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Post-mining land use determination based on land suitability analysis: a case study in Bokaro district of India

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ABSTRACT

Large scale coal-mining activities result in extensive environmental degradation. Appropriate ecological restoration is required to reduce these impacts of mining on the environment and ecosystems. The present study assesses the suitability of abandoned mining sites for conversion into forests and agriculture lands in Bokaro district of India. Land suitability analysis was carried out using selected topographic variables like elevation, slope, aspect, relief and distance from the rivers. Normalization and clustering techniques were used to classify the area into four land suitability classes namely unsuitable, less suitable, moderately suitable and highly suitable. For each of the selected mining sites, a suitable land use alternative was suggested for its restoration based on the analysis as well as past and present land use status. On the basis of the results, it was concluded that 28.7% of the site area in Govindpur and 33.9% in Kathara are highly suitable for transformation into forests or agriculture while other areas require substantial and preliminary land reclamation. The abandoned mine sites of Bokaro have a high potential for development into useful and attractive recreation point and plantation activities.

Key words: *Mining, Land suitability, Land use, Ecological restoration, Bokaro*

Introduction

Environmental degradation caused by mining operations disrupts ecosystem functions and reduces biological diversity. Abandoned and degraded mined lands deteriorate the environment quality and prevent beneficial utilization of natural resources like forests, air, water and soil and also endanger human health and safety. In order to mitigate these negative impacts and to achieve sustainable development, there is a need to reverse this process as much as possible through appropriate ecological restoration (Benayas *et al.,* 2009; Feng *et al.,* 2013). A number of methods have been used to restore the degraded landscapes in mining areas from engineering techniques (Gao *et al.,* 1998 Wang *et al.,* 2001; Sklenicka *et al.,* 2002) to reclamation planning. Reclamation planning forms a very crucial component of ecological restoration programs. Land suitability analysis is used to select the optimal post-mining land use type and forms the basis of any reclamation planning (Wang *et al.,* 2011; Wang *et al.,* 2017) and has been adopted in many studies (Pavloudakis *et al.,* 2009; Soltanmohammadi *et al.,* 2010). The post-mining lands could be put to various different land uses like forests, agriculture and also into developed land like residential areas, recreation parks, etc. The suitability level for possible land use alternatives are based on many factors like the topographic conditions, local climate and

other socio-economic conditions. East Bokaro landscape in central India has undergone massive changes in last few decades due to mining activities (Upgupta *et al.,* 2020). The abandoned coalfields have land under different levels of ecological deterioration and require an effective reclamation planning. The aim of this study is to assess the land suitability of the mined landscape for development into forests and agriculture based on natural evaluation factors and suggests appropriate alternatives for land transformation.

Study Area

East Bokaro coalfields are located in the Bokaro district of India (Fig. 1). The geographical extent of the study area is 23^0 45′ to 23^0 50′ N and 85^0 30′ to 86^0 03′ E with a total area of 259 sq. km. The elevation ranges from 141-967 m and most of the region (especially the northern part) has rugged topography with isolated hillocks. The important coal seams found in the coalfield include Jarangdih seam, Kargali seam, Bermo seam and Karo seam. Damodar and Bokaro are the primary rivers draining the landscape from north to south. The area has a tropical climate with an average temperature of 30 °C during summer season while 20 °C during the winter season.

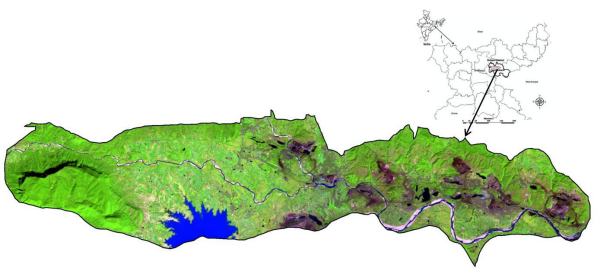

Fig. 1. Study area (true color satellite image)

Materials and Methods

Landsat data for the month of November 2016 was used to extract the study area. A thorough ground survey was conducted in the same month to assess the present scenario of mining areas and identify sites which are drastically deteriorated. A total of five sites were finalized for analysis and recommendation of effective land-use alternatives. Five evaluation factors namely elevation, slope, aspect, relief and the distance from the rivers were selected based on literature survey and data availability. ASTER-DEM (Advanced Spaceborne Thermal Emission and Reflection radiometer - Digital Elevation Model) was used as a source of elevation data. The ASTER-DEM was also used to generate the slope, aspect (nine classes from north to south) and relief maps. The drainage map was used to generate the distance to rivers using Euclidean Distance tool in ArcMap 10.5. The spatial layers were then clipped for the mining areas and then minimum-maximum normalization (0-1 range) was applied to generate the evaluation indicators based on their suitability for forests and agriculture development. as shown in the equations below:

$$V_{minmax}\text{ (standardized value)} = \frac{\text{Actual value (x) - Minimum value (x)}}{\text{Maximum value (x) - Minimum value (x)}} \quad \text{.. Eq. (1)}$$

$$V_{maxmin}\text{ (standardized value)} = \frac{\text{Maximum value (x) - Actual value (x)}}{\text{Maximum value (x) - Minimum value (x)}} \quad \text{Eq. (2)}$$

Equation (1) is for factors in which good suitability is indicated by higher values while **Equation (2)** is for factors in which good suitability is indicated by lower values. For example, low elevation areas have been considered most suitable for the establishment and growth of forests in a number of forest suitability analyses (Ma *et al.,* 2011). Lower elevation areas are also more suitable for croplands and the suitability decreases with increasing elevation. For slope and relief, higher suitability was indicated by lower values for any kind of land reclamation alternative. For aspect, southern, south-eastern and south-western facing slopes was assigned the most suitable for forest and agriculture while the northern, north-western and north-eastern aspects were assigned as unsuitable. A greater distance from the rivers was considered less suitable and vice versa. Moreover, the reclaimed lands in the vicinity of the roads, rivers and settlement are more suitable for restoration to developed land.

The evaluation indicators for the entire study area are shown in Fig. 2. The final land suitability value was obtained by taking a simple average of all the indicators. The averaged values were further grouped into four natural data clusters namely unsuitable, less suitable, moderately suitable and highly suitable by using the Jenk's Natural Breaks algorithm in ArcMap 10.2. Google Earth was used as a reference for the current conditions. Suitable land use alternatives were then recommended based on land suitability map, previous land use types, adjacent vegetation type and proximity to roads and settlements. No socio-economic factor was taken into account as forest and agriculture

development is less dependent on socio-economic factors like distance from roads and cities.

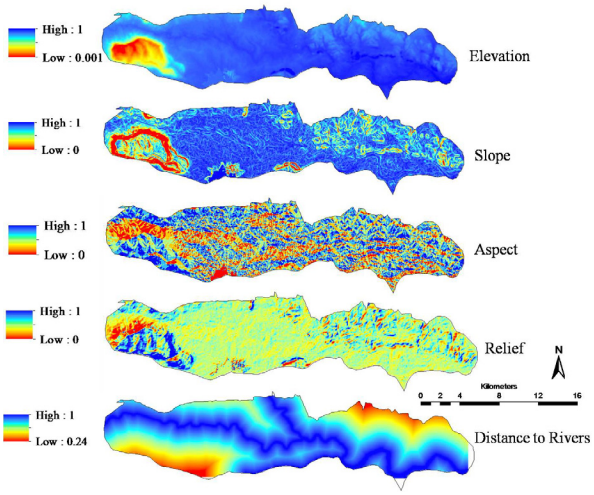

Fig. 2. Evaluation indicators

Results and Discussion

The selected mining sites for the analysis include: 1) Govindpur, 2) Kathara, 3) Subhas Nagar, 4) Kargali and 5) Tarmi. The spatial pattern of land suitability obtained in the results exhibit different levels of suitability (Fig. 3). The outputs show that majority of the sites especially Batkaro and Kargali have large patches of land which is unsuitable for either plantation activities or crop cultivation. Govindpur and Phusro mines are highly suitable for forestry and agriculture development while Tarmi, Kathara, Barwabera and Subhas Nagar areas have different levels of suitability. However the areas found unsuitable for forest and agriculture have the potential for being utilized for infrastructure development.

The proportion of land under different suitability classes at each mine site is shown in Table 1. Govindpur has 33.98 % moderately suitable and 28.71 % as highly suitable area and only 0.52 % under not suitable. Tarmi has equal proportions under less suitable (43.67 %) and more suitable (49.62 %) classes. The Kathara mines are more suitable for plantation activities with more than 55 % area under moderate to high suitability and 35 % area under no to marginal suitability. It is also interesting to note that the Kargali and the Batkaro coal mining areas have no area under highly suitability class.

The recommendations for the individual sites are detailed below

Govindpur mines : This site has three big mine water bodies, two over burden dumps and one excavated area. Previous land use/land cover consisted mainly of forest and agriculture. The region on the western parts of the site across the Konar River has been planted for forestry purposes. The area is surrounded by green cover on all sides and is less dis-

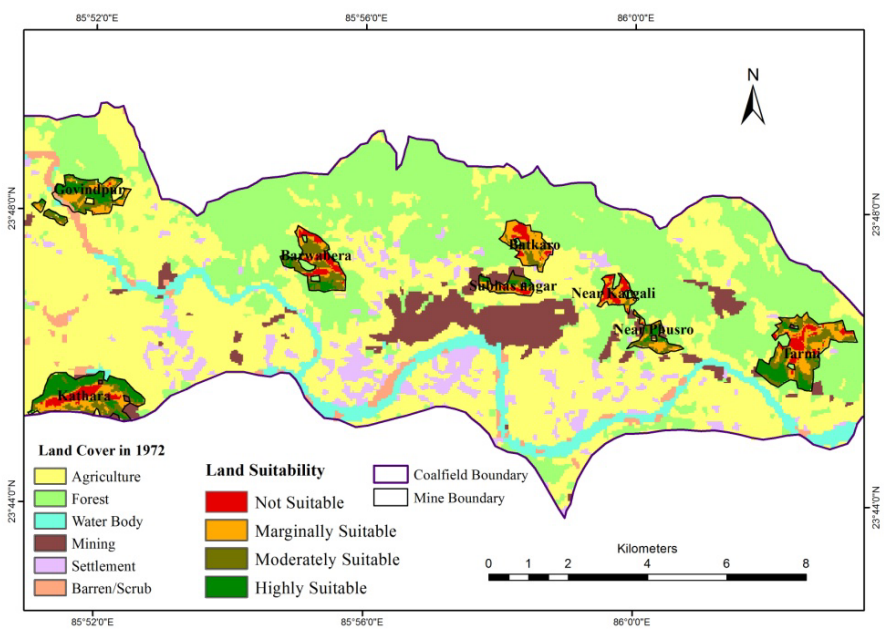

Fig. 3. Land Suitability map in East Bokaro mining sites

turbed by human activities. The results show majority of the areas under high to moderate suitability levels while marginally and highly unsuitable include the steep slope areas. Based on these observations it is recommended that the site is suitable for development into a biodiversity conservation area. The water filled area may be developed as a lake for wildlife habitat and migratory birds. The slopes in the excavated areas can be contoured and planted with appropriate trees after proper land reclamation. The over burden dumps maybe reclaimed into a planted forest.

Kathara Mines: The northern parts of this mining site consisted of agriculture both previously as well as in the present state. The western and the eastern parts have village settlements. Within the mining site there are two big mine water bodies, a large waste rock dumping site, settlement areas, excavated areas and wastelands. The current analysis indicated that the entire northern part is suitable for forestry or agriculture. The southern parts are suitable for planting trees while the central parts are unsuitable for planting forests due to steep and north facing slopes. It is recommended that the northern boundary may be utilized for agriculture and croplands and the immediately adjacent area planted with plantation trees. The mine water bodies can be developed into recreational lakes and the water may also be supplied for irrigation purposes to the surrounding agricultural fields. The entire overburden dump can be planted with native species. The development of an Eco-friendly Mine Tourism Circuit seems suitable as it is a perfect site for mine tourism having a strategic location with view of Damodar River (South), Tenughat and Lugu Hill (West), Bokaro Power Plant (North) and forests (East).

Subhas Nagar: This site has a water-filled area in the southern part with very steep slope (30 meters deep from the ground level. This is located within 60 m distance from the nearby human settlement and is a high risk zone. The region north of the water body has a gradually rising ground towards the upper forested areas. The land suitability maps show that the entire northern part is highly suitable for reforestation through plantation programmes. The deep gorge in the southern part may be developed into a small lake for aesthetics. Since the area is surrounded by settlements on three sides, conservation is not an option hence development of a recreational site in the form of a park is required.

Kargali: This site has a lot of wasteland, small mine water bodies and the excavated sites with steep slopes. The area is not suitable for either agriculture or human habitation. The land suitability maps show that the entire area is unsuitable for plantations as well. It is recommended that the excavated areas be filled and leveled so as to decrease the elevation differences and generate a moderate slope of the ground. Since the area was previously forested, and is still surrounded by green cover on most sides, it is recommended that after appropriate land and soil reclamation, the whole area may be planted with suitable tree species.

Tarmi: Tarmi is the largest site with four big mine water bodies and over burden dumps located outside the mining area. Majority of the site is covered with waste and is rendered barren. The analysis showed that the southern parts of the site are highly

Table 1. Land Suitability statistics of East Bokaro mines

Mine Site Name	Total Mine Area (ha)	Land Suitability Class							
		Not Suitable		Marginally Suitable		Moderately Suitable		Highly Suitable	
		Area (ha)	Proportion (%)	Area (ha)	Pro portion (%)	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)
Govindpur	137.45	0.72	0.52	30.05	21.86	46.71	33.98	39.47	28.71
Batkaro	90.49	17.62	19.47	47.67	52.68	19.55	21.61	0.00	0.00
Barwabera	125.34	29.45	23.49	23.90	19.07	49.00	39.09	14.24	11.36
Subhas Nagar	44.62	5.67	12.71	14.84	33.27	11.22	25.15	7.12	15.96
Kargali	48.23	19.19	39.78	18.10	37.53	3.50	7.26	0.00	0.00
Phusro	50.45	0.24	0.48	13.28	26.31	21.00	41.62	9.66	19.14
Tarmi	233.28	32.34	13.87	69.52	29.80	74.83	32.08	40.91	17.54
Kathara	221.33	34.15	15.43	44.78	20.23	49.36	22.30	74.95	33.86

suitable for plantation activities. This site seems appropriate for development into a multifunctional integrated landscape with a variety of land use types. It requires proper site preparation and soil restoration for planting trees in selected areas. The northern parts with gentle sloping land can be utilized for cultivation of crops which can help in reclaiming the soil back to its pre-mining state. The mine water bodies in the northern parts can be developed for recreational activities.

Conclusion

East Bokaro is a major source of medium coking coal in India. However, the incessant coal mining and its related activities have played havoc with the landscape which needs to be refurbished and reconditioned. Land suitability analysis is an effective method of determining the optimal land use appropriate for every site. Post-mining land that becomes a liability to human well-being and environment can become a positive asset through careful planning and design.

Conflict of Interest

There is no conflict of interest with anyone.

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