explained by the increasing interspersion and juxtaposition index that is from 74.02 to 84.59 as well as the very steep fall in the Euclidean nearest neighbor distance from 245.15 to 86.86 since 2016 (*Table 4*). There was also an increase in the edge density of the water bodies from 4.56 in 1972 to 6.30 in 2016. Although, the shape complexity decreased from 4.88 to 3.17 from 1972-2016 the perimeter to area ration increased from 91.31 to 120.86 (*Table 4*).

Mining

Due to growing mining and developmental activities, the number of patches for mining, settlement and barren lands also increased till 2001 (*Table 4*). This can probably be due to the cropping up of new mining sites and settlement points. The year 2001 onwards has seen a decrease in the number of patches as well as patch density for these categories indicating the expansion of mines and merging of smaller settlements into larger settlement groups by clearing the agricultural lands. The mean patch area for mining has decreased over time and the aggregation index has slightly increased since 1972 to the current period.

Settlements

Patch density and number of patches in the settlement category did not change significantly and they improved in 2016 after an initial increase in 2001. The largest patch Index has also increased to 5.60 (2016) as compared to 0.35 in 1972 (*Table 4*). Edge density is a measure of the per unit edge length and the settlement class has undergone a high change in edge density. The edge density increased from 7.03 to 19.50 in 2016.The shape complexity has increased to a great extent for the settlements with the shape index values ranging from 1.90 in 1972 to 7.20 in 2016 (*Table 4*) but the perimeter to area ration decreased considerably. For the aggregation metrics it was found that there was tendency for the patches to mix which is indicated by the IJI and the AI values increasing steadily. There is also a simultaneous decriease observed in the ENN distance between the similar patches.

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Barren lands

For the barren lands and the scrublands, it was observed that though it occupies only 10-18% of landscape area, the number of patches is comparable to the cultivated and the forested lands. The patch density too is the second highest after the settlements. The only important things to note for this category are the mean patch area, PARA and the IJI indices. The perimeter to area ratio increased from 174.94 in 1972 to 241.93 in 2016 while the IJI increased from 45.51 to 69.86 from 1972-2016 (*Table 4*). The mean patch size increased to 151.85 in 2001 but it decreased drastically to 38.58 in 2016.

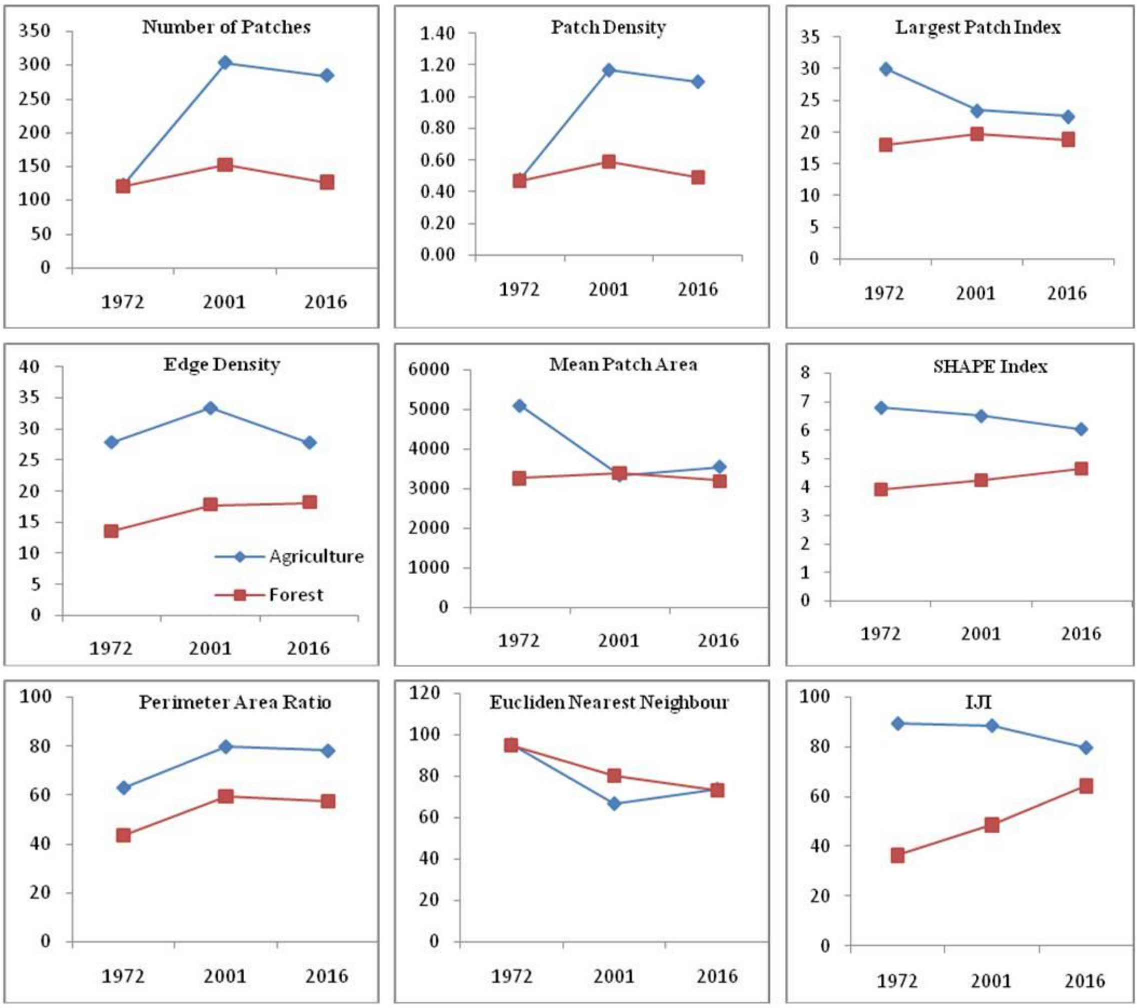

Figure 3. *Temporal changes in the fragmentation metrics of forests and agriculture in the study area*

Discussions

Mining activities extend their ecological footprints beyond the area that is directly impacted. Within the primary impact zone, mining causes complete removal of forest and changes in the composition of any remnant forest while the adjacent areas are the secondary impact zones. The secondary impacts are manifested in the form of land use changes including fragmentation, habitat modifications, wildlife migration and changes in forest types. The developmental activities associated with mining like roads, building,

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and transmission lines lead to forest fragmentation which in turn exposes the interiors of forest to disturbances.

In the current study, the unfolding of the change dynamics of each land cover type, as shown in *Table 2*, *Table 3* and *Figure 3* shows that over the last 44 years the dynamics of evolution are different for the forest and agriculture categories but quite similar for the mining, settlements and barren land categories. Analysis of the trend line revealed that the pattern of land cover changes did not follow a linear pattern and it worked both ways over the 44 year study period. This suggested that the some of the land cover types like forests and water bodies showed increasing and decreasing trends. The forest cover declined at a faster rate from 1992-2001, while the decline rate decreased from 2001-2016. This high decline rate was due to more and more acquisition of forested lands (along with the agricultural lands) by mining projects. However, there is an overall decline in the forest cover but also a substantial increase in the forest cover was observed since 2001. *Figure 2* shows that the increase in forest cover is mostly confined in and around the previously mined and abandoned mines and can be attributed to the vigorous plantation activities being carried out in the reclaimed mine sites and over burden dumps. The subsidiaries of Coal India Limited have carried out extensive tree plantation programmes which include plantations on overburden dumps, plantation around mines, residential colonies and avenue plantations. Coal India planted over 73 millions of plants since 1993-94 covering an estimated land area of over 32000 hectares (CIL). Plantation activities have been integrated into the annual activities of all the existing and new coal subsidiaries.

There was substantial decrease in agricultural land observed in the study area (*Table 2*). This decrease is apparently due to the anthropogenic activities acting in conjunction with the commercial, political and socio-economic factors. The shrinkage of agricultural lands is driven by the diversion of lands for new mining projects, already rugged terrain as well as non profitable agribusiness. This has resulted in shifting the interest of people from conserving the land for agriculture to other more lucrative livelihood options like jobs in mining and allied industries thusultimately ruining the biodiversity. Agriculture and forests have always been the main source of livelihood in the area and some parts are still dependent on agriculture for their livelihoods. The decline in water bodies though not very significant yet the area is suffering from the shortage of availability of clean water for drinking and irrigation purposes.

The area occupied by mining seems to be steadily gaining in appearance from 1972-2016 (*Table 4*). The advent of mining and its increasing representation in the landscape has completely disturbed the ecology which is at high risk of degradation and large scale land use changes. There is a high rate of immigration of people from surrounding regions into the area for livelihood opportunities in the mining sectors. The tremendous mining practices ongoing in the East Bokaro region has led to the evolving new settlements areas concentrating around the mining sites. The settlement areas have increased by more than 250% since 1972 causing a sudden burst in human population and threatening the ecology of the area. The increasing barren lands are an indication of the changing land use practices in the study area.

The framentation outputs depicted the level of landscape configuration changes occurring in East Bokaro. The figures reveal that the different land cover types have undergone varied levels of fragmentation during the study period. The large patch index of agriculture class decreased successively from 1972 to 2016 indicating towards an increasing division of land into other land cover classes. There is observed a high

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increase in the number of patches as well as the patch density from 1972 to 2001 which signals towards high fragmentation rates (*Table 4*). The decreasing intermixing of the patches as indicated by the fall in IJI values show that over the period of time the patches do not show mixing and this might be due to high human interventions.

The increased patch number and density with improved large patch index of the forest class till 2001 implied that the fragmentation of the forests was strengthened during 1972 to 2001 period but decreased from 2001 onwards. The IJI values show that the forest patches have mixed over time. This is quite evident in 2016, where the level of landscape fragmentation as observed for the forest class is not very high. The decreasing ENN index values is due to new plantation areas which can be credited to the vigorous plantation efforts by the mining companies as a part of their reclamation policies. But the SHAPE and PARA indices show that the increasing complex shape of forest patches with a high perimeter to area ratio points towards higher edge influence and decline in the forest interior. Patch shape and patch size interaction can have important implications for some ecological phenomenon. According to Saunders et al. 1991 and Harris 1984, there are large number of evidences to prove that habitat fragmentation may have deleterious effects on species and lead to substantial loss of local and global biodiversity.

Conclusions

In the current study, a multi-temporal approach integrating remote sensing, geographical information system and ground observations was used to assess the spatial changes in various land use categories and the degree of land cover fragmentation. From the analysis, it was concluded that the East Bokaro coalfields is a highly fragile ecosystem which is vulnerable to degradation and drastic land use changes. Agricultural lands registered a drastic decrease in their representation as compared to any other land use category. The plantation efforts have improved the representation of the forests in the landscape but their ecological role still remains threatened. The other land use categories like mining, settlements and barren lands have also increased considerably. The increasing human disturbance driven by coal mining and associated industries has made the forest patches more vulnerable to fragmentation. The study emphasizes that the increasing mining accompanied by rising anthropogenic activities and unsustainable practices are posing a potential threat to the region's local biodiversity. Fragmentation analysis deals with the detailed dynamics of each land cover category (Uuemaa et al., 2013) and this study gives up-to-date information on the level of fragmentation operating in the area. Remote sensing knowledge information coupled with landscape fragmentation can be very advantageous in evaluating the land cover changes and the process of habitat fragmentation occurring at different locations at different periods of time. Thus it is very important to understand such changes in the landscape composition as well as configuration at different temporal scales and their implications so that they can be utilized in appropriate landscape management planning. Such studies augment the requirement of utilizing a landscape level approach rather than patch level approach for policy and management planning. There is a need to manage entire landscapes, not just the components.

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