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Forest Risk and Vulnerability Assessment: A Case Study from East Bokaro Coal Mining Area in India

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***Abstract*—**The expansion of large scale coal mining into forest areas is a potential hazard for the local biodiversity and wildlife. The objective of this study is to provide a picture of the threat that coal mining poses to the forests of the East Bokaro landscape. The vulnerable forest areas at risk have been assessed and the priority areas for conservation have been presented. The forested areas at risk in the current scenario have been assessed and compared with the past conditions using classification and buffer based overlay approach. Forest vulnerability has been assessed using an analytical framework based on systematic indicators and composite vulnerability index values. The results indicate that more than 4 km^2 of forests have been lost from 1973 to 2016. Large patches of forests have been diverted for coal mining projects. Forests in the northern part of the coal field within 1-3 km radius around the coal mines are at immediate risk. The original contiguous forests have been converted into fragmented and degraded forest patches. Most of the collieries are located within or very close to the forests thus threatening the biodiversity and hydrology of the surrounding regions. Based on the vulnerability values estimated, it was concluded that more than 90% of the forested grids in East Bokaro are highly vulnerable to mining. The forests in the sub-districts of Bermo and Chandrapura have been identified as the most vulnerable to coal mining activities. This case study would add to the capacity of the forest managers and mine managers to address the risk and vulnerability of forests at a small landscape level in order to achieve sustainable development.

***Keywords*—**Coal mining, forest, indicators, vulnerability.

I. Introduction

BEING a very crucial natural resource, forests have substantial implications for global biodiversity, hydrological cycle and livelihoods. Forest ecosystems play an important role in trapping the atmospheric carbon and sequestering it in the form of biomass. However, the forest resources are likely to become vulnerable to climatic and anthropogenic drivers in the 21stcentury [7]. Therefore, it is a critical pre-requisite to assess vulnerability of forests and identify the drivers of vulnerability in order to deal with risks to forests [10], [12].

Natural and undisturbed forests are quite resilient to changes due to their inherent properties (like species diversity, canopy cover density, photosynthesis, etc.), while disturbed forests are more prone to unfavorable influences due to paucity of these inherent properties [14]. Anthropogenic disturbances in the form of coal mining and related infrastructure – roads, railways and thermal power plants etc., into intact forests results in habitat fragmentation which has far-reaching impacts. Forests which are not protected by any legal boundaries are more prone to degradation and are an easy target to be sacrificed for industrial purposes like coal mining.

India has very few intact forest landscapes which require safeguarding from the increasing population pressure and rapid industrialization. Forests occupy 69.2 Mha of land area, which constitute 21.05% of the total geographical area [4]. Most of India's rich forest resources are situated on top of the mineral resources like coal (Fig. 1). About 98.5% of coal is mined in eight states of India, of which20.22%is contributed by Jharkhand. Tropical Dry Deciduous forest is the majority forest type affected by coal production [5]. The state of Jharkhand has more than 90% Tropical Dry Deciduous forests, and is thus at a higher risk due to the current and future coal mining activities. Future projections for 2013-14 to 2032-33 by Coal India show that the coal mining area in Tropical Dry Deciduous forests will increase to 0.45% (currently 0.18%) and in Tropical Moist Deciduous Forests will increase to 0.33% (currently 0.13%). This indicates that large tracts of forests are at a potential threat of being diverted for coal mining. The Ministry of Environment and Forests diverted 400,687 ha of forest land for non-forest purposes like mining and power projects between 2002 and 2011 [6].

The manageability of forest ecosystems begins with the assessment of "inherent vulnerability" of forests addressing both the current and future sources of vulnerability, including climate change [13]. Inherent vulnerability is related to the ability of forests to resist and adapt to changes which in turn is related to the biodiversity [15]. Therefore, in order to reduce the inherent vulnerability of forests, it is necessary to address the factors which influence biodiversity. Climate change is one of the important driving forces behind changes in biodiversity; however, additional non-climatic drivers need to be identified.

There have been vulnerability assessment studies by [8], [9] at the regional level. However, for proper ecosystem management, the spatial scale that is most suitable is the landscape level [11]. Wang in 2008 [16] assessed the vulnerability of various sectors including forests at the landscape level, but vulnerability assessment studies exclusively for forests at the landscape level are lacking. The present study is an attempt to assess the inherent as well as vulnerability to mining activities at a small landscape level using the tool developed by [14]. The specific objectives of the study include:

1. Assessing the forest area at risk in East Bokaro landscape for past and the current mining conditions.

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2. Assessing inherent vulnerability of forests and vulnerability to mining activities using an indicator based approach.

II. Study Area

A. Location and Geography

The East Bokaro Coalfield is located between 23° 45' to 23° 50' N latitude and 85° 30'to 86° 03' E longitude and lies in Bokaro district of Jharkhand state (Fig. 1). The coalfield spans an area of 259 km^2 and is drained by three prominent rivers; Bokaro in the central part, Konar in the east and Damodar in the south. The terrain is comparatively rugged in the northern part, while the southern part possesses a gently undulating topography [1]. Lugu Hill separating east from west Bokaro coalfield forms a prominent landmark. Bokaro Thermal Power Plant is the major industrial set up.

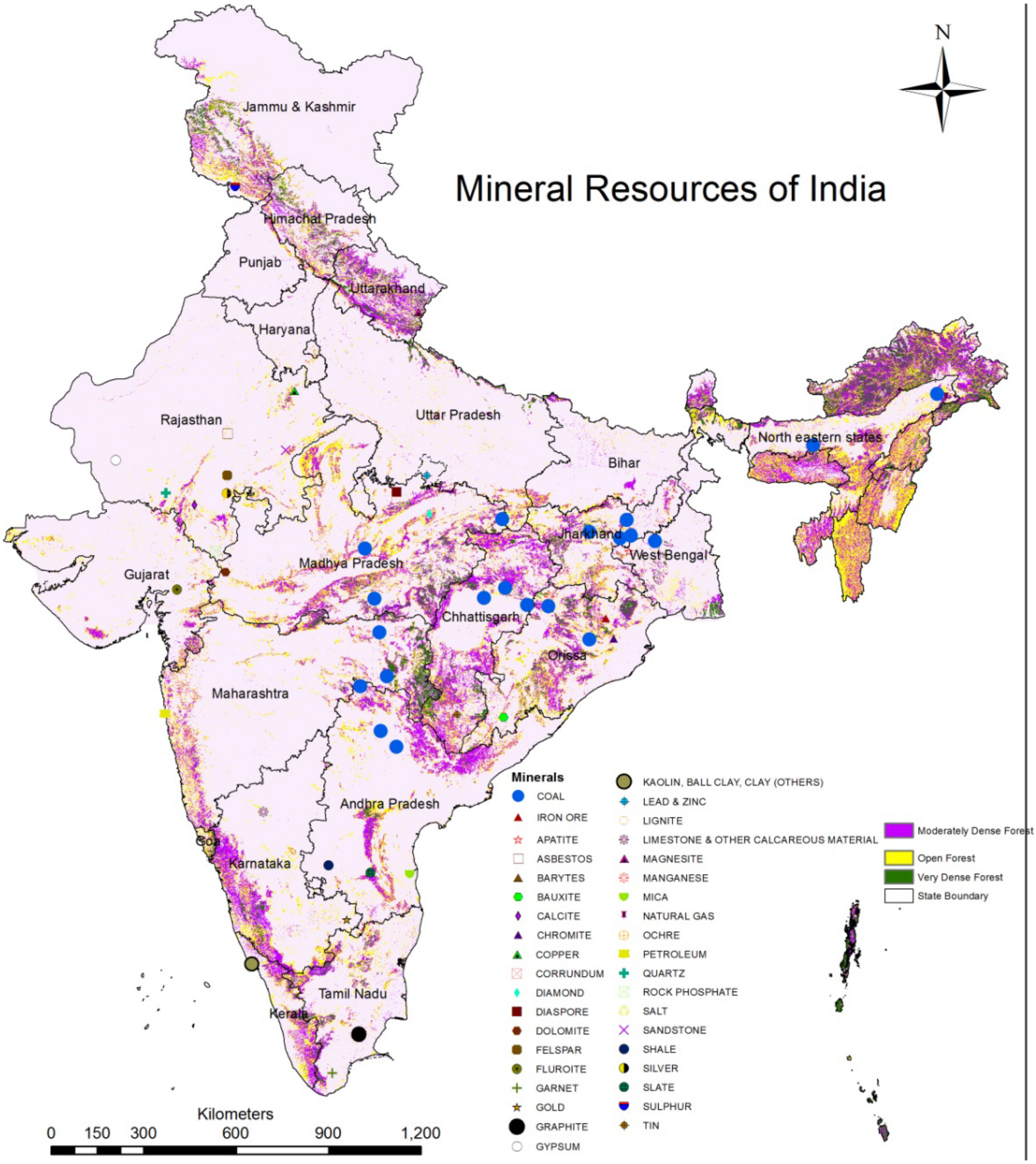


Fig. 1 Map of mineral resources overlaid on forest cover map of India

B. Climate

The average temperature during summer season is 30°C, while during the winter season it is 20°C. The maximum temperature during summer rises up to 44°C, while the minimum temperature during winter falls to lows of 2°C. Average rainfall is 1200 mm with the bulk of rainfall occurring around the July-September period.

C. Status of Forest Types and Forest Cover

Currently, 28.1% of the total geographical area of East Bokaro is under forest cover. The majority of this forest belongs to the Forest Type Group Tropical Dry Deciduous. There are 16.6 km^2, 36.9 $km^2$and 21.6 km^2 of the forest, which represent very dense (>70% canopy density), moderately dense (40–70% canopy density) and open forests (10–40% canopy density), respectively [3]. Fig. 3 shows the forest canopy density distribution in East Bokaro, as per Forest Survey of India data.

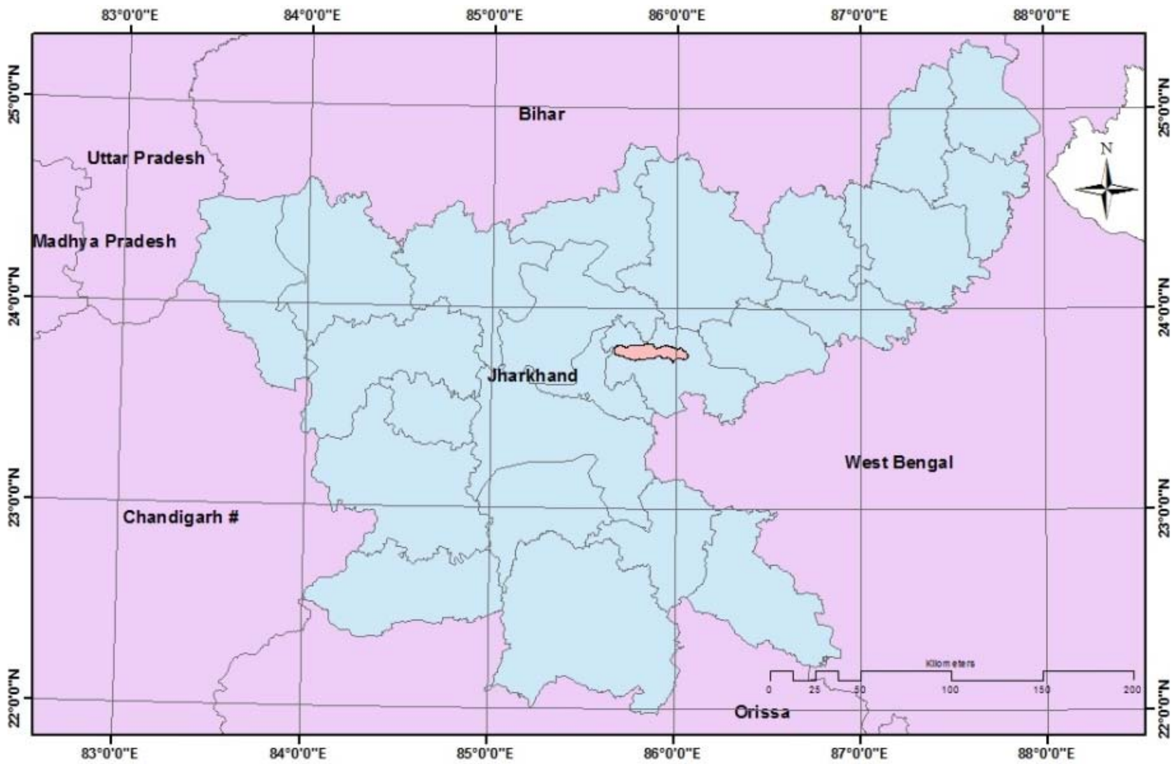


Fig. 2 Location map of East Bokaro Coalfield

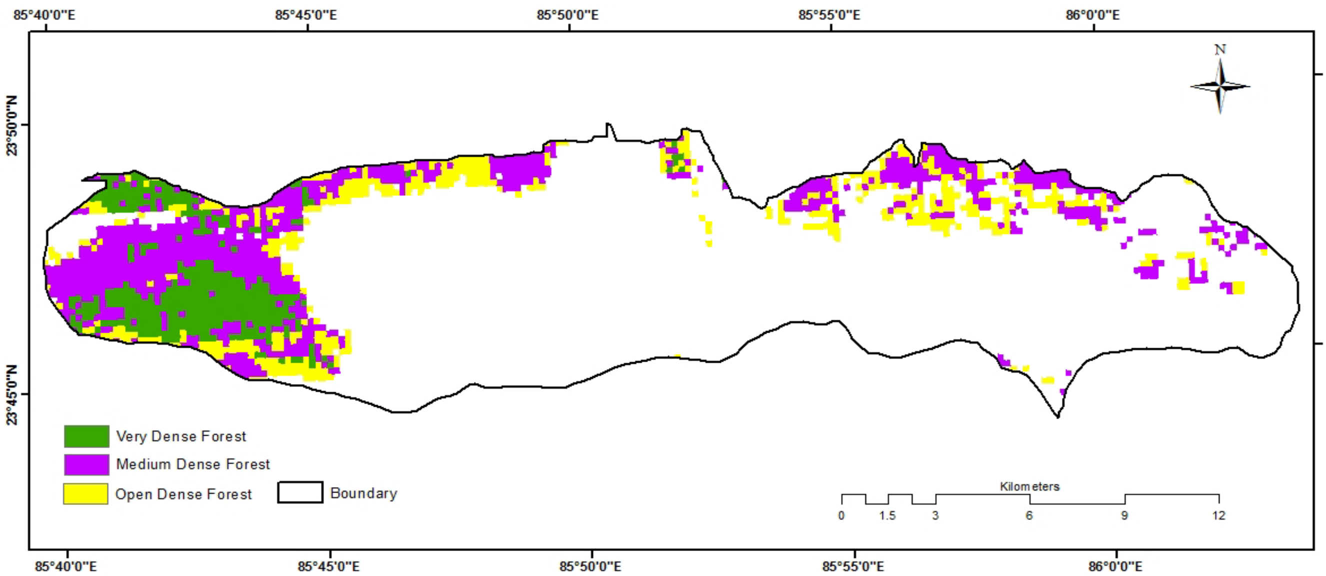


Fig. 3 Distribution of open, medium dense and very dense forests in East Bokaro

III. Materials and Methods

A. Data Used

1. Primary Data

Landsat satellite image was used for classification and extraction of the current forested and mining areas. Data that were available from the month of November 2016 were used in the analysis. Open access digital elevation data of SRTM was used to generate slope maps for vulnerability analysis.

2. Secondary Data

Survey of India (SOI) topographic maps numbered 73E/9, 73E/10, 73I/1, 73I/2, 73E/13 and 73E/14, on 1:50,000 were used to derive the base map of 1973. Biological Richness (BR) and Disturbance Index (DI) data from Indian Institute of Remote Sensing (IIRS) database were used for vulnerability analysis along with canopy cover database of Forest Survey of India.

B. Approach

1. Base Map Preparation

The Survey of India (SOI) topographic maps were electronically scanned and geo-rectified through Erdas Imagine 9.2 software. Land cover features like forests, rivers, water bodies, settlements, mining areas, scrub and barren areas were digitized to prepare the base map.

2. Land Cover Classification

Landsat Level 1 products are already geo-rectified. The Landsat images were atmospherically corrected using the parameters from Landsat metadata file through QGIS semi-automatic classification plug-in. The enhanced and False Color Composite (FCC) image of bands 2-7 were then used for land cover classification of East Bokaro. Based on image interpretation keys the training sets were selected/ identified and signatures generated for each land use/cover class. Supervised method using maximum likelihood classifier in ArcMap 10.1 was carried out on the Landsat FCC images to generate the final land cover map with the land cover classes like forest, agriculture, water bodies, mining, settlement and wasteland. The overall accuracy of the classification was finally assessed with reference to ground truth data by generating 100 random points in the entire study area.

3. Spatial Analysis

The analysis was carried out using ArcMap 10.1. The area of the land cover types were estimated for the past (1973) and the recent (November 2016) period. Forest and mining areas were extracted into separate layers for each time period. The Buffer module in ArcMap 10.1 was used to create multiple buffer zones around the mines. The result was concentric bands of buffers of specific distance around the mine sites, the radius of each band was 1 km. Cross tabulations were then applied to calculate the forest areas within the buffer zones. Near tables were also generated to find out the smallest and farthest distance of forest from the mine sites. Maps showing the mining and forested areas of 1973 and 2016 overlaid with multiple buffers were generated to show the final results.

4. Vulnerability Analysis

The methodology of vulnerability assessment of forests presented here has been adapted from the methodology reported by [13]. The stepwise methodology is shown below:

1. Biological richness, disturbance index, canopy cover, and slope and population parameters, along with the weights assigned to them were used as indicators that determine the current vulnerability of forests. The weights assigned to these indicators by [12] are 0.507, 0.250, 0.137, 0.035 and 0.071, respectively.
2. The study area was divided into 92 grids of 2x2 km.
3. Indicators were first grouped into three classes namely low, medium and high vulnerability class and assigned the values 1, 2 and 3, respectively. Next the area-weighted vulnerability-class value of an indicator for a grid was obtained as sum of the products of the proportion of area of the grid under different vulnerability classes and vulnerability-class values (3-high, 2-medium, and 1-low vulnerability). Then, the vulnerability for a grid for one indicator was obtained by multiplying the vulnerability-class values and weight of the indicator. Finally, the vulnerability values of all the indicators for a grid were added to arrive at a vulnerability value for that grid.
4. The vulnerability profile across the study area was depicted by classifying the vulnerability values into four classes namely, low, and medium, high and very high.
5. To assess the vulnerability of forests to mining, the inherent vulnerability values were combined with the mining impacts (exposure to mining activities) and the area of forest (risk to forest area loss). Thus, the effects of exposure to mining hazards are imposed on the inherent vulnerability to get the forest vulnerability to mining activities. For this, the numbers of grids that are occupied by mining sites were estimated simply based on the presence of a mine site within a grid. The mining grids having more than 10% area under mining were given a value of 1. Also, the grids having more than 10% area under forest cover (as obtained from Landsat classified image) was given a value of 1. Finally, the vulnerability index value for a grid is calculated as the sum of the inherent vulnerability class ranking value, the mining grids and the forested grids. Maps were generated to show the profile of inherent vulnerability of forests and vulnerability to mining overlaid on grids showing the majority forest canopy density class.

IV. Results

A. Buffer Analysis

Forests are mostly located in the northern and western parts of the study area. The data analysis showed that the total forested area in 1973 was around 96 km^2 and total mining area was 4 km^2. The forests were continuous with no fragmented patches or exposed areas (Fig. 4 (a)). However, in 2016 the forest cover declined to 92 km^2 with highly fragmented patches (Fig. 4 (b)) and mining areas increased tremendously from 4

km^2 to19 km^2.

The results of the buffer analysis and cross tabulations are presented in Table I. For every 1 km buffer around the active mining sites the total forest area at risk was estimated. With buffer size of 1 km, approximately 18.77 $km^2$of forest were under impact zone in 1973 and for every 1 km increase in buffer radius, the total forest area under risk increased. With a buffer size of 3 km, 45.6 $km^2$of forest area came under risk zone.

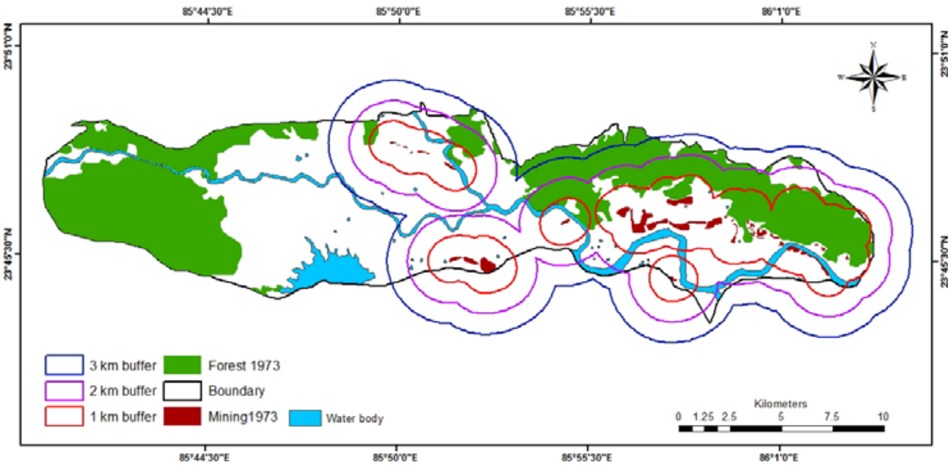
Comparatively, when we look at the current scenario of 2016, around 25 km of forests are at potential risk due to mining activities and these lie within a 1km buffer zone of the mines. With a buffer of 3 km there is 41 km^2 of forested area are at risk of degradation.

The East Bokaro coalfield does not come under any protected area network. Even within a 3-10 km radius around the forests there is no national park or wildlife sanctuary. The nearest located protected areas include Parasnath and Topchanchi Wildlife Sanctuaries covering only 49.33 km^2 and 12.82 km^2 area, respectively [17]. As per the coal block maps from Central Coalfields Limited (CCL) [1] the entire study area of 259 km^2 is covered by more than 50 coal mining blocks.

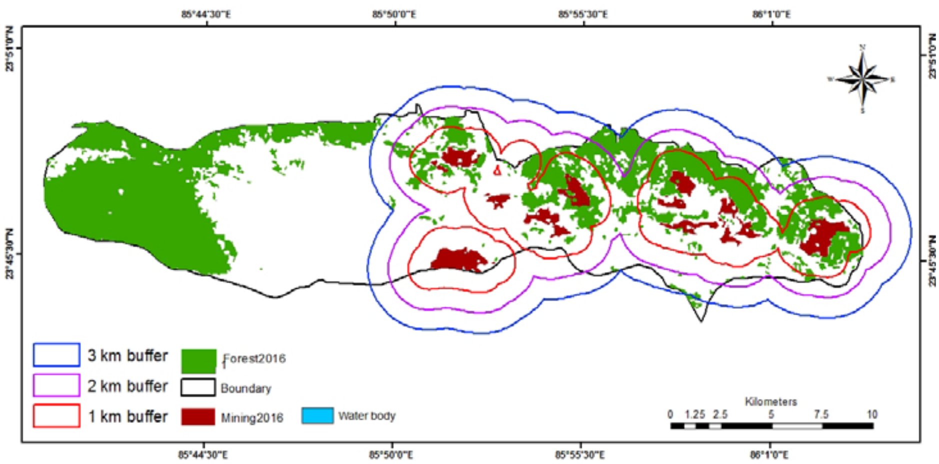
The results of the proximity analysis using Near Table are presented in Table II. As per this analysis, in 1973, most of the coal mines were located in the close vicinity of the forests. The minimum and maximum distance between the coal mines and the nearest forest area ranged from 0-813 meters. Majority of the coal mines were located at more than 100 meter distance from the coal mines with an average of 140 meters. The scenario has changed completely in 2016 where majority of the mining areas are located either within or very close to the forest. The minimum and maximum distance between the coal mines and the nearest forest area ranges from 0-300 meters with an average distance of 39 meters.

TABLE I
FOREST AREA UNDER DIFFERENT BUFFER DISTANCES

Sl. No.	Buffer Size (km)	Total Mining Area (km^2)		Forest Areas under risk (km^2)	
		1973	2016	1973	2016
1	1	4	19.23	18.77	24.56
2	2	4	19.23	35.04	37.3
3	3	4	19.23	45.56	41.16



(a)



(b)

Fig. 4 Forests of East Bokaro overlaid with mining sites and 1-3 km buffers in (a) 1973 and (b) 2016

A. Vulnerability Analysis of Forests

The study area is dominated by only a single forest type group - Tropical Dry Deciduous forests with very negligible distribution of plantations and Tropical Moist Deciduous forests. Break-up of the forest area under different canopy cover classes is shown in Table III.

TABLE II
NEAR TABLE OF COAL MINES WITH RESPECT TO THE FOREST

Mining Site	Near Distance in 1973 (m)	Mining Site.	Near Distance in 2016 (m)
1	0.00	1	0.00
2	0.00	2	134.92
3	0.00	3	0.00
4	26.86	4	0.00
5	18.64	5	0.00
6	106.52	6	0.00
7	76.50	7	0.00
8	17.70	8	0.00
9	176.62	9	0.00
10	24.07	10	0.00
11	78.29	11	0.83
12	113.04	12	193.86
13	23.48	13	0.00
14	136.43	14	41.41
15	104.12	15	0.00
16	16.31	16	0.00
17	0.00	17	64.78
18	0.00	18	0.00
19	0.00	19	118.40
20	0.00	20	0.00
21	31.51	21	5.90
22	323.03	22	300.83
23	536.39	**Average**	**39.13**
24	269.05		
25	45.12		
26	52.79		
27	57.62		
28	0.00		
29	0.00		
30	238.57		
31	297.97		
32	270.82		
33	253.60		
34	219.07		
35	813.20		
36	718.91		
Average	**140.17**		

There are a total of 37 forested grids. Out of the 37 forested grids, 14 grids have more than 100 ha of forest (i.e. 38% of the total grids), while only 7 grids (i.e. 19%) have forest area ranging 5-10 ha. Around 54% of the grids have less than 5 ha forest area while 57% of the grids have 10-50 ha of forests. The forest in the entire coalfield area is under severe anthropogenic pressure. All the forested grids have been used in the assessment as only the forest grids under different vulnerability classes would be assessed irrespective of the extent of the forest area.

Forests having <40 % canopy cover density, according to FSI data, have been considered as open forests [4], while forests with >40 % canopy cover density have been considered as dense forests. Open forests are characterized by high disturbance, low stocking, and higher abundance of invasive species, and as a consequence, are likely to have lower resilience and higher inherent vulnerability [13]. To look at the latest scenario, forest areas from Landsat classified image were extracted grid-wise to generate a new set of forested grids. Out of the 50 forest grid in Landsat classified image,22 grids (44 %) have average canopy cover of morethan 40 % (dense forests) and 28 (56 %) have average canopy cover of less than 40 % in the landscape (open forests).

TABLE III
FOREST AREA UNDER DIFFERENT CANOPY COVERS IN EAST BOKARO

Forest Cover Type/Density	Total Forest area (km^2)	No. of grids with forest area (ha)				
		<5	**5-10**	**10-50**	**50-100**	**100-500**
Very Dense	16.6	18	1	5	0	3
Medium Dense	36.9	0	2	6	9	8
Open	21.6	2	4	10	5	3
Total	**75.1**	**20**	**7**	**21**	**14**	**14**

B. Inherent Vulnerability

The inherent vulnerability values for the entire landscape ranged between 0.059 – 2.65. For the forested grids the values estimated were from 1.97 to 3.85. Using ArcMap clustering algorithm based on Jenk's Natural breaks, the range of grid inherent vulnerability values were further clustered into four groups. Jenk's algorithm arranges data clusters by minimizing variance within a cluster and maximizing it between clusters [14].

The spatial distribution of inherent vulnerability in the landscape is shown in Fig. 5. Out of the 50 forest grid points (based on Landsat 8 2016 image classification) in the landscape, 1, 9, 12 and 28 grids have been assessed to be in the low, medium, high, and very high inherent vulnerability classes, respectively. It can be observed from the spatial distribution of the vulnerability that 16 grids in dense forest class are highly vulnerable while 14 grids in open category are highly vulnerable. Most of the open forest grids have low vulnerability values due to very lesser area of forests in them. The higher vulnerability of the dense forests grids can be attributed to (1) higher anthropogenic pressure, (2) road and river passing through the dense forests and (3) steep undulating terrain in all the forested areas.

The number of grids vulnerable and their percentages for each cover class are shown in Table IV. In the open forests category, 3.6%, 32.14%, 21.43% and 42.86% grids are vulnerable in the low medium and high and very high vulnerability classes, respectively. On the other hand, in the dense forests, no grids are vulnerable in the low and medium category and 27.27% and 72.73 % grids are vulnerable in the high and very high categories.

C. Vulnerability to Mining Activities

The results of the vulnerability to mining activities are shown in Table V and the spatial distribution is shown in Fig. 6. As seen from Fig. 6 and Table V, the majorities of the very high vulnerability grids are located in the open forest category that is about 25% compared to 9.15% of the dense category.

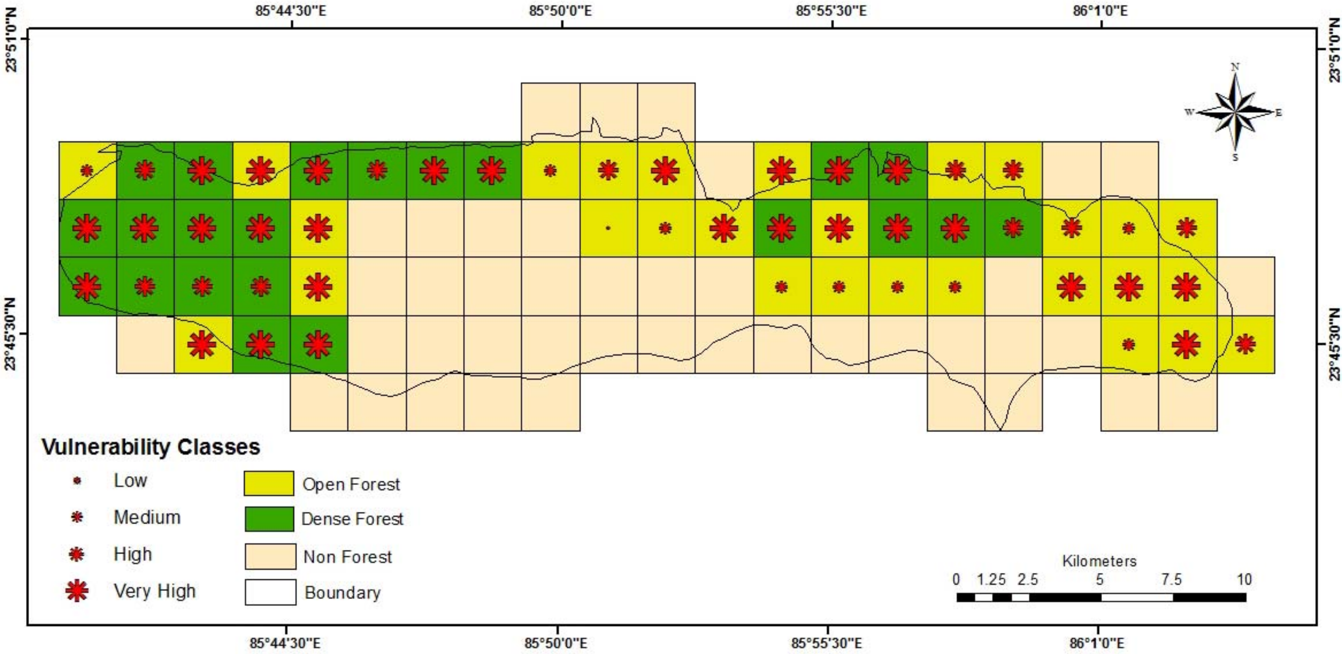


Fig. 5 Distribution of Inherent Vulnerability of forests in East Bokaro

TABLE IV
NUMBER OF VULNERABLE GRIDS AND THEIR PERCENTAGES FOR EACH COVER CLASS

Forest Canopy Cover Type	Total No. of grids	Inherent vulnerability							
		Low		Medium		High		Very High	
		No. of grids	Percent	No. of grids	Percent	No. of grids	Percent	No. of grids	Percent
Open	28	1	3.6	9	32.14	6	21.43	12	42.86
Dense	22	0	0	0	0	6	27.27	16	72.73

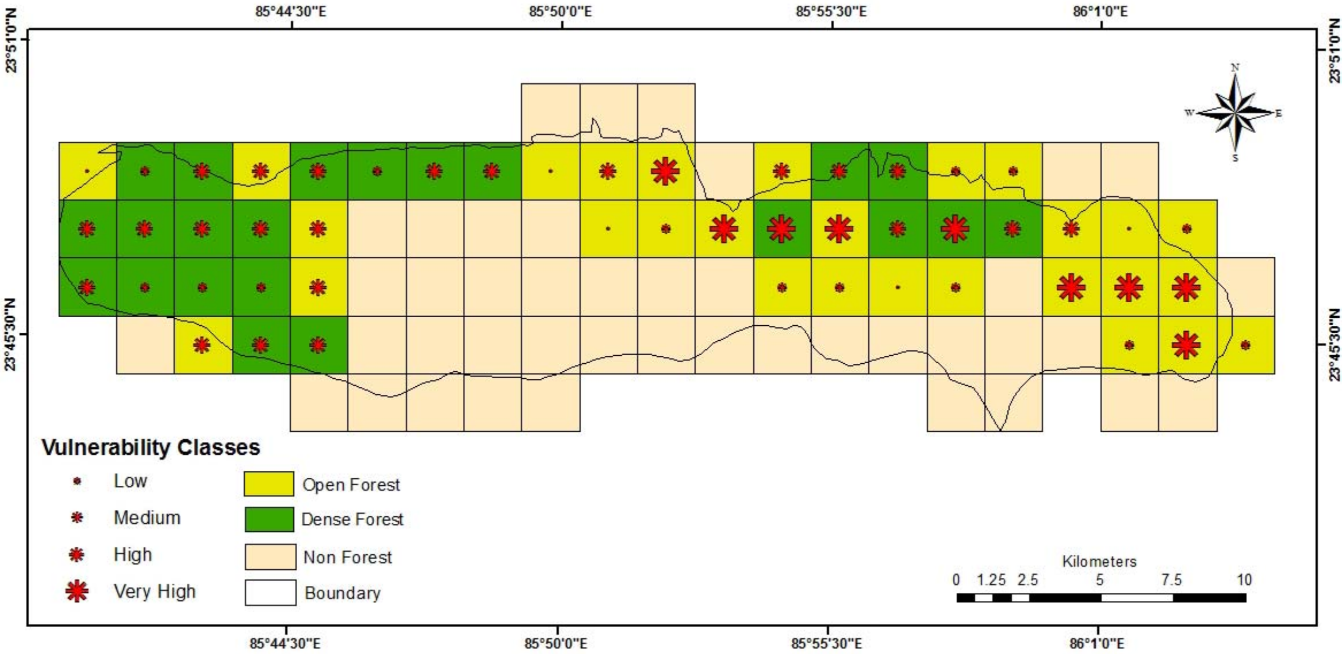


Fig. 6 Spatial distribution of vulnerability of forests to mining activities in East Bokaro

TABLE V
NUMBER OF GRIDS VULNERABLE TO MINING AND THEIR PERCENTAGES FOR EACH COVER CLASS

Forest Canopy Cover Type	Total No. of grids	Total No. of Mining grids	Inherent vulnerability							
			Low		Medium		High		Very High	
			No. of grids	Percent	No. of grids	Percent	No. of grids	Percent	No. of grids	Percent
Open	28	15	5	17.86	9	32.14	7	25	7	25
Dense	22	3	0	0	5	22.73	15	68.18	2	9.1

All the open forest very high vulnerable grids are mining grids indicating that mining activities are a threat to the forests. Due to the intrusion of mining sites within the dense forest areas, the dense forest grids in the mining areas also show very high vulnerability. When overlaid with the sub-district map, the forests of the coalfield falling in the Bermo and Chandrapura divisions showed to be the most vulnerable.

V. CONCLUSIONS AND RECOMMENDATIONS

The ecological and environmental losses caused by coal mining are far more than its economic benefits [2]. The extractive industries give more priority to the economy while society and environment are often highly neglected; therefore, a balance is essential between these three interconnected factors to achieve sustainable development. Due to an increasing dependency on coal for energy generation, there is an increased pressure for diversion of more and more forest land for coal mining purposes. The current study has addressed the following points:

- Forest area at risk around the active mining sites from past to present.
- Distribution of inherent vulnerability in the East Bokaro landscape.
- Vulnerability to mining activities in the East Bokaro landscape.

This information has very crucial implications for management of forests within different coal mining blocks. It is also of paramount importance to the forest managers in decision making by identifying the forest areas which are vulnerable and at risk of loss and degradation due to mining projects.

The analysis revealed the area of forest at risk that has increased from 18.77 km^2in 1973 to 25 km^2in 2016 within a buffer radius of 1 km around the coal mines. These are the areas of immediate and highest impact zones. Also, in 1973, most of the coal mines were located in the vicinity of the forested areas and at more than 100 meter distance from the coal mines; whereas, in 2016 majority of the coal mines are within the forested area with an average distance of 39 meters.

The vulnerability analysis has identified location and canopy cover-wise vulnerability in the landscape. The mining vulnerability maps point to the concentration of highly vulnerable grids in the northern part of the landscape. This can be correlated to the large scale coal mining activities in the northern part. This clearly indicates that coal mining is a very critical driving force behind the loss and degradation of the biodiversity in the region.

The East Bokaro forests are not protected by any national park or Wildlife Sanctuary boundary thus making it an easy target by mining companies. Although plantation has been done on the overburden dumps and backfilled areas, due to which, there is a rise in the area of forest cover in the recent years; the plantations however cannot compete with natural forest as far as conserving ecosystem stability is concerned. Plantations are monocultures with a limited variety of species, and thus, do not contribute to the biodiversity, livelihood or carbon sequestration benefits of a mature and diverse natural forest. As per this study, coal mining is the single largest threat to the forests in the area. It does not make any sense to destroy some of the country's last remaining forests for a resource that could soon get over anyway [5]. The diversion of forest land for expansion of coal mining will have devastating influences on the forests, water resources, biodiversity as well as the forest dependent communities. Therefore, the primary focus of the policy makers should be more on conserving and protecting the native forests rather than destroying them first for infrastructure development and economic benefits and then planning restoration of the degraded lands.

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