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Identifying the Impacts of Opencast Coal Mining on Rivers of Raniganj Coalfield from Remotely Sensed Data

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Abstract: *Opencast method of coal production is getting more importance nowadays in India due to less production cost and wastage. However, in the opencast method, huge amount of waste material accumulates due to the removal of overlying rock and soil layers. These materials (referred as overburden) are dumped near the mining sites. Thus, anthropogenic landforms like mine pits, spoil dumps, overburden dumps have changed the topography of mining sites. Rivers are affected by open cast mines as the alteration of topography disrupts the natural drainage system and the flow of rivers is largely affected. The objective of the present research work is to explore the impact of opencast mining of Raniganj coalfield on the rivers of the Raniganj area using geoinformatics. The study reveals that the river channels are largely affected by the dumping of mining waste on the riverbed. Thus, natural flow of the rivers is blocked. Topographic changes by opencast coal mining are further responsible for the sedimentation of nearby rivers. After the extraction is over there is no backfilling of the abandoned pits or restoration of the channels. These impacts of opencast mining on the river need urgent attention for future management.*

Keywords: *Opencast coal mining, anthropogenic landforms, channel morphology, remote sensing and GIS.*

Introduction

Coal mining is considered an important economic activity in India, as it contributes largely to the power sector. Major consumer of coal in India is thermal power sector, and in the production of steel, cement, sponge-iron, aluminum, fly-ash bricks, paper, textile, etc. In India coal is usually extracted using two types of mining methods —underground (UG) method and opencast (OC) method. In the UG method, coal is extracted by tunneling whereas, in OC mining method coal is extracted by removing the overlying rock and soil layer.

Though OC mining is more profitable it has severe environmental impacts when compared to UG mining. Landscape transformations associated with mining are among the first noticeable effects of anthropogenic pressure (Dulias, 2016). OC mines are responsible for changes in topography due to the dumping of waste materials (Chitade and Katyar, 2010). Anthropogenic landforms like dumps and landfills are formed due to extraction of coal by OC mining method (Obiadi *et al.*, 2016). The environment of OC mining sites may get seriously affected by coal mining (Bian *et al.*, 2009). Dumped materials from the OC mines are responsible for the changes in the topography and control the water and energy cycle of landscape (Pandey and Kumar, 2014). Land and water environment got seriously affected by coal mining due to the dramatic changes in the landscape (Chabukdhara and Singh, 2016). Air, water and soil quality changes due to the removal of coal overburden along with soil and vegetation within the OC mines (Baruah *et al.*, 2016).

Though OC mining is economically more profitable than underground mining, but its effect on the drainage system of the mining area is also profound. River basins that are experiencing OC mining, are subjected to contamination by pollutants due to the discharge of wastewater both from surface and subsurface sources (Czaja, 2005). Sediment carried out by the river finally settles down within the reservoir (Singh *et al.*, 2005). Topographical changes by OC mining have an important impact on the flow of water and energy within a landscape (Pandey and Kumar, 2014). Siltation of rivers is another major problem of OC coal mining due to the changes in topography. Thus, mining activities should be carried out sustainably with proper measures. To manage the impact of mining, monitoring mining-induced changes is essential. Remote Sensing is an effective tool for the assessment of mining-induced changes due to the availability of multispectral images over various periods at affordable cost (Venkataraman *et al.*, 1997).

Raniganj coalfield is the oldest coalfield in India and more than 80% of the coal produced here is by the OC method (ECL Annual Report, 2018–19), and it has significant impact on the environment of this area. Within Raniganj coalfield OC mines extend up to the riverbeds. (Lahiri-Dutt, 2001). The present study is empirical in nature and it aims to understand the specific impact of OC coal mining on the rivers of the Raniganj mining area using geoinformatics.

Objectives

The principle objectives of the present study are as follows:

- To analyse the different impacts of OC coal mining on the river system of the study area.
- To study the spatio-temporal changes in channel morphology of the rivers due to OC coal mining.
- To suggest suitable measures for the management of the problems.

Data source and methodology

The present study is based on techniques of geoinformatics, supported and verified by field observations. (Table 1).

The present study aims to understand the impact of OC coal mining on the rivers of the study area with the help of Remote Sensing and Geographical Information System (GIS). To fulfil this objective, Survey of India (SoI) Topographical sheets have been collected and georeferenced to Universal Transverse Mercator (UTM) projection with World Geodetic System (WGS 84) datum using image to image georeferencing method from Landsat 8 Images.

Georeferenced topographical sheets have been mosaicked to prepare the base map of this coalfield. SoI Topographical sheets have been used as a base map to identify the pre-mining drainage condition of the area. Rivers of the study area have been identified from the SoI topographical sheets. Existing OC coalmines have been identified from images available on Google Earth. Shapefile of OC mines have been superimposed on the river layer to analyse the impacts. Images available from Google earth of different time period have been georeferenced to analyse the impact of OC coal mining. This helped in identifying the changes in a particular area.

Table 1. Data sources

Data Source	Used as	Purpose	Year of survey/ Image acquisition date	Scale/ Spatial Resolution
SoI Topographical Sheets No. 73I/5, 73I/9, 73I/10, 73I/13, 73I/14, 73M/1, 73M/2, 73M/5, 73M/6 and 73M/7	Base map	To understand the pre-mining conditions	1971–75	R.F 1:50,000
Images available from Google Earth platform	Change detection maps	To understand the impact of OC mining on river	2003–2019	Various images are used by Google Earth and resolutions are not specifically mentioned
Tandem-X 90 DEM/ Tandem X 90 M DEM	Digital Elevation Model	To understand the changes in surface topography due to OC mining	2018	90 m

For GIS analysis purpose ArcGIS version 10.2.1 has been used. Profile of OC coal-mining sites have been extracted from the TanDEM-X 90 m Digital Elevation Model (DEM) through Spatial Analysis Tool of ArcGIS 10.2.1. Field verification has also been done to obtain a brief idea about the nature and extent of environmental degradation and for ground truth verification.

Study area

Study area is situated within the Ajoy-Damodar Interfluve Zone of Raniganj coalfield (23°32′30″N to 23°57′30″N and 86°30′50″E to 87°17′30″E), situated in Paschim Burdwan district of West Bengal and Nirsa district of Jharkhand (Fig. 1). Ajoy-Damodar interfluve zone is subjected to intense mining activities (Manna and Maiti 2016). The Raniganj coalfield is the oldest in the country. Coal mining in India first started in the Raniganj coalfield in the year 1774. It is regulated by Eastern Coalfields Limited (ECL). The study area is drained by three major rivers namely Ajoy, Damodar, and Barakar and numerous small tributaries of these three rivers. Within this interfluve zone, the main tributaries of Damodar and Ajoy river are Khudia, Singharan, Nunia (a tributary of Damodar river) and Tumuni (a tributary of Ajoy river).

Results and discussion

Opencast coal mining in Raniganj coalfield

According to the annual report of ECL (2018-19), coal production, under ECL from UG mines was only 9.06 million tonnes (18.06%), whereas, with OC mines, production was 41.10 million tonnes (81.94%) in the year FY 2018-19 (Table 2). This indicates that the OC mining method is dominating over UG method.

Table 2. Production of coal by OC and UG method under ECL (2018-19).

Mining Method	Production (Mt.)	Percentage
UG	9.06	18.06%
OC	41.10	81.94%
Total	50.16	100%

Source: ECL annual report, 2018-19

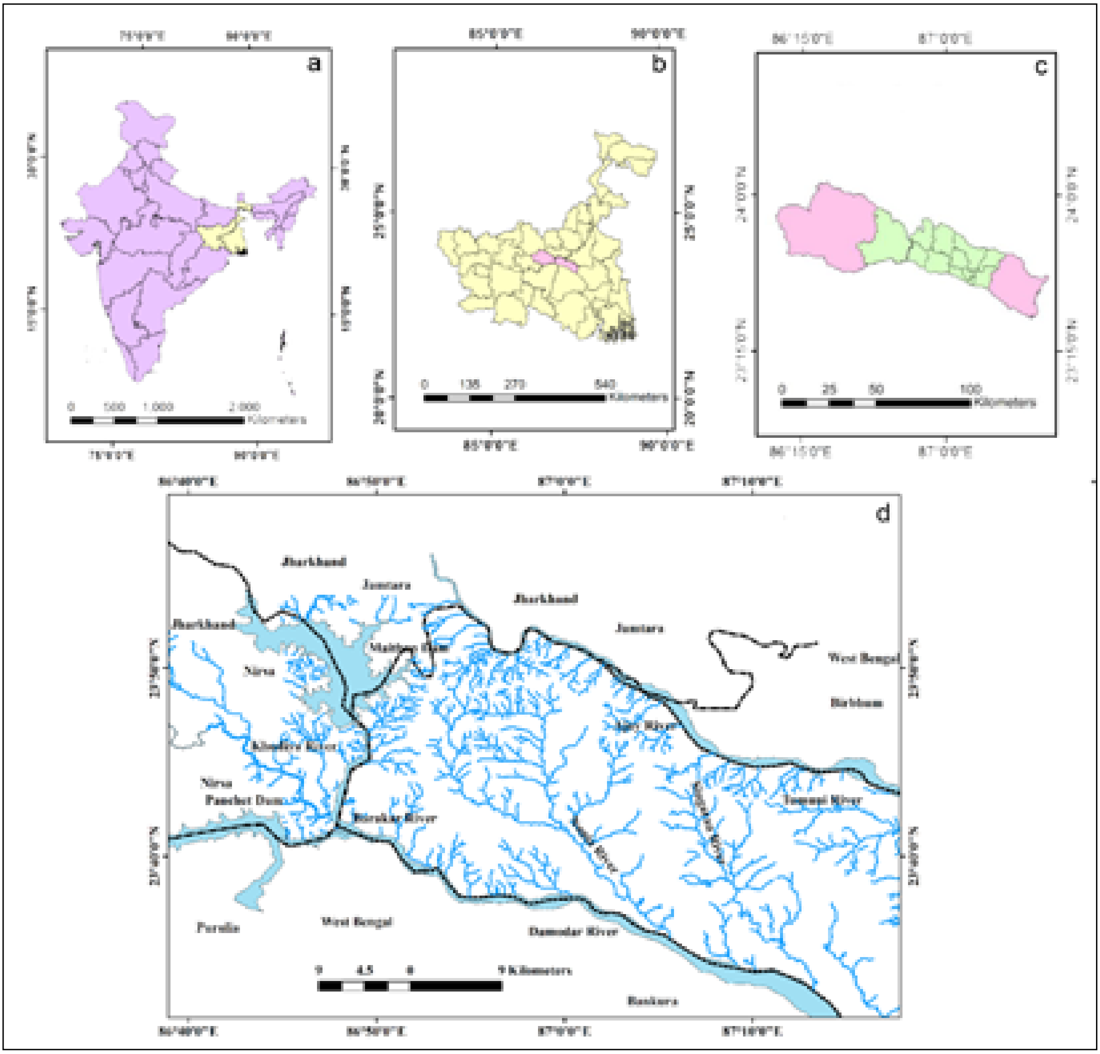

Figure 1. Location map of study area: a) Location of West Bengal and Jharkhand in India, b) Location of Dhanbad and Pashchim Bardhaman districts in West Bengal and Jharkhand, c) Location of the study area in Dhanbad and Pashchim Bardhaman districts, d) Details of the study area along with the major rivers area

It should be mentioned that most UG mines in Raniganj coalfield are operated manually, as a result of this production is very low in these mines. Lesser scope for application of modern technology leads to greater involvement of manpower within these mines. Further, the production cost is very high and most of the mines are unprofitable. Thus, UG coal production in Raniganj coalfield declined over time.

Opencast coal mining and formation of anthropogenic landforms

In the OC method of mining the overburden materials, which consist of topsoil, boulders and other overlying materials are removed to extract the coal deposit. These overburden materials are dumped at places near the mining site. In Raniganj coalfield OC mines are responsible for the change of topography and formation of anthropogenic landforms

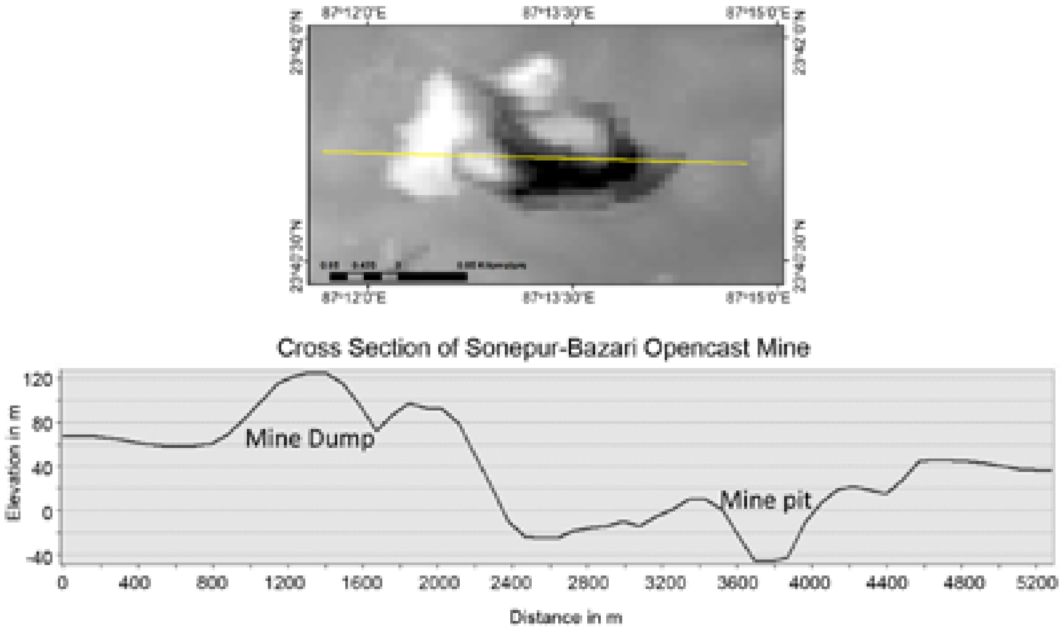

Figure 2. Representation of Sonepur-Bazari OC mine, where, anthropogenic landforms like mine pit and mine dump are formed and topography has been changed due to OC mining. (Source: TanDEM-X 90 Metre Digital Elevation Model)

like mine pits, overburden dumps etc. Further, most of the abandoned mine pits and mine dumps are left without backfilling. Thus, Raniagnj coalfield is subjected to a drastic change of landscape due to OC Coal mining (Fig. 2).

Mine pits are formed due to the extraction of coal and other overlying materials. After the extraction is over backfilling of mine pits is necessary (Central Pollution Control Board, 2011). However, due absence of backfilling mine pits are gradually filled with rainwater or groundwater and becomes pit lake. Dumping of overlying materials like boulders, rock, soil and other surface materials leads to the development of mine dumps. Dumping is generally done near the mine pits to reduce transportation cost. Mine dumps are subjected to erosion by rainfall and many rills and gullies develop over them.

Impact of opencast coal mining on rivers of Raniganj coalfield

OC mining method is responsible for the changes in topography and leads to the development of anthropogenic landforms. Formation of anthropogenic landforms drastically changes the altitude, slope and associated geomorphic settings of the landscape. Change in the geomorphic setting by the OC coal mining affected the direction and amount of flow of water over the landscape. The various forms of impact of OC mining over the rivers of the study area are discussed below-

Dumping within the river bed

Dumping of materials within channel also causes the inflow of extra-fluvial sediments within the river. In most cases, these sediments are large boulders, which are beyond the competence limit of the rivers (Plate 1C). Thus, the natural flow of the rivers is restricted or diverted from their original course. Materials dumped from OC mines within channel, or adjacent to the channel causes deposition of materials within the riverbeds (Plate No. 1A and 1B). Dumping of waste materials from the OC mines changes the channel pattern and channel morphology of the rivers. Obstruction in the natural flow further reduces the water availability of the rivers.

Reduction of the width of the rivers

The width of the rivers is reduced due to the dumping of waste materials within the channel from the OC mines. Dumping of waste materials within the channel reduced the channel width. During the time of the field survey, it is seen that mine dumps developed adjacent to the channel or within the channel. Dumping of waste materials within the bed of the river reduced the width as well as the water holding capacity of the channel.

Deformation of channel by mine pit

Channel deformation due to OC mining is also widespread throughout the Raniganj coalfield. Formation of mine pit along the channel causes the deformation of channel. Formation of mine pit increase the depth and width of the channel. As a result of this, surface flow of the rivers is affected by OC mine pit and makes the river flow misfit for the channel (Fig. 6). After the extraction is over, the mine pit forms a lake. In Raniganj coalfield after the extraction is over most of the OC mines are left without backfilling. Thus, mine pits are affecting the drainage basins for longer duration.

Impact of OC mining on different rivers of Raniganj coalfield

Impact on Damodar river

Damodar river originates near Kamarpet hills of Palamou region of Chotanagpur plateau and flows through the state of Jharkhand and West Bengal. (Mukhopadhyaya and Das, 2010). Total length of the river is 540 km and the area of the River basin is 21,500 Km^2. (Rudra, 2004). In Raniganj the southern part of the coalfield is drained by the Damodar river.

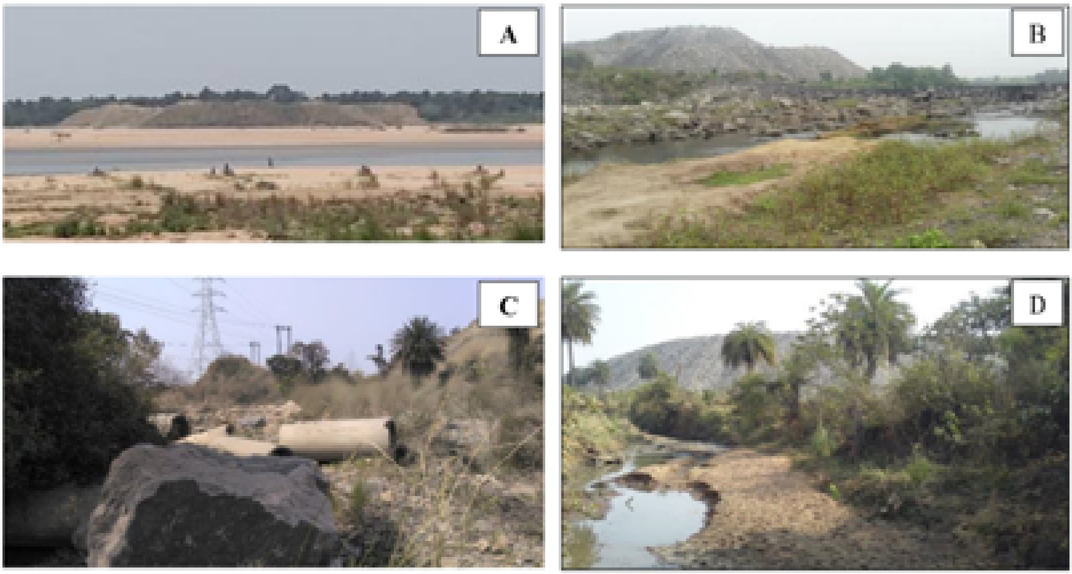

Plate 1. A) Dumping of waste materials at the bed of Damodar river, B) Dumping of waste materials at the bed of Khudiya river, C) Pipes and boulders are dumped along the channel of Tumuni river, D) Formation of point bar at Tumuni river.

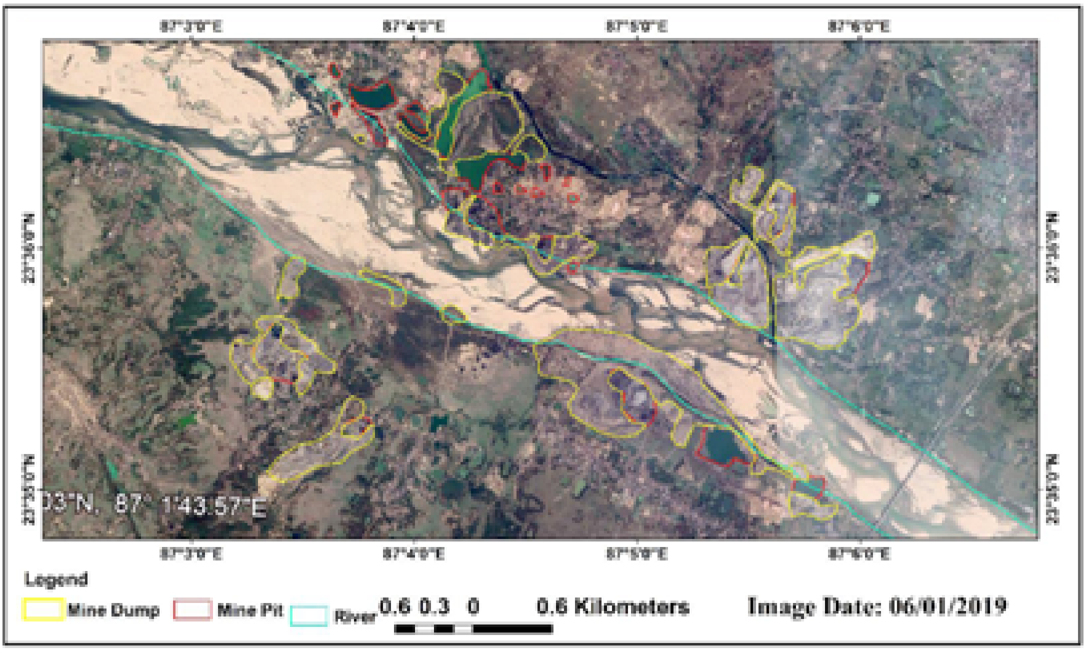

Figure 3. Impact of OC mining on channel of Damodar river (Source: Image available from Google Earth).

Major parts of the Damodar river channel are severely affected by the OC mining. A number of OC mines dumped their waste materials along the bed of Damodar river. As a result of this Damodar riverbed is encroached by the dumped materials of these OC mines. Dumping within the bed have resulted deposition of materials within the bed of the river. Damalia and Narankuri OC mines have dumped their overburdens along the bed of Damodar river. Thus, eroded materials of the mine dump causes sedimentation within the riverbed. Dumping also causes the alteration of the morphology of the bed and bank of the river (Plate 1A and B).

It should be mentioned that informal mining is also carried out at the bed of the Damodar river which resulted the distortion of the riverbed and channel (Fig. 3). Informal mines are developed without maintaining any of the environmental guidelines. As a result of this pollution is widespread from the informal OC mines developed along the riverbed. Mine pits developed along the riverbed extract the bed materials of the river and left permanent scars on the bed. As these informal mines are operated only for exploitation of coal resource, therefore there is no liability for restoration of riverbed after the mining is over.

Data collection about informal mining has been a difficult task during the time of the field survey. People of the informal mining areas were not ready to provide answers to the questionnaire survey due to security reasons. People also suspect that providing the answer to the questionnaire may expose the informal mining to the local administration and they may lose their earning opportunities. Informal mining can be classified into four main types — informal mining in closed or abandoned OC mines, informal mining in active OC mines, collection of coal within the haul roads and informal mining through illegal OC mines. However, during questionnaire survey it is very difficult to differentiate the different informal OC mines.

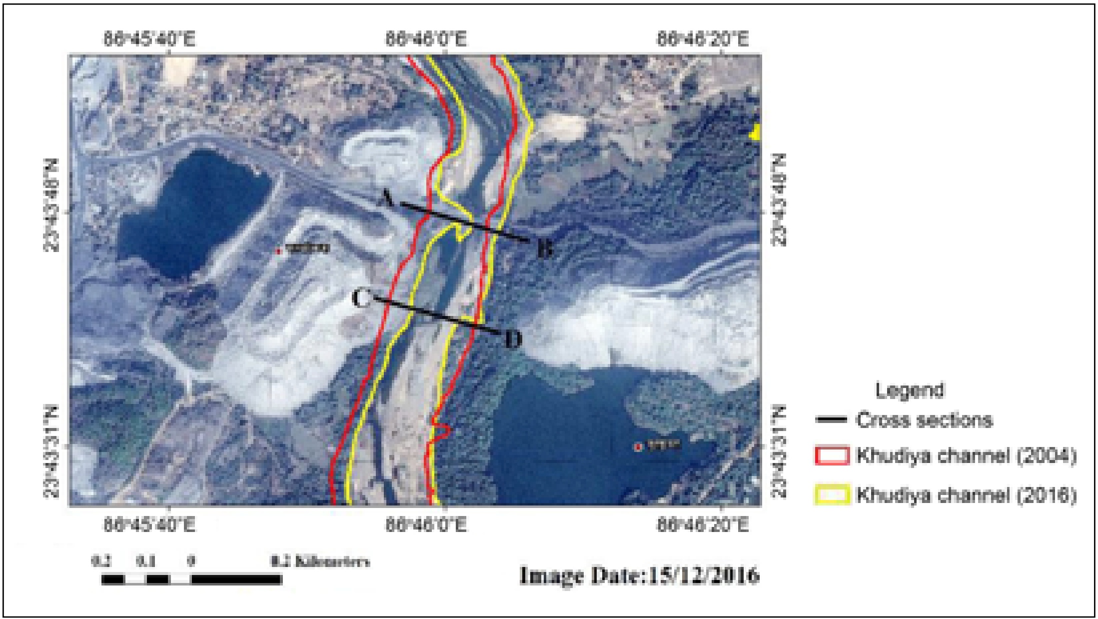

Figure 4. Reduction of the width of the Khudiya river channel due to the dumping of waste materials from the Basantimata OC mine (Source: Image available from Google Earth).

Impact on Khudiya river

Khudiya is a tributary of Barakar river. Khudia river drains a major part of the Raniganj coalfield. Khudiya river is also significantly affected by OC mining. Basantimata OC mine dumped its waste materials on the Khudiya riverbed (Fig. 4). As a result of dumping, the channel width has been reduced and the riverbed contains substantial amount of extra-fluvial sediment (Plate 1B).

From Fig. 4 it is seen that Khudiya river has been affected due to the road construction along the channel for the transportation of coal. Along the A-B cross-section, width of the channel of Khudiya river has been reduced from 130.04 m in 2004 to 67.05 m in 2016. A similar trend can be observed along C-D cross-section, where the width was 184.15 m in 2004 and it decreased to 101.04 m in 2016 (Table 3).

Channels of the Khudiya and Pusai rivers are also affected by OC mining. Dumping and extraction of coal from the riverbed resulted in the deformation of channel in major part of the rivers.

Impact on Nunia river

Nunia is a tributary of Damodar river. Total length of the river is 40.81 km and the basin area is 321.253 km^2. It joins the river Damodar near New Egara and Damalia village of Raniganj block. Garui river is a major tributary of Nunia river.

Table 3. Reduction of the width of the Khudiya river channel due to the dumping of waste materials from the Basantimata OC mine (based on Fig. 4)

Cross-Sections	Width of Khudiya river in 2004 in m	Width of Khudiya river in 2016 in m
A-B	130.04	67.05
C-D	184.15	101.04

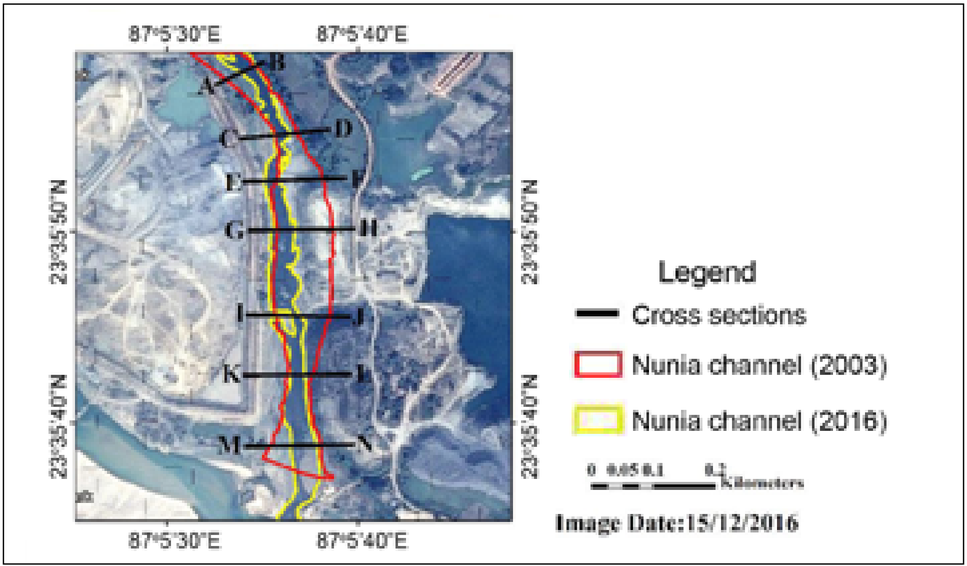

Figure 5. Reduction of the width of the Nunia river channel due to the dumping of waste materials from the Damalia and Narainkuri OC mines (Source: Image available from Google Earth).

Nunia river channel is also affected by OC mining as the dumping of boulder, topsoil and other waste materials narrowed the channel and affected the natural flow of the river (Fig. 5). Reduction of the width of the Nunia river has been measured from the historical Imagery tool of Google Earth and represented in Fig. 5. It is seen that dumping along the channel of Nunia river reduced the width of the river from 82 m in 2003 to 39.61 m in 2016 along the cross section G-H. Likewise width of the Nunia river has been reduced from 76.45 m in 2003 to 21.55 m in 2016 along the cross section E-F (Table 4). Dumping within the riverbed also forced the river to change its path.

Impact on Singharan river

Singharan river is another tributary of Damodar river (Fig. 1). Total length of the river is 33.07 km and the basin area is 145.73 km^2. From Fig. 6 it is seen that within Singharan river channel, abandoned mine pit formed due to the extraction of coal by OC method (Fig. 6). Formation of mine pit along the channel is responsible for the change of channel morphology of Singharan river and subsequent deformation of the channel.

Table 4. Reduction of the width of the Nunia river channel due to the dumping of waste materials from the Damalia and Narainkuri OC mine (based on Fig. 5).

Cross Section	Width of Nunia river in 2003 in m	Width of Nunia river in 2016 in m
A - B	47.82	24.00
C – D	35.91	19.00
E – F	76.45	21.55
G – H	82.12	39.61
I – J	77.15	49.02
K – L	36.07	21.44
M – N	78.90	40.19

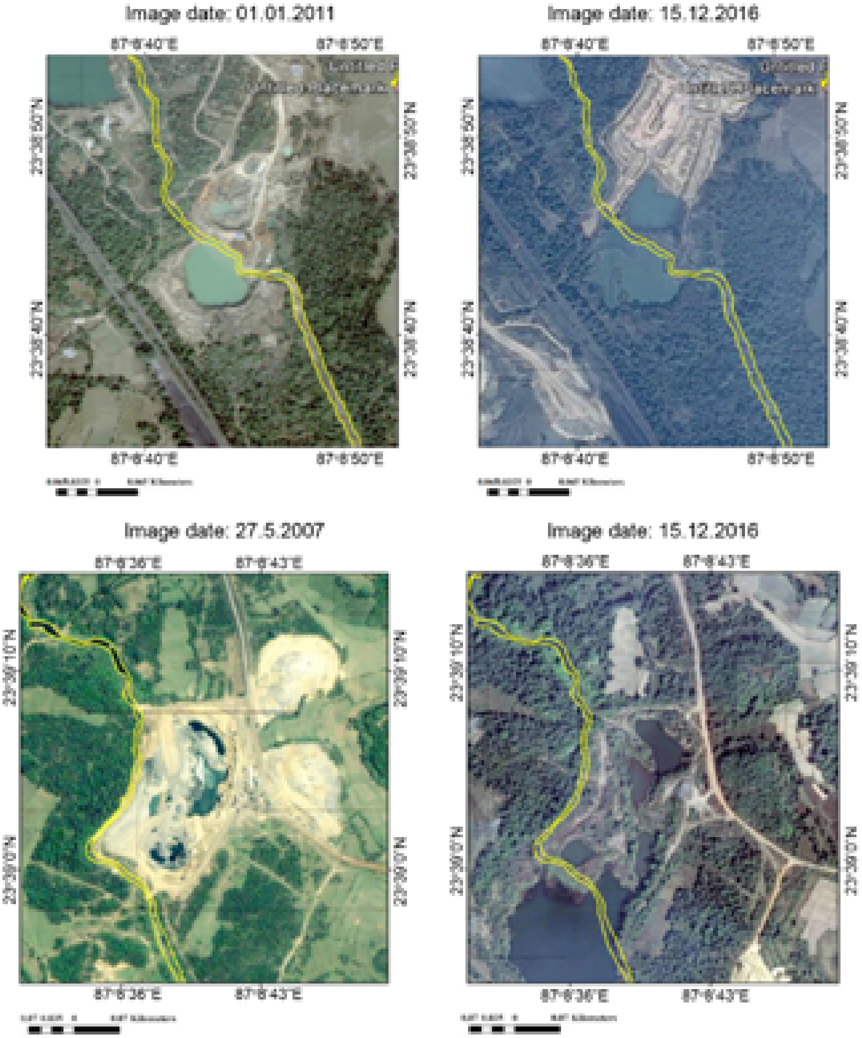

Figure 6. Changes in Singharan river channel at two sites affected by the mine pit formed due to OC mining (Source: Image available from Google Earth).

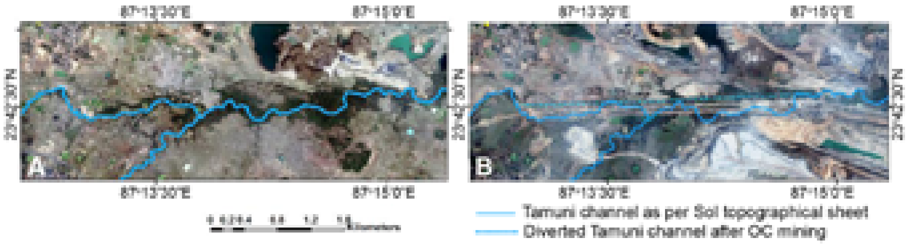

Figure 7. Large part of Tumuni river is divertate to facilate the extraction of coal by OC method. A) The Tamuni river channel prior to the development of OC mine; B) Tamuni river channel diverted after the development of mine. (Source: SoI Topographical Sheets (1971-75) and Image available from Google Earth).

After the extraction was over the topography and configuration of the channel were not restored. As a result the deformation of the channel by mining had a long-term impact.

From the historical imagery tool of Google Earth it is seen that dumping within the riverbed is responsible for the changes in channel configuration of Singharan river. Flow of the Singharan river channel is largely altered due to the dumping of waste material. Dumping along the channel is responsible for restriction of the natural flow of the river.

Impact on Tumuni river

Tumuni river is a tributary of Ajoy river. Total length of the river is 41.08 km and the basin area is 166.05 km^2. Large part of the Tumuni channel is also destroyed by OC mining. Upper part of the river is degenerated due to the formation of OC mines. As a result of this lower part of the river is suffering from water scarcity (Fig. 7). A large part of the river is also diverted to extract coal by OC method (Fig. 7).

Channel of Tumuni river is affected by the mine dumps from Mahalaxmi OC mine. Here, dumped materials contained numerous large boulders, pipes etc. (Plate 1C). Extra-fluvial sediment restricted the flow of the river and changed the path of the river. Boulders having more than 2 m diameter are seen within the bed of the river (Plate 1C). A number of mid-channel bars are also formed within the riverbed due to the deposition of waste materials (Plate 1D).

Environmental compliance reports regarding the impact of OC mining and the condition of the river systems

Environmental compliance reports are published by the mining authorities and submitted to the Central Pollution Control Board (CPCB). These include specific directives to protect the riverine system. During the time of field survey it was seen that most of the conditions were not followed in majority of the mines (Table 5).

To manage the impact of OC mining on the rivers, protective measures should be taken according to the environment compliance reports (Table 5). Such measures include the construction of sediment-walls to stop the inflow of sediments into the nearby rivers, construction of catchment walls to entrap the sediments coming from mine dumps etc. Usually, these catchment-drains discharge the sediments into sediments ponds. Garland drains and retaining walls are other measures

Table 5. Excerpts from the environmental compliance directives and the actual field observation

Compliance	Field Observation
There shall be no overflow of overburden into the river and into the agricultural fields and massive plantation of native species shall be taken up in the area between the river and the mining project.	Overburden materials are left within the channel and agricultural fields. There is no space for plantation along the river and mine.
Catchment-drains and siltation ponds of appropriate size shall be constructed to arrest silt and sediment flows from soil, overburden and mineral dumps. The drains shall be regularly desilted and maintained properly.	Catchment-drains and siltation ponds are absent along the rivers. Catchment-drains and sediment ponds are finally discharging onto the rivers. Artificial drains are constructed only to discharge of wastewater.
Dimension of retaining wall at the toe of the dumps and overburden benches within the mine to check runoff and siltation shall be based on rainfall data	There is no retaining wall at the toe of the overburden dumps to check the runoff and siltation
River/ nallahs shall be desilted and restored back to functional state	River and nallahs are not desilted and monitoring of siltation of rivers are also absent. In many places boulder, coal borne dusts are left within the riverbed.

that are used to entrap the sediment. However, within Raniganj coalfield these types of measures are completely absent in majority of the OC mines. OC mines that have developed beside the rivers or adjacent to the rivers are least concerned with the sedimentation of the rivers. During field surveys, it was seen that protective measures like sediment-walls, catchment-drains, or garland drains are completely absent near the rivers in the majority of the OC mines. Thus, rivers are suffering from the problem of sedimentation from the OC mines. This kind of situation has been observed near Damalia and Narankuri OC mine both of which are situated near the confluence of Nunia and Damodar rivers. Here the absence of sediment walls, catchment drains, etc. cause sedimentation within Nunia and Damodar rivers. In the Basantimata OC mine, protective measures are absent beside the Khudiya river. Protective measures are also absent for Bermor OC mine, situated beside Barakar river, or between Mahalaxmi OC mine and Tumuni river. OC mines that are situated beside small streams are not concerned about sedimentation. The absence of protective measures to prevent sedimentation is degrading the small streams. There is also a lack of monitoring and assessment by the Pollution Control board regarding the impact of OC mining on rivers and violation of the guidelines mentioned in the reports. Discharge of wastewater into the rivers has direct impact on the water quality of the rivers.

Conclusion

Raniganj coalfield is a leading industrial region of the country and has experienced significant population growth and urbanisation. Mining is responsible for the destruction of drainage lines in the vicinity of Raniganj coalfield. Coal mining by OC method in the study area creates various anthropogenic landforms like mine pits spoil dumps and others, which degenerates or blocks a number of rivers. Lower reach of the rivers suffer from water scarcity due to the reduction in runoff by OC coalmines. Tributaries of Ajoy and Damodar are blocked by spoil dump from OC mines. Sedimentation from the unconsolidated mine dump changes the channel morphology as well as reduces the channel capacity. Thus, during flood, the flow of these rivers is unable to drain through the degenerated channel and causes inundation in the surrounding area. Destruction of drainage lines within this coalfield can cause future water scarcity.

To prevent the sedimentation of the nearby rivers and other major water bodies due to dumping of mine-waste from OC mining the following protective measures should be taken:

- Demarcation of the riverbed with the help of satellite images to identify the stretches where the impact of OC mining on the river is most likely.
- Riverbed should be avoided for dumping.
- Restoration of the degraded drainage system of the area.
- Use of underground mining method to extract the coal that lies below the drainage lines.
- Desiltation and removal of waste material from the riverbeds that are affected by mine dumps.
- Proper monitoring of the drainage lines should be done on a regular basis.
- Construction of sediment walls to stop the inflow of sediments into the nearby rivers and construction of catchment drains to entrap the sediments coming from mine dumps.

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