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Opencast Coal Mining Induced Degeneration of Streams: A GIS Based Study of the Raniganj Coalfield, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: Extraction of coal by the opencast (OC) method generates huge amounts of waste materials due to the removal of overlying rock and soil. These materials (overburden) are dumped near the mining site. Thus, anthropogenic landforms like mine pits, spoil dumps, and overburden dumps have been formed, which changes the topography of mining site. Rivers are affected by OC mines, as the alteration of topography disrupts the natural drainage system of the mining site, and the flow of rivers is largely affected. With this background, the objective of the present research work is to identify the nature and extent of stream degeneration by OC coal mining.

Place and Duration of Study: The study area is the Raniganj coalfield (23°32'50"N- 23°50'30" N and 86°39'49" E-87°16'41" E), which is situated in the Paschim Bardhaman District of West Bengal, and the Mugma area (Dhanbad District) of Jharkhand. Coal mining in the coalfield is regulated by Eastern Coalfield Limited or ECL.

Methodology: Streams in the study area were identified from the Survey of India Topographical sheets (1: 50,000 scale) and OC mines were identified from Google Earth images (2016). Stream

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degeneration was measured by superimposing streams and OC mines in a Geographical Information System (GIS) environment.
Results: The study reveals that rapid growth of OC coal mines (total area of OC mines in 1990 was 26.15 sq.km. and 48.52 sq. km in 2016) within the Raniganj Coalfield degenerates the tributaries of the Ajoy, Damodar and Barakar Rivers in study area.
Conclusions: A total of twenty eight catchment basins have been affected by OC coal mines and out of twenty eight, ten catchment basins have more than 90% degeneration. Thus, a sustainable management plan is needed to protect the environment and to maintain the riverine system of the study area.

Keywords: Stream degeneration; anthropogenic landforms; remote sensing; geographical information system.

1. INTRODUCTION

Coal mining as an industry plays vital role in the economic development of a country [1]. Coal is widely used for generating electricity in thermal power plants, and thermal power plants meet 70% of the total energy demands in India [2]. Beside electricity, coal is also used in steel, cement, sponge-iron and other industries. In India, coal extraction is done by two type of methods, one is the underground (UG) mining method, and the other one is the opencast (OC) method. In the UG mining method, coal is extracted by tunneling underground, while with the OC method, coal is extracted by removing the soil and rock materials (overburden). OC coal mining recovers a greater proportion of coal deposits than UG methods, as more of the coal seams in the strata may be exploited. Moreover, use of heavy and modern machinery (dump trucks, loaders, backhoes, cranes, trucks and bulldozers), and modern mining techniques reduced the production cost of the OC mining method. The OC mining method is the most common method of coal mining as, 70% of total coal production in India is done by the OC method [3].

Materials removed from OC coal mines (topsoil and rock layers) for the extraction of the underlying coal strata, are dumped outside of the mining area [4]. The generation of a huge amount of waste materials, and alteration of the local topography are the biggest noticeable impacts of OC coal mining. Alteration of the topography blocks or diverts streams, and the natural flow path of streams is disturbed by OC coal mines [5,6]. Changes of land use, land cover, topography, generation of huge overburden, and formation of mine pits has a great impact upon the watershed [7]. Moreover, removal of overburden leads to the discharge of fine particulate material [8].

Coal mining in Raniganj Coalfield is regulated by Eastern Coalfields Limited [9]. According to the annual report (2016) of Eastern Coalfield Limited, India, coal production, under Eastern Coalfield Limited, from UG mines was only 7.329 million tonnes (18.23%), whereas with OC mines, production was 32.880 million tonnes (81.77%) in the year 2015-16 [10]. This clearly indicates that the OC mining method is more important than the UG method.

The rivers of the Raniganj Coalfield have been affected by OC mines, because the overburden dumps are extended up to the channels [11]. Extraction of coal, and piling of overburden materials, causes obstruction in stream flows, and also reduces the water availability in the lower parts of catchment basins of the Raniganj Coalfield [9]. Drainage lines of the Raniganj coalfield have degenerated or have been blocked and diverted, to extract coal by the OC mining method. This study attempts to understand the degeneration of the streams of the Raniganj coalfield by OC coal mining. This paper aims to identify the degeneration of streams from the OC coal mining with the help of Geographical Information System (GIS) techniques.

1.1 The Study Area

Study area falls under the Ajoy-Damodar interfluve zone of the Raniganj Coalfield. The eastern part of the study area is bounded by the Mugma (parts fall under Raniganj Coalfield) area of the Jharkhand State, and the western part of the study area is extended to Kajora, Bankola, Pandabeswar and the Jhanjra coal mining area of the Paschim Bardhaman District, West Bengal state.

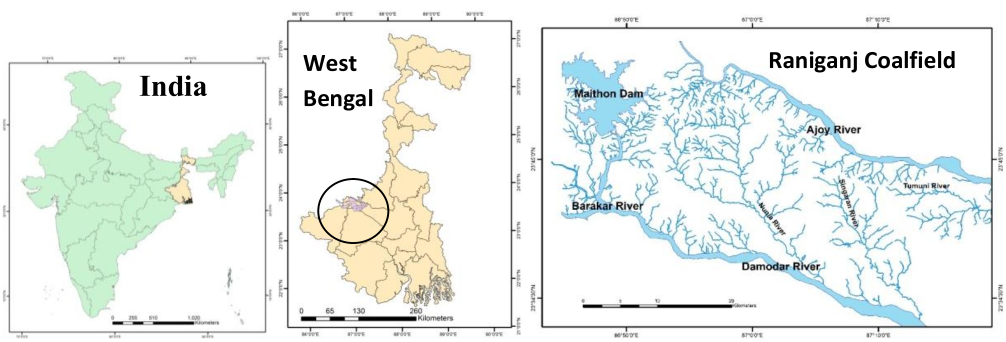

Fig. 1. Location of the study area

The study area is drained by three major rivers, namely the Ajoy, the Damodar, the Barakar, and numerous small tributaries of these three rivers. Within this interfluve zone, the main rivers are the Khudia, the Singaran, the Nunia (tributaries of the Damodar River), and the Tumuni (tributary of the Ajoy River) (Fig. 1).

1.2 Objectives

Major objectives of this study are as follows:

i) To study the spatio-temporal growth area of OC mines within the study area.
ii) To assess the nature and extent of degeneration of streams by OC coal mining with the help of GIS techniques.
iii) To suggest suitable restorative measures for the overall problems.

2. METHODOLOGY

In this study, the Geographical Information System (GIS) method was applied to identify and analyze the nature and extent of stream degeneration within the study area from OC coal mining. Catchment basins, those affected by OC coal mines, were identified from the Survey of India (SOI) Topographical sheets (1970-75), and images available from Google Earth (Table 1).

2.1 Evaluating the Growth of OC Mines within Raniganj Coalfield

To study the spatio-temporal growth of OC mines, Landsat satellite images were used. The images have spatial resolution of 30 meters. Expansion, of the areas of OC mines, was measured from Landsat images of 1990, 2000, 2010 and 2016.

2.2 Selection of Affected Catchment Basins

To select the small catchment basins affected by OC coal mining, streams of the study area were digitized from the Survey of India (SOI) Topographical sheets using ESRI ArcGIS 10.2 software. Topographical sheets with information about elevation (contour lines), physiography, vegetation, and land use provides useful information about a region. The sheets are published by the Survey of India, and the years of the survey were from 1970 to 1975. Existing OC coal mines in the study area were identified from images available in Google Earth. Finally, streams identified from the SOI Topographical Sheets, and OC coal mines identified from Google Earth, were superimposed in a GIS environment to identify the affected catchment basins. A total of twenty eight small catchment basins have been identified by this method. These small catchment basins were tributaries of the Nuniya, the Khudiya, the Tumuni, the Singharan, the Ajoy and the Barakar Rivers (Fig. 2).

2.3 Assessment of Nature and Extent of Stream Degeneration

To study the nature and extent of stream degeneration, the total length of the streams in each catchment basin, degenerated by OC mines, was measured using ESRI ArcGIS 10.2 software. Finally, the percentage of length of stream degenerated by OC mines, with respect to the total length of streams (main stream and its tributaries) in each catchment basin was calculated. The percentage value was calculated to understand the nature and extent of degeneration, and to compare the affected catchment basins.

Table 1. Data used in the analysis

Data used	Date of data acquisition	Pixel Size/Resolution/Scale
Landsat 5 TM	12/23/1990	30 meters
Landsat 5 TM	12/02/2000	30 meters
Landsat 5 TM	12/14/2010	30 meters
Landsat 8 OLI_TIRS	03/17/2016	30 meters
Point elevation data from Google Earth	N.A.	N.A.
Survey of India Topographical sheets	1970-75	1:50,000
Image available from Google Earth	2003-2016	N.A.

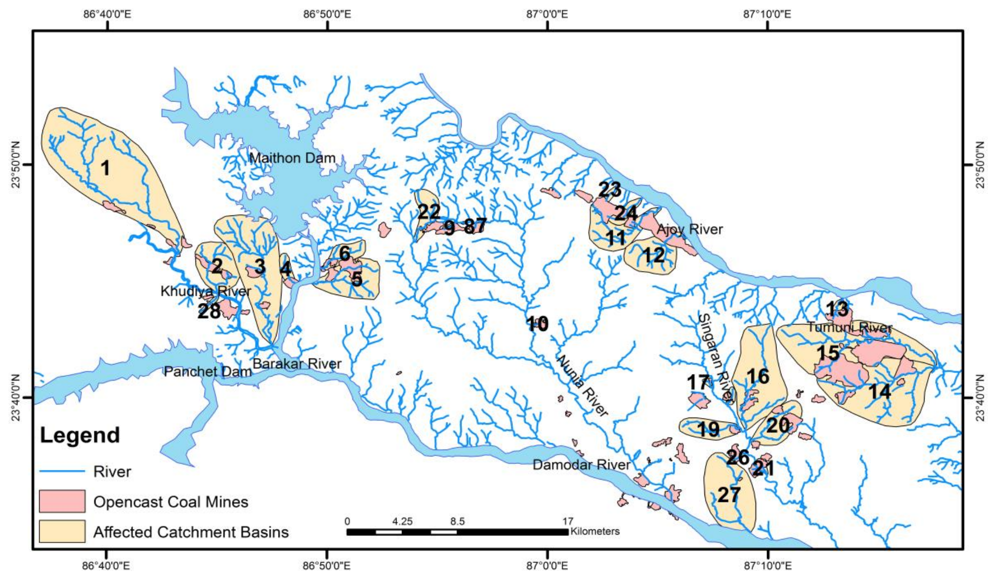

Fig. 2. Catchment basins affected by OC mines

2.4 Preparation of Elevation Map

An elevation map from the SOI Topographical sheets and Google Earth was prepared to compare the pre mining and post mining elevation changes in the catchment basin no. 15. Basin no. 15 was selected in this regard because it is one of the largest affected catchment basins in the study area. The elevation map was prepared from the SOI Topographical sheets by interpolating contour value, while elevation map obtained from Google Earth by interpolating point elevation data in ESRI ArcGIS 10.2 software. A profile of cross section AB was drawn to compare the elevation changes (Fig. 4).

2.5 Field Verification

Field visits were carried out to evaluate the impact of OC mining. Field photographs of selected sample sites were taken to represent reality, as compared to the maps.

3. RESULTS AND DISCUSSION

3.1 Process of OC Coal Mining and Formation of Anthropogenic Landforms

OC mining, or open pit mining, is a surface mining technique where overlying rock and soil materials are removed to extract the underlying coal strata. The area of excavation forms a large pit (mine pit) in earth's surface. Excavation is done by blasting rock and soil (overburden), and extracting the coal. After extraction, coal is transported by truck from the mines to coal processing plants. With the process of OC mining, huge amounts of waste materials are generated and piled up outside of the mining area. Thus, anthropogenic landforms like overburden dumps, mine pits etc., are formed. Anthropogenic landforms changes the elevation of an area, and along with elevation the relative relief, the absolute relief also changes. Fig. 3 is the comparison of elevation maps of basin no. 15, prepared from the SOI topographical sheets (1970-75), and the elevation map prepared from the data available from Google Earth. In Fig. 3, the development of OC mine brought drastic changes in the elevation of catchment basin no. 15. The absolute relief was 122 meters and the relative relief was 44 meters in the SOI Topographical sheets, whereas in Google Earth, the absolute relief is 161 meters and the relative relief is 119 meters. Thus, the topography of the mining site changed due to the development of OC mines (Fig. 4).

3.2 Growth of Opencast Coal Mining in Raniganj Coalfield

The expansion of the total area of OC mines within the Raniganj Coalfield was measured from Landsat images in 1990, 2000, 2010, and 2016, and are represented in Table 2, and Fig 5. In Table 2 there is rapid growth in the area of the OC mines from 28.15 sq. km. in 1990, to 48.52 sq.km. in 2016. In Jamuria (OC Mine area 11 sq. km. in 2016) and Pandabeswar (OC Mine area 15.67 sq. km. in 2016) blocks the growth of area of OC coal mines was highest. Growth of OC mines was also high in Jamuria Municipality (OC Mine area 2.85 sq. km. in 2016), Barabani Block (OC Mine area 3.02 sq. km. in 2016) and Salanpur Block (OC Mine area 4.11 sq. km. in 2016), compared to other blocks. In Kulti Municipality (OC Mine area 2.96 sq. km. in 2016), and Raniganj Block (OC Mine area 0.73 sq. km. in 2016) growth of OC mines was relatively low. High population density and a higher rate of urbanization increases the scarcity of land within the Kulti and Raniganj blocks. As OC mines require a huge amount of land for excavation, dumping of waste materials, building roads for transportation, and parking for vehicles, the area of OC mines is relatively low in these blocks. Growth of OC mines was high in blocks situated in the Ajoy River Basin compared to blocks situated in the Damodar River Basin, Since the rate of urbanization is lower in the Ajoy River Basin (Salanpur, Pandabeswar and Barabani Block) compared to the Damodar River Basin (Kulti Municipality, Andal Block, Raniganj Block). In the Andal Block and the Nirsa block (those parts that fall under the Raniganj Coalfield) of the Jharkhand state, the area of OC mines shows a negative growth.

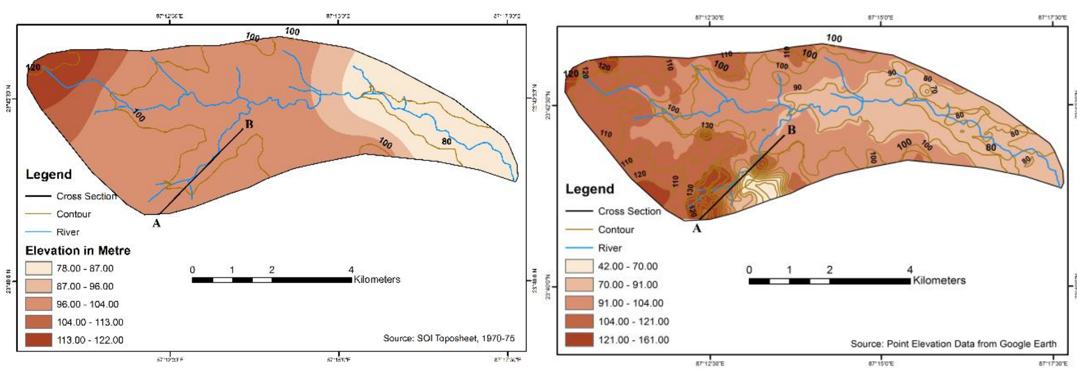

Fig. 3. Elevation map of catchment basin No. 15 from the SOI topographical sheets and the Google Earth

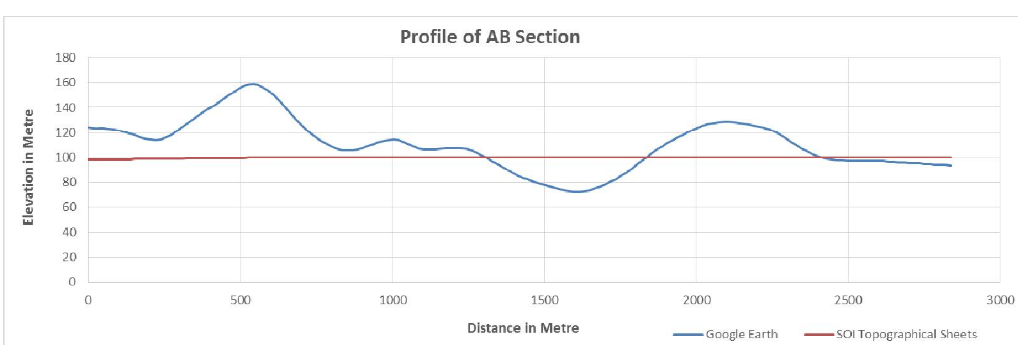

Fig. 4. Profile of AB section from the SOI topographical sheet and Google Earth

Table 2. Expansion of area of OC mines within Raniganj Coalfield (1990-2016)

Block/Municipality	Area of OC mines (Sq.km)			
	1990	2000	2010	2016
Kulti Municipality	2.09	2.26	2.47	2.96
Salanpur Block	3.08	2.14	3.36	4.11
Barabani Block	1.21	2.57	3.5	3.02
Pandabeswar Block	4.33	6.22	9.65	15.67
Andal Block	1.56	1.87	1.66	1.1
Jamuria Block	0.1	3.26	10.23	11
Jamuria Municipality	0.7	1.2	1.4	2.85
Raniganj Block	0.3	0.4	0.63	0.73
Nirsa Block	12.78	8.78	5.08	7.11
Total	26.15	28.73	37.98	48.52

Source: Landsat Images of 1990, 2000, 2010 and 2016

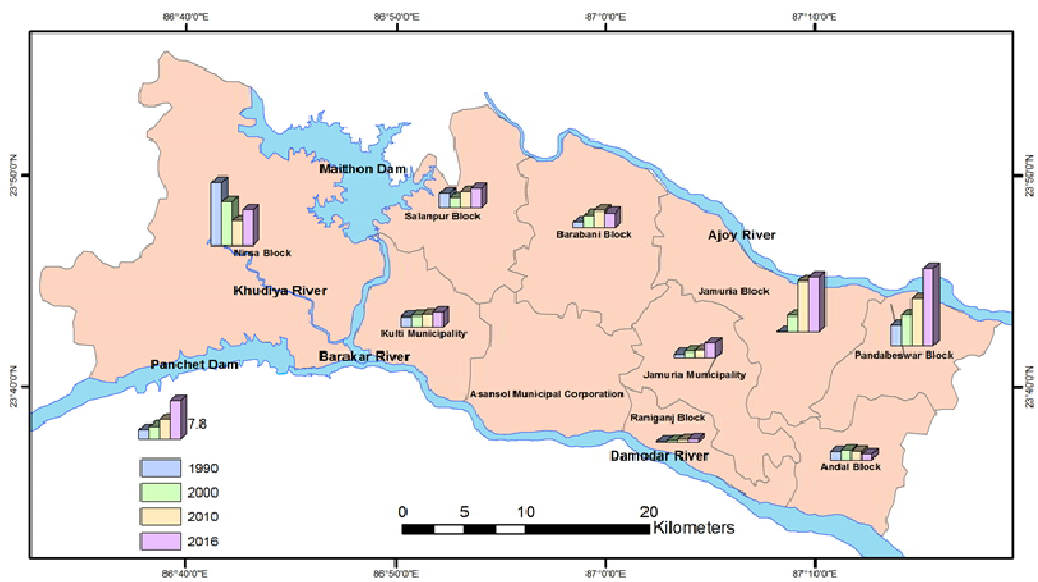

Fig. 5. Growth of area of opencast coal mines in different blocks of the Raniganj Coalfield
Source: Landsat Images of 1990, 2000, 2010 and 2016

3.3 Opencast Coal Mining Induced Degeneration of Streams

Formation of overburden dumps and alteration of topography affects the drainage lines of the Raniganj Coalfield. Mine tailings restrict the surface flow of streams, and blocks the streams of the study area. Moreover, void spaces of excavated areas or mine pits act as a reservoir for surface runoff, and reduces the flow of streams. Thus, rapid and widespread development of OC mines throughout the Raniganj Coalfield destroys the natural drainage systems. The tributaries of the Ajoy, Damodar and Barakar Rivers that flow through the coalfield are blocked by the materials dumped from the OC mines. Deformation of surface topography by OC mines disrupts the drainage system in a number of catchment basins. Catchment basins, those affected by OC mines, are shown in Fig 6. To analyze the nature and extent of stream degeneration, the total length of the streams (main stream and tributaries) in each affected catchment basin, and the total length that degenerated by OC mines, is calculated and shown in Table 3.

From Table 3, catchment basin No. 6, 7, 8, 9, 10, 12, 15, 16, 21, 22, 24, 25, 26, 27, and 28 are the main affected catchment basins of the Raniganj Coalfield. Based on the nature and extent of degeneration, the catchment basins were classified in Table 4. From Table 4, those basins, where OC mines developed along the channel are mainly degenerated due to the obstruction in stream flow by mine materials dumps or mine pits. Moreover, OC mines that developed near the mouth or confluence zone of the catchment basins blocked the entire channel, therefore caused 90-100% degeneration of the catchment basins. OC mines that developed in the upstream section of the catchment basins have comparatively lesser impact on the basin. Another interesting fact is that catchment basins, those that are situated in the Nirsa block of Jharkhand state, do not experience any degeneration, even though the OC mines developed along the channel (catchment basin no. 1, 2 and 4). In these basins, the channel was either diverted, or transformed into an artificial channel, to maintain the OC mines. The streams in the West Bengal part experienced degeneration from OC coal mines.

Beside the degeneration of small catchment basins, OC mines also affect the channel morphology of the streams. Dumping of overburden materials within channel reduces the width of the streams. Development of OC mines within the channel also diverts the streams in many places within the Raniganj Coalfield. Waste materials from OC coal mines are dumped in the bed of the streams (Photograph No. 3). Therefore, the natural flow of the streams is restricted and the channel becomes narrow. Materials dumped from OC mines within channel, or adjacent to the channel also causes deposition of materials in the stream beds (Photograph No. 1). Obstruction in the natural flow reduces the water availability in the lower part of the streams (Photograph No. 2).

Table 3. Nature and extent of stream degeneration within the catchment basins

Catchment basin no.	Total area (SQ. K.M.)	Stream order	Area of OC mines (SQ. K.M.)	Total length of all streams (K.M.)	Length degenerated by OC mines (K.M.)	Percentage of length degenerated
1	57.56	4	1.21	49.19	0	0%
2	10.37	3	1.42	11.65	0	0%
3	29.36	4	1.12	36.35	1.53	4.20%
4	1.82	2	0.25	4.07	0	0%
5	11.95	4	2.45	14.64	3.44	23.48%
6	4.20	2	0.90	6.04	6.04	100.00%
7	0.10	1	0.09	0.46	0.46	100%
8	0.07	1	0.07	0.49	0.47	97.14%
9	0.58	2	0.43	1.60	1.60	100.00%
10	0.22	1	0.2	0.97	0.92	94.05%
11	9.95	3	1.73	17.95	2.80	15.59%
12	10.89	3	1.35	13.90	13.90	100%
13	1.16	2	0.55	2.19	0.93	42.47%
14	33.51	3	6.81	32.22	8.37	25.98%
15	34.27	3	7.92	27.40	19.91	72.66%
16	23.88	3	1.12	20.01	13.57	67.81%
17	0.37	1	0.08	1.16	0	0%
18	0.73	1	0.17	1.38	0	0%
19	5.96	3	0.39	8.52	0	0%
20	8.32	2	1.72	8.25	0.57	6.92%
21	0.32	1	0.16	1.11	0.62	56.13%
22	7.41	2	0.37	6.68	6.57	98.33%
23	0.70	1	0.06	1.70	0	0%
24	2.45	1	0.78	3.73	3.73	100%
25	0.27	2	0.25	1.30	1.20	92.58%
26	0.44	1	0.19	1.27	0.74	58.11%
27	19.40	2	0.67	0.89	0.79	88.98%
28	0.66	1	0.06	2.05	2.05	100%

Source: SOI Topographical Sheet and Images from Google Earth

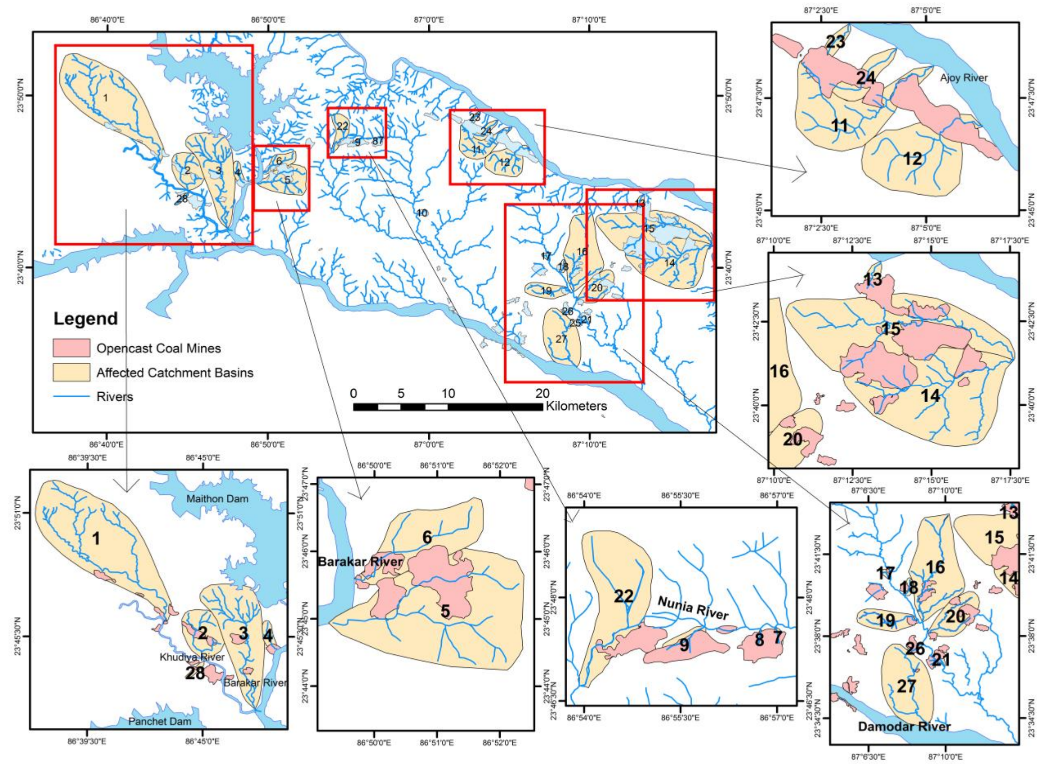

Fig. 6. Opencast coal mine affected catchment basins of the Raniganj Coalfield

Photograph No. 1: Dumping of waste materials near a bed initiates deposition of sediment in channel, Photograph No. 2: River bed becomes dried due to the obstruction of flow by opencast mines, Photograph No. 3: Dumping of waste materials in the channel

Table 4. Classification of affected catchment basins of the Raniganj Coalfield

Category	Catchment basin number	Location of the OC mine	Remarks
More than 90% degeneration	6, 7, 8, 9, 10, 12, 22, 24, 25, and 28	Near mouth along channel	The mines developed in the confluence zone of these streams, and a large part of these streams was degenerated.
More than 50% degeneration	15, 16, 21, 26, and 27	Middle portions along channel	The mines developed in the middle portions of these basins, as a result, 50% of the total catchment was degenerated.
More than 25% degeneration	In basin no. 13, and 14	Upstream Section along channel	In these basins, OC mines developed in upstream portions. In these catchment basins, OC mines have a comparatively lesser impact upon the streams.
Less than 25% degeneration	3, 5, 11, and 20	Inside of basin with minute restriction to channel	In these basins OC mines degenerated minute portions of the catchments.
Undegenerated basins	1, 2, 4, 17, 18, 19 and 23	Inside of Basin without any restriction to the channel	OC mines developed within these basins without blocking the natural flow of the streams. In basin no. 1, 2, and 4, the flow of the streams was maintained though the OC mines developed along channel. Streams within these basins were converted into artificial channels.

Expansion of OC coal mines within the Raniganj Coalfield destroys the drainage arteries. Degeneration of streams was overlooked in many cases, as these streams are small in size and dimension. However, with the degeneration of streams, the rivers of the Raniganj Coalfield are also affected. Degeneration of the tributaries reduces the water availability of the Ajoy, Damodar, Barakar, Singharan, Nuniya and Khudiya Rivers. Obstruction in flow causes water scarcity in the lower part of the streams. As the Raniganj Coalfield is a water stressed region, degeneration of these small streams further intensifies the problem. People of this region depend upon river water for their day-to -day work. Degeneration of streams not only destroys the riverine ecosystem, but also affects local people.

4. CONCLUSION

Rivers shape the majority of the surface landforms of the Earth. They also have great importance in developing and sustaining human civilization. Rivers not only provide water to human society, but also work as source of irrigation, means of transportation and replenisher of farmlands. However, unscientific utilization by humans affects river health, and creates a number of problems affecting their natural settings, and increases the intensity and magnitude of river-related hazards. Management of rivers is now a growing concern among geographers and other scientific disciplines, due to the deterioration of river health and its adverse impacts on society.

Coal mining provides the opportunity of livelihood generation, and it also helps to develop the economy of the mining areas through infrastructural development, industrial agglomeration, urbanization etc. Mining is one the most important economic activities which helps to develop the Raniganj Coalfield region. Now the OC mining method is gaining more importance than the UG method, due to its lower production cost than UG method. Thus, OC mines are increasing in area and number.

However, OC mines disrupt the drainage system of the mining site, and causes degeneration of streams. Obstruction in the channel causes water scarcity in the lower part of streams. Moreover, due to obstruction of the natural flow, during the time of high rainfall, obstruction in the flow of streams causes flooding in the adjoining areas. Thus, sustainable measures should be taken to avoid deterioration of streams, including development of OC mines in a planned way so that the impact on streams is minimum. Avoiding stream beds for mining, promoting sustainable mining measures, mapping of streams with the help of GIS techniques can be save the riverine system in the study area. Furthermore, investigations should be carried out in collaboration with the mining authorities and

Central, and State regulators to reveal the impacts of this degeneration on the affected streams, and its surrounding environments in the view of establishing opportunities for their minimization. Planned development of OC mines is necessary, and by this approach riverine ecosystems in the OC mining areas will be saved.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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