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RESEARCH ARTICLE

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Opencast Coal Mining Induced Defaced Topography of Raniganj Coalfield in India - Remote Sensing and GIS Based Analysis

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Abstract With the advent of mining activities at Raniganj coalfield in India, the natural topography has been defaced in some elongated tracts by either excavation or dumping. This paper deals with opencast mining induced defaced topography of Raniganj coalfield, which needs to be reclaimed properly right after mining. This paper investigated intensity of defacing topography, magnitude of topographic deformations through a number of ex-situ measurement. Consequences of these topographic deformations are also investigated in this study. Through a number of ex-situ measurement based on Geographical Information System (GIS) techniques, generating contour and profiling them over the spoil dumps and excavated lows using fine resolution digital elevation data (Remote Sensing image), a total 132 (85 are abandoned and 47 are working) patches of defaced topography have been identified, which covers 43.26 sq km. surface area. Some working opencast quarries are more than 95 m deep, with an area of more than 2.4 sq km and dumped ridges are more than 60 m high (peak), with area more than 1.5 sq km. In case of abandoned mine (more than 20 years) some quarries are more than 28 m deep with area 0.99 sq km. and some of dumped ridges are more than 28 m high (peak), with area 0.29 sq km. These kinds of defaced surface remain for a long time, such quarries contain acidic logged water and spoil dump leads to acid mine drainage and erosion of loose soil particle. It deteriorates the entire land, water system of the region. The study suggests restoring land right after mining and the area made to be ecologically conformable.

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Introduction

Coal contributes 66 % of India's energy production. Raniganj coalfield produced 20.72 % of India's total coal production in 2010 (www.coal.nic.in). In India 60 % of the total mineral production is from opencast mines. In Raniganj coalfield most of coal (76.07 %) production by Eastern Coalfield Limited (ECL) a subsidiary of Coal India Limited (CIL), are done by opencast mining method and rest (23.93 %) are from underground method in 2010–2011 (Annual Report 2010–2011, ECL). In Raniganj coalfield 23 opencast mines are operating under ECL and 3 under Bharat Coking Coal Limited (BCCL) and Indian Iron and Steel Company (IISCO) as on 01.04.2012 (http://www.easterncoal.gov.in). Shallow coal seams are mined through opencast method. Opencast quarry is related to excavation and removal of overburden rock and surface soil layers. Destruction of land is the most direct and unavoidable consequence in opencast mining. In Raniganj coalfield every one million tonne coal production through opencast mining removes 2.54 Million Cubic metre overburden at ECL's command area (Annual Report 2011–2012, ECL). Ghosh (1990) stated that every one million tonne of coal extracted in India by surface mining methods damages a surface area of about 0.04 km^2. In comparison to underground coal mining, opencast coal mining gets the advantages of full scale mechanization, particularly high output per man-shift, low unit cost etc. Increasing demand of coal and technical improvement helps opencast method to get those previously mentioned advantages. Opencast mine also begins production much earlier than an underground mine (Melnikov and Chesnokov 1969). As Raniganj coalfield has an experience of mining for more than two centuries, it has adopted the opencast mining method very earlier over the outcrop tracts of coal bearing geologic formation. Opencast mining is increasing extensively after nationalization of Indian coal mines in 1972–1973. Deformation of natural topography (landscape) is continuing since long past and is increasing year after year. The terrain covering Raniganj coalfield is more or less flat to gently undulating (Dutta and Dutta 2003), varying between 60 m (at the easternmost part) to 160 m (at the western most part) along with some hillocks (maximum landmark 643 m) at south western part (Based on Survey of India toposheet, 1975–76). Along the outcrop of coal bearing Barakar and Raniganj Formations, a series of elongated quarries and spoil dump ridges are still threatening natural topography.

Some earlier works have been done by different authors. Surface erosion and sediment control at opencast mines in Southern Africa have been studied by Ward et al. (1984). Mine spoil characteristics of the dump area and deterioration in soil properties of Raniganj coalfield, India have been studied by Shadhu et al. (2012). Soil layer extracted by opencast quarry in relation to coal production has been studied by Ghosh (1990). Open cast excavation of coal deposits involves the removal of overlying soil and rock debris and their storage in overburden dumps change the natural land topography, affect the drainage system and prevent natural succession of plant growth (Bradshaw and Chadwick 1980; Wali 1987; De and Mitra 2002). Mining operations degrade significant areas of land and replace existing ecosystem with undesirable waste materials in the form of mine spoil dumps (Singh et al. 2007). Landscape alteration by opencast quarry has been assessed through visual impact evaluation by Dentoni and Massacci (2007). Taylor et al. (2009) analysed hydrologic response of loose dumped mine soil through runoff Curve Number. Landforms associated with or induced by coal seam fires also studied by Kuenzer and Stracher (2012). Kainthola et al. (2011) studied stability of overburden coalmine dump through analysing optimum dump angle. Other various effects of mining were noticed by Ghose (1996); Dutta and Agrawal (2002); Banerjee et al. (2004); Singh and Singh (2006); Ekka and Behera (2011). Necessity of land rehabilitation for mine waste area has been assessed by Niroula and Thapa (2005); Otte and Jacob (2008). Chen and Li (2009) have tried to reshape the mined out surface by a land levelling project to permit the efficient application of irrigation water to provide adequate surface drainage without causing erosion or water logging. Most of the earlier works have concentrated on the environmental impact and the biological restoration or reclamation of abandoned opencast mine. But little works has been done on impact of opencast coal mining on regional topography and magnitude of topographic deformation that the authors tried to put emphasis upon.

Study Area

Damodar-Koel valley is one of important coal deposit tracts in India. Raniganj coalfield is the easternmost member of Damodar-Koel valley's coalfield. Raniganj coalfield is bounded by the latitudes 23°22′ to 23°52′N and longitudes 86°36′ to 87°30′E. Geographically major portion of Raniganj coalfield is sandwiched between Ajoy and Damodar River and small portions lie at north of Ajoy River, south of Damodar River and west of Barakar River (Fig. 1). The Raniganj coalfield spreads over 1900 km^2 in the state of West Bengal and Jharkhand. In West Bengal, the coalfield covers part of Bardhaman district with the northern, southern and south-western fringe area falling in the districts of Birbhum, Bankura and Purulia respectively. In Jharkhand, western part of the coalfield located in Dhanbad and Santal Pargana districts. More than 90 % area of Raniganj coalfield is mined by ECL, a subsidiary of CIL. Only a small area is mined by BCCL, also a subsidiary of CIL and IISCO.

A specific studies have been conducted for some abandoned opencast quarries and spoil dumped ridges (extended between 23°46′ to 23°48′N and 86°41′ to 86°43′E), within Mugma mine area under ECL, at Nirsa block of Dhanbad district in Jharkhand. The other area under study consists of working quarries and dumped ridges (extended between 23°40′30″ to 23°42′N and 87°12′ to 87°15′30″E), is Sonepur Bazari opencast project at Sonepur Bazari mine area under ECL, at Pandabeswar block of Burdwan District in West Bengal.

Geology of Raniganj coalfield mainly consists of five rock formations. Coal seams are located in the Raniganj and Barakar rock formation and opencast mining operating over the exposure of these two rock formation (Fig. 1d). Complete stratigraphic succession of rock strata is as follows (Table 1).

Materials and Methods

Nature of earlier unaltered topography is studied from numbers of earlier topographic map (US-AMS Topographic Maps NF-45-2 and 3, with scale 1: 250000, 1955) and Survey Of India Toposheets (73I/9, I/10, I/13, I/14, 73 M/1, M/2, M/5, M/6 with scale 1: 50000, 1975–76). The earlier coal quarry marks are also identified from those topographic maps and are

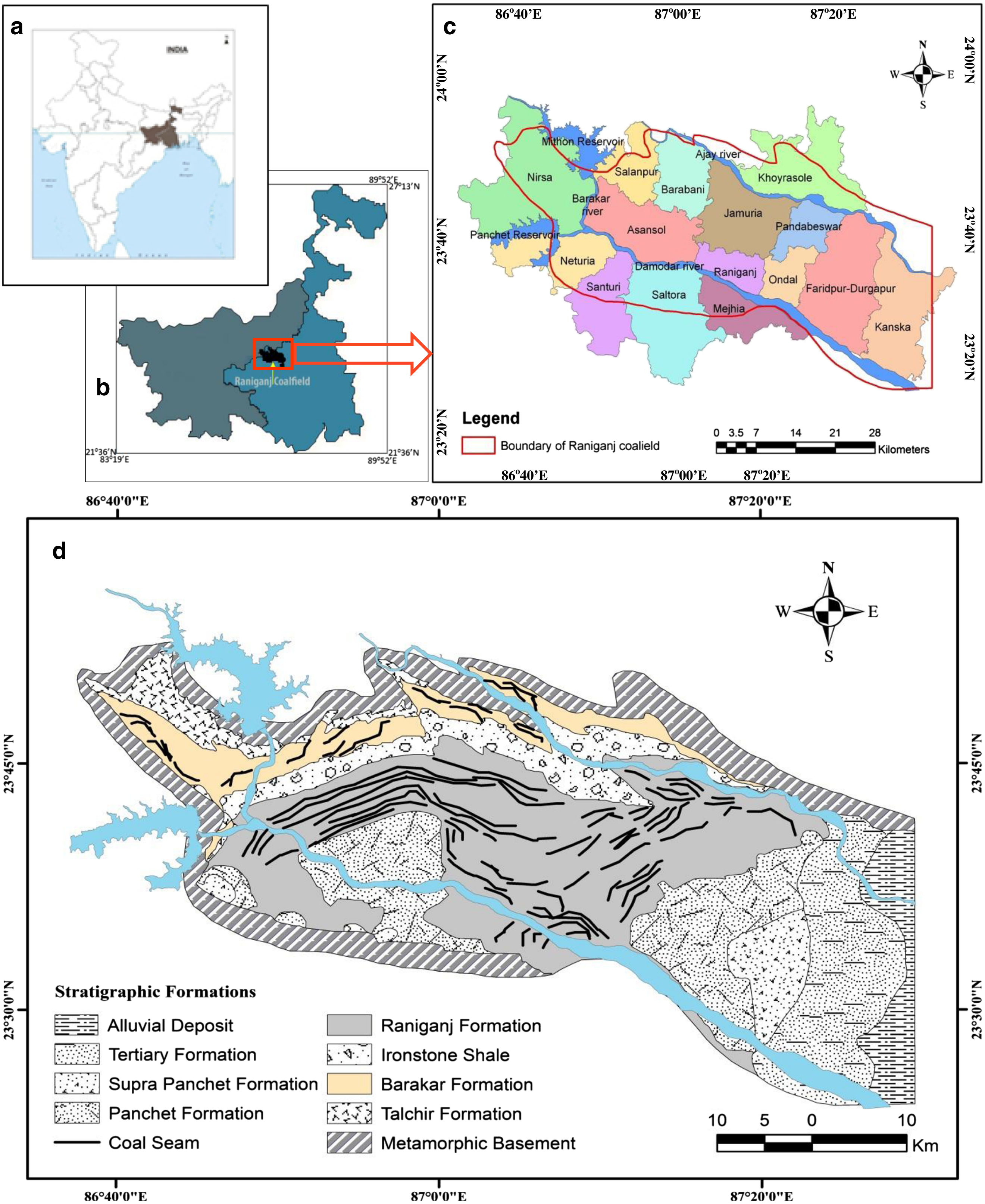

Fig. 1 Location of Raniganj coal field (**a** India, **b** West Bengal and Jharkhand, **c** Raniganj coalfield over Blocks of West Bengal and Jharkhand, **d**. Geology and coal seam of Raniganj coalfield, *Source*: GSI, Kolkata)

Table 1 Geologic formation of Raniganj coalfield (Dutta and Dutta 2003)

Geologic time	Staratigraphic rock series		Constituent rocks	Max. thickness
Upper Gondwanas	Supra Panchet		Sequence of coarse grained, ferrugineous sandstone (with rounded sub-round pebbles of quartzite and quartz) and red shale/claystone.	1000 ft
	Panchet		Green and yellowish brown sediments-mudstone, micaceous sandstones and red clays.	2000 ft
Lower Gondwanas	Damuda Series	Raniganj measures	Coal bearing formation, sequence of sandstone (fine grain size and uniform), shales and coal seams.	3400 ft
		Barren measures	Dark grey to black Ironstone shales (including carbonaceous shales).	1200 ft
		Barakar measures	Coal bearing formation, arkose and quartzo-feldspathic sandstone with variable grain size, lower part represented by boulder or pebble content conglomerate.	2100 ft
	Talchir Series		Alteration of sandstone and shale	900 ft
	Large Unconformities			

verified with data available from ECL. To identify and locate the abandoned and working quarries and spoil dumped ridges, SOI Toposheets (1: 50000 scale, 1975–76), multiband Landsat TM image of 1990, 2000, 2005 and 2010, multi-temporal Google Earth image from 2003 to 2012 and landuse of Raniganj coalfield reported to ECL by Central Mine Planning and Design Institute Ltd. (CMPDI), a subsidiary of Coal India Ltd. have been used. Temporal changes in excavated surface area of a working mine have been demarcated by multi-temporal Landsat TM image analysis. Geological map from Geological Survey of India, have also been used to project the quarried area over outcrop of coal bearing rock formation.

To analyze the magnitude of present defaced topography, satellite based Digital Elevation data, co-registered Ortho-image (Carto-DEM, 2008) available at 1 arc-sec. i.e. 30 m of resolution have been used (source, http://www.nrsc.gov.in). This image is able to give elevation information of each pixel in Arc GIS software. A series of ex-situ measurements have been performed to quantify topographic deformations in GIS platform. Surface topography is represented by contouring (4 m interval) from digital elevation image using surface analysis technique in GIS Spatial Analyst tools with the help of Arc GIS 9.3.1 software. Surface profiles of dump ridges and quarries from such contour are represented by interpolation method using interpolate line of 3D Analyst GIS tools in Arc GIS 9.3.1 software. Areas covered by spoil dumped ridges and quarries are calculated through GIS technique (polygon vector layer on UTM projection) from Remote Sensing data.

To estimate volumetric balance between positive deformation (spoil dump) and negative deformation (quarries) it is necessary to calculate the volume of excavations and spoil dumps. The Grid Method (also known as the Borrow Pit Method) is used by applying 100 square metre grid over the excavations and spoil dumps in both the case study area.

Volumes are calculated using following equation.

$$V = ((D_1 + D_2 + D_3 + D_4 + D_n)/n)^*A)$$

Where,

V volume (cubic metre)
A area (calculating from grid square metre)
D depth of cut/height of dump (metre) in a grid.

Field investigations have also been conducted for ground verification.

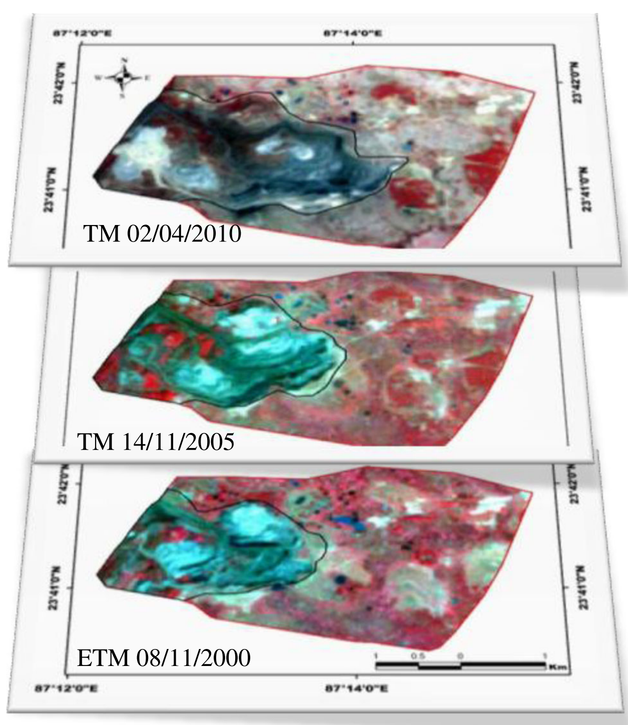

Fig. 2 Temporal increase of defaced topography at Sonepur Bazari Opencast Mine area

Result and Discussion

Case Study1: Status of Working Opencast Mine Topography at Sonepur Bazari

Sonepur Bazari opencast mining project started its operation in 1995, located at the Eastern part of the coalfield. It has been defacing topography since 1995 by generating spoil dumps, quarries and other typical features like topsoil stockpiles, bare topsoil areas, steep outslopes, ramps, haul roads etc. This large scale mining lease boundary is of 12.06 km^2 and already defaced 5.03 km^2 by 2010 (Fig. 2). Local topographic datum is considered at 48 m based on Cartosat satellite DEM image on WGS-84 datum with UTM projection. Sonepur Bazari Area presently contains two large spoil dumps; one is featured by 113 m peak height, 900 m horizontal expansion and 65 m net height with steep side wall (Fig. 3, Profile 1). It covers footprint area of 0.63 km^2 and contains 12250025 cubic metres volume. The another featured by 108 m peak height, 1600 m horizontal expansion and 60 m net height with steep side wall (Fig. 3, Profile 3). It covers footprint area of 1.98 km^2 and contains 57216000 cubic metres volume. The active quarry is characterised by 96 m net depth and more than 1800 m horizontal expansion with steep side wall (Fig. 3, Profile 2). It covers a footprint area of 2.4 km^2 and contains 94944000 cubic metres volume. Volume of the negative topography (excavation) is more than the volume of positive topography (two spoil dump together).

Case Study 2: Present Status of Abandoned Opencast Mine Topography at Mugma Mine area

Considering 86 m as local topographic datum based on Cartosat DEM satellite image on WGS-84 datum with UTM projection, Mugma mine area contains numerous abandoned opencast mine (abandoned more than 20 years) located at the Western part of the coalfield. An abandoned quarry zone (quarry zone 1 in Fig. 4, operation closed in 1991–1992) is featured by eroding spoil dump with 114 m peak height and 600 m horizontal expansion with 28 m net height (Fig. 4, Profile 1). It covers footprint area of 0.19 km^2 and contains

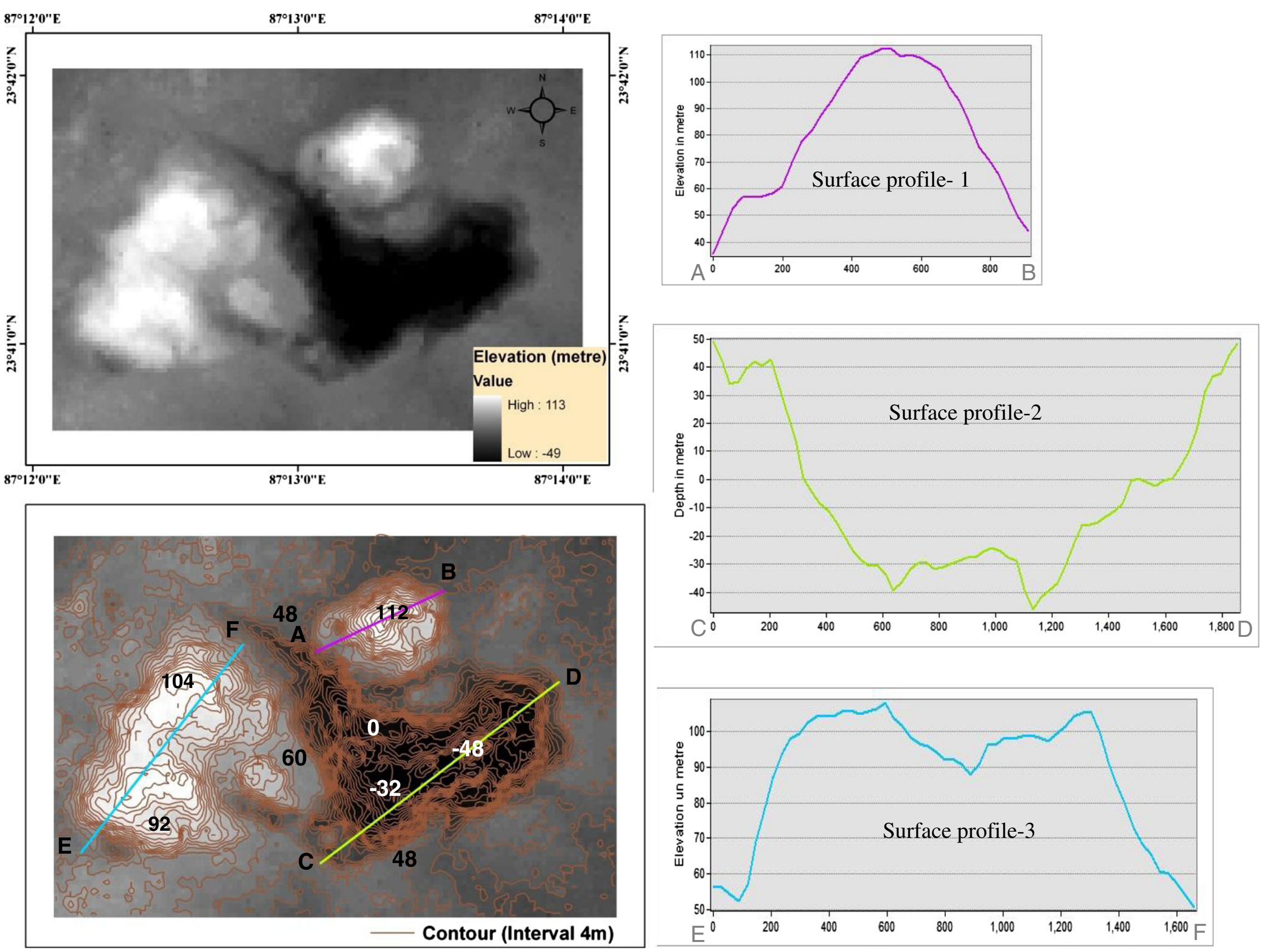

Fig. 3 Cartosat DEM image of Sonepur Bazari opencast mine (working) with contour and surface profiles

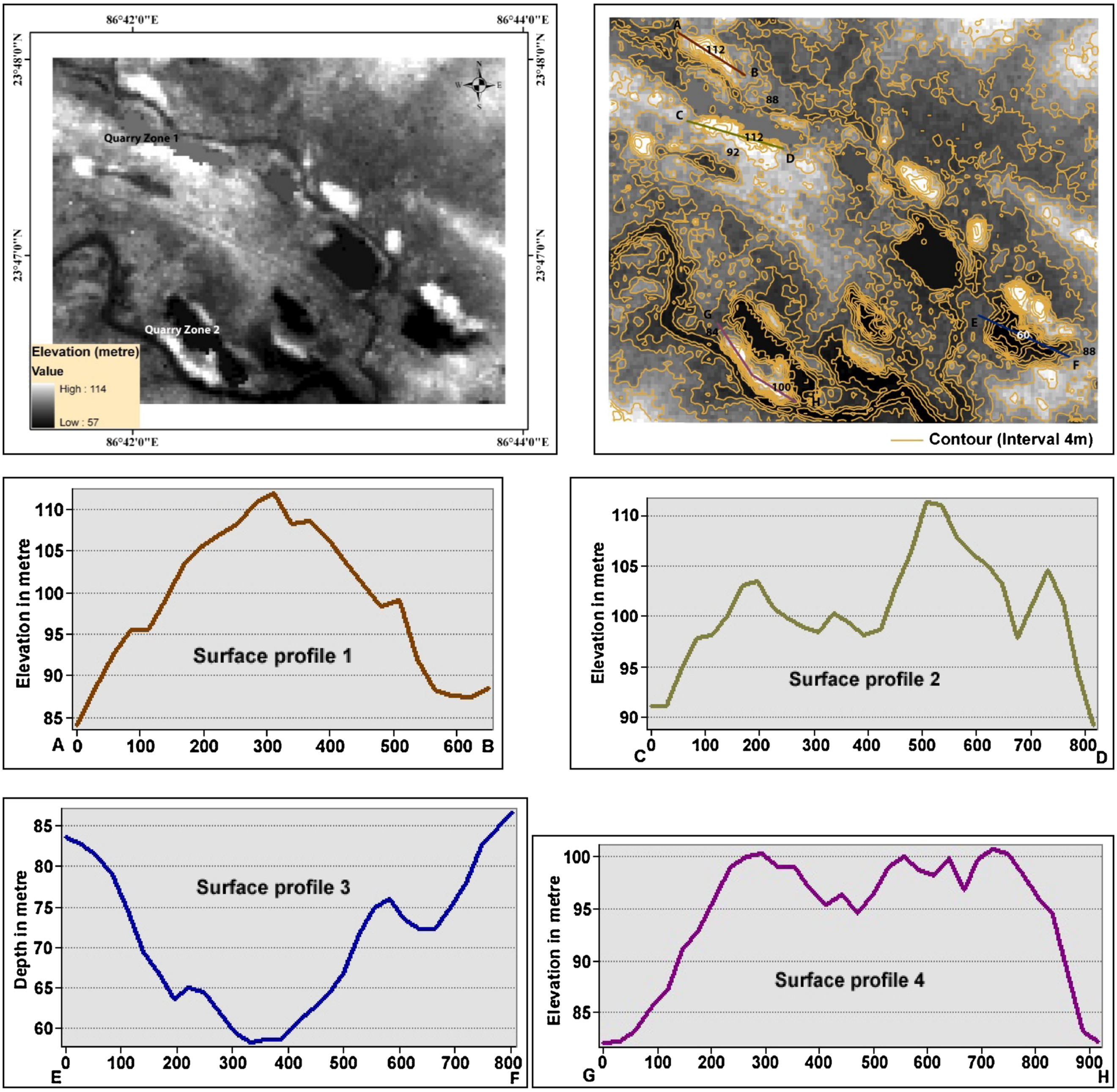

Fig. 4 Cartosat DEM image of a part of Mugma area (abandoned opencast mine area) with contour and surface profiles

1523500 cubic metres volume. Another spoil dump (quarry zone 1 in Fig. 4) is featured by 113 m peak height and 800 m horizontal expansion with 27 m net height (Fig. 4, Profile 2). It covers footprint area of 0.22 km^2 and contains 1550714 cubic metres volume. The quarry is featured by 29 m net depth and the depth is derived from working mine on same coal seam in that same area, as huge water storage in the abandoned quarry does not provide the digital elevation data. This depression spreads more than 800 m horizontally (Fig. 4, Profile 3). It covers footprint area of 0.29 km^2 and contains 4012400 cubic metres volume. Another spoil dump (quarry zone 2 in Fig. 4, abandoned more than 20 years) contains 101 m peak height and 900 m horizontal expansion with 17 m net height even after long erosion (Fig. 4, Profile 4). It covers footprint area of 0.16 km^2 and contains 1269058 cubic metres volume. Volume of the individual negative topography (excavation) is comparatively high and number of negative topography in this abandoned mine site is more. On other hand the volume of individual positive topography (spoil dump) is less after long erosion and in many small patches. This imbalance makes the regional topography as defaced.

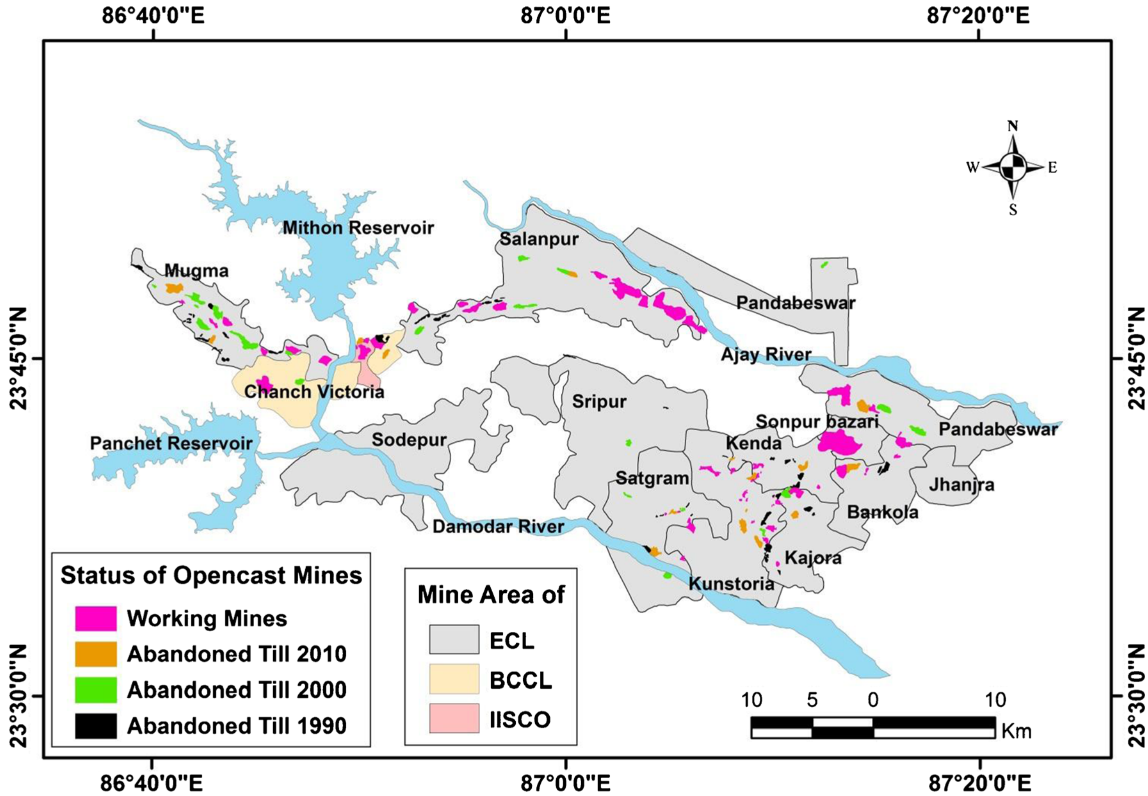

Fig. 5 Defaced topography by working and abandoned opencast mine

Defaced Topography by Abandoned and Working Opencast Mines in Raniganj Coalfield

Considering Quarry and Spoil dump together as topographic deformation, there are 47 working opencast mining patches over the Raniganj coalfield and these have defaced 26.45 km^2 surface areas out of 846.41 km^2 command area of different mining companies (ECL, BCCL and IISCO). In the same way 16 abandoned opencast mine patches which were abandoned from 2000 to 2010 A.D, have defaced 5.3 km^2 surface areas. 22 mine patches which were abandoned from 1990 to 2000 A.D, have defaced 6.76 km^2 surface areas. 47 abandoned opencast mine patches which were abandoned before 1990, have defaced 4.75 km^2 surface areas. Total 85 abandoned mine patches cover 16.81 km^2 surface area. Both abandoned and working mine have defaced 43.27 km^2 surface areas (Fig. 5 and Table 2). During pre-nationalization (before 1972–73) period

Table 2 Account of abandoned and working opencast mines

Year	Status	Number of patches	Cumulative number of patches	Defaced area (Km^2)	Cumulative of defaced area (Km^2)
Before 1990	Abandoned	47	47	4.75	4.75
1990–2000	Abandoned	22	69	6.76	11.51
2000–2010	Abandoned	16	85	5.3	16.81
Till date	Working	47	132	26.45	43.26

Table 3 Abandoned opencast mines and year of closure

Sl. No.	Name of mine	Mine area	State	Year of closure
1	Nabakajora/ Ghanasyam OC	Kajora	WB	84–85,89
2	Ratibati OC	Satgram	WB	81–82
3	Purusottampur OC	Pandaveswar	WB	88–89
4	Nimcha OC	Satgram	WB	87–88
5	Sheebpur OC	Sripur	WB	83–84
6	Alkusa-Gopalpur OC	Salanpur	WB	84–85
7	Kenda/Dobrana OC	Kenda	WB	77–78
8	Dhandadih OC	Kajora	WB	93–94
9	Dabor OC	Salanpur	WB	93–94
10	Gangaramchak OC	Pandaveswar	WB	93–94
11	Poidih OC	Sodepur	WB	91–92
12	Dalmiya OC	Salanpur	WB	95–96
13	Palasthali OC	Pandaveswar	WB	93–94
14	Chapapur 1OC	Mugma	Jharkhand	87–88
15	Badjna/Pusai OC	Mugma	Jharkhand	91–92
16	Kapasara OC	Mugma	Jharkhand	92–93

Source: Unpublished data collected from Eastern Coalfield Limited, Dishergarh, Burdwan

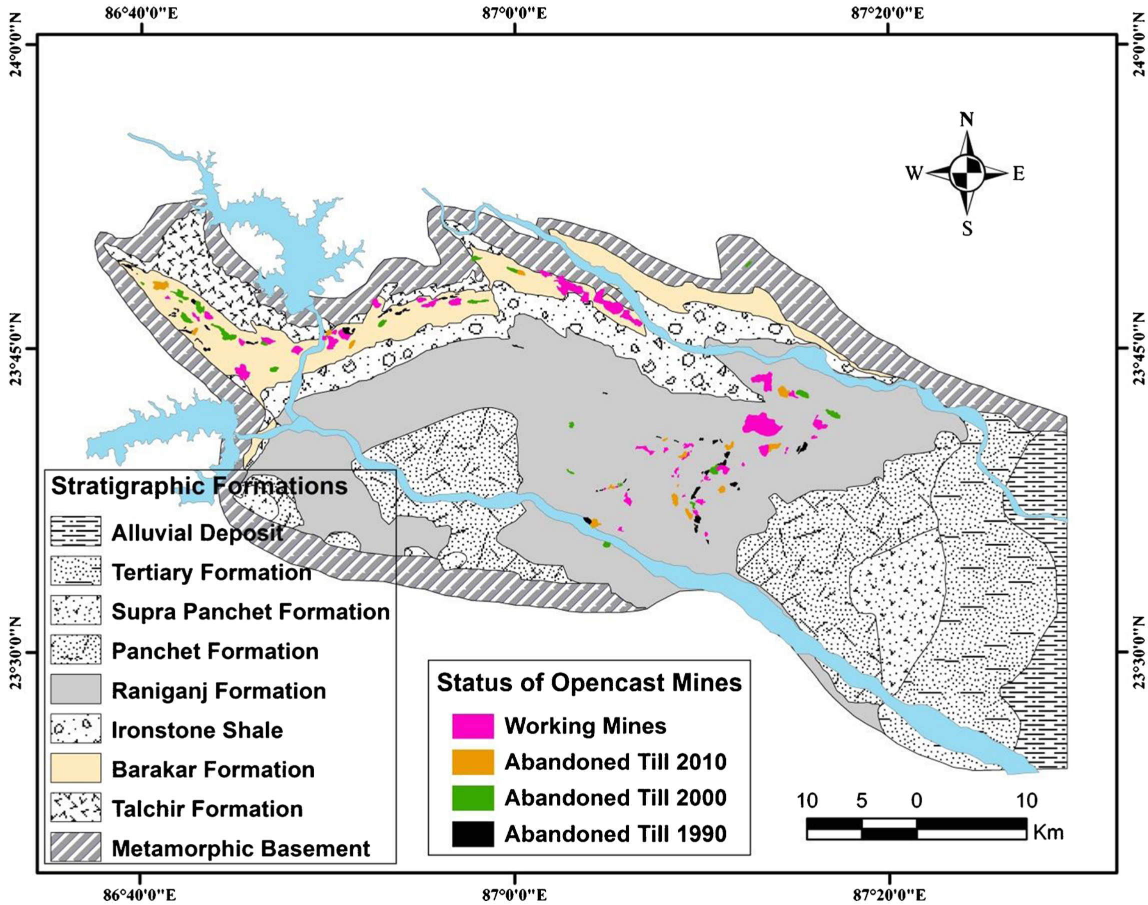

Fig. 6 Topographic deformation over geologic formations (*Source* of Geologic map: GSI Kolkata, Source of Stratigraphic order: Dutta and Dutta 2003)

of Indian coal mines numerous small patches were quarried and these were not reclaimed, because private owners did not show responsibilities to reclaim after quarry. That's why numerous older abandoned opencast mine patch remains left as defaced topography. After nationalization (1972–73) of Indian coal mines some large opencast mine patches were worked out and left as defaced topography (Table 3), as only the afforestation was adopted in 1980s (Samanta 2000) and the Mine Closure Plan is newly adopted by India in 2003. Cumulative number of patches and cumulative area of abandoned opencast mine shows both are gradually increasing (Table 2).

Defaced Topography over Geologic Formation

As coal seams developed in Barakar and Raniganj rock formation, surface topography over these formations has defaced due to opencast quarry. Narrow elongated Barakar formation lies in the Western and North-Western part of the Raniganj coalfield. Thus topographic deformation is also concentrated on a narrow elongated tract. Shallow coal seams were extracted through opencasting, which are more than 36 m in depth (Shampur top seam) at Western part and that depth is further more at Eastern part on Barakar formation (Dutta and Dutta 2003). 12.01 % of surface exposure of Barakar formation in the Raniganj coalfield has been defaced by opencast quarry (Fig. 6). Raniganj formation is wide and opencast mining is operating over Eastern part of this rock formation. To quarry shallow seams, they have to excavate overburden upto 25 m depth (upper kajora seam) or more (Dutta and Dutta 2003). 2.40 % of surface exposure of Raniganj formation in the Raniganj coalfield has been defaced by opencast quarry (Fig. 6, Table 4).

Environmental Consequences of Topographic Deformation

Land degradation and landscape change are the most important environmental impacts of surface coal mining. Landscape changes are accelerated by generating some typical features

Table 4 Topographic deformation over rock formations

Rock formation	No. of patches	Defaced area (Km^2)	% of Defaced surface area over rock formation
Barakar	57	22.26	12.01
Raniganj	75	20.97	2.4

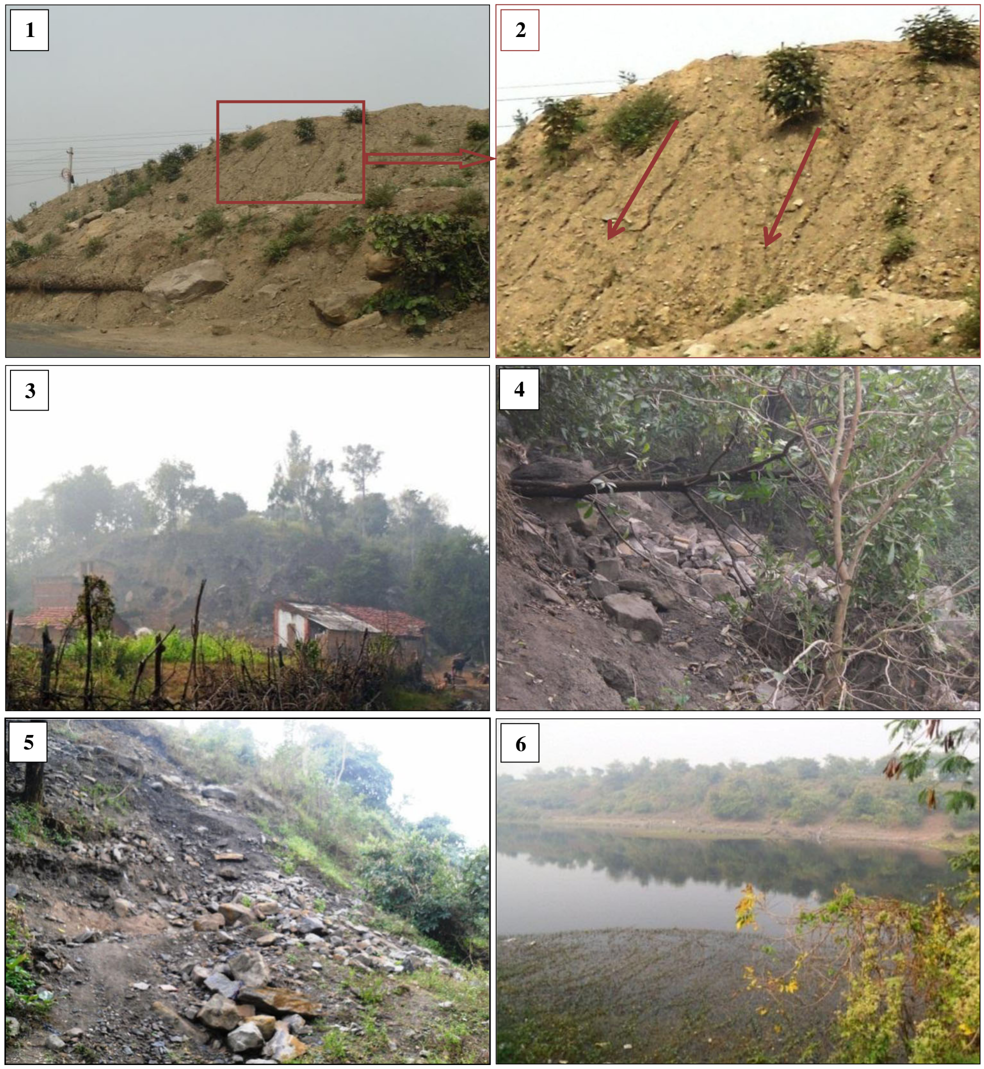

Fig. 7 **Plate 1** Less compact spoil dump at working mine site; **Plate 2** Spoil dump initiating rill formations; **Plate 3** 20 years old spoil dump at Mugma abandoned mine site; **Plate 4** Slided spoil dump at Mugma abandoned mine site; **Plate 5** Waste rock and tailings produced from spoil dump at Mugma abandoned mine site; **Plate 6** Logged water at Mugma abandoned mine site

like top soil stock piles, spoil piles, waste dump, bare top soil areas, steep out slopes, ramps, haul roads, lateral pits, water contain lows etc. in working opencast mines. Abandoned quarry zones also content such typical features along with vegetation and scrub covered dump, rat-hole drilling, slided side slope, etc. Degraded land and defaced topography results several environmental consequences. Forest, cultivated land and water bodies are degraded due to tremendous increased mining area (Khan and Javed 2012). Schroeder (1987) found that soil loss from graded mine spoil slopes. As the spoil dumps are generally loose (less compact) and consist of mixed (fine, coarse soil particles, coal fragments and rock tailings) particles, these are highly prone to rain washing and soil erosion through rill and gully formation that leads to sediment yield to the river channels and Acid Mine Drainage (Fig. 7). Slope instability is associated with larger heights dumps with steeper slopes (Muthreja et al. 2012). Abandoned steep elevated scarp of spoil dumps are also prone to slide (Fig. 7). Such dumps produce huge solid waste including waste rock and tailings (Chen and Li 2009) and that can be seen in Fig. 7. These spoil dumps are potential sources of trace elements (De and Mitra 2002) and these trace metals (Fe, Mn, Cu, Zn, Ni, Pb and Co) lead to toxicity problems in plant growth (Mukhopadhyay and Maiti 2011). After long time abandonment, quarries are filled with toxic element containing water (Fig. 7).

Conclusion

Production of coal in Raniganj coalfield is increased 15.80 M. Tonne in 2002–03 to 30.084 M. Tonne in 2011–12, mainly by increasing production from opencast project. As opencast mine projects are becoming large in terms of surface area, topographic deformation is also increasing and the depth of opencast quarry is increasing day by day. Despite the temporary activities of coal mining it degrade the land, soil and water for long time and the region turns into a derelict land.

This defaced topography cumulates environmental consequences like soil erosion, sedimentation and surface water pollution. Proper backfilling should be adopted after quarry of a part other than dumping the spoil elsewhere. Overburden spoil should be dumped with a managed way that it would not release toxic elements. Dumping should follow the well-managed geometry (less peak height and gentle gradient) that it would not be slided. Topographic restoration should be practised along with Biological reclamation following dumping that it would not cumulate further environmental consequences.

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References

Annual Report of ECL (2010–2011). http://www.easterncoal.gov.in/annualreport/annualreport10-11.pdf

Banerjee, S. K., Mishra, T. K., Singh, A. K., & Jain, A. (2004). Impact of plantation on Ecosystem development in disturbed coal mine overburden spoils. *Journal of Tropical Forest Science, 16*(3), 294–307.

Bradshaw, A. D., & Chadwick, M. J. (1980). *The restoration of land: The ecology and reclamation of derelict and degraded land*. Los Angeles: University of California Press. 317.

Chen, Y., & Li, D. (2009). Monitoring of landscape change for waste land rehabilitation in Haizhou opencast coal mine. *WSEAS Transactions on Information Science and Applications, 6*(3), 447–456.

De, S., & Mitra, A. K. (2002). Reclamation of mining-generated wastelands at Alkusha-Gopalpur abandoned open cast project, Raniganj Coalfield, eastern India. *Environmental Geology, 43*(39), 47.

Dentoni, V., & Massacci, G. (2007). Visibility of surface mining and impact perception. *International Journal of Mining, Reclamation and Environment, 21*(1), 6–13.

Dutta, R. K., & Agrawal, M. (2002). Effect of tree plantations on the soil characteristics and microbial activity of coal mine spoil land. *Tropical Ecology, 43*(2), 315–324.

Dutta, R. K., & Dutta, A. B. (2003). Coal resource of West Bengal. *Bulletin of the Geological Survey of India, Series A, 7*(45), 109.

Ekka, J. N., & Behera, N. (2011). Species composition and diversity of vegetation developing on an age series of coal mine spoil in an open cast coal field in Orissa, India. *Tropical Ecology, 52*(3), 337–343.

Ghose, M. K. (1996). Damage of land due to coal mining and conservation of topsoil for land reclamation. *Environment and Ecology, 14*(2), 466–468.

Ghosh, A. K. (1990). Mining in 2000 AD—challenges for India. *Journal of the Institution of Engineers (India), 39*(ii), 1–11.

Kainthola, A., Verma, D., Gupte, S. S., & Singh, T. N. (2011). A coal mine dump stability analysis—a case study. *Geomaterials, 1*(1), 13.

Khan, I., & Javed, A. (2012). Spatio-temporal land cover dynamics in open cast coal mine area of Singrauli, M.P., India. *Journal of Geographic Information System, 4*, 521–529.

Kuenzer, C., & Stracher, G. B. (2012). Geomorphology of coal seam fires. *Geomorphology, 138*(209), 222.

Melnikov, N., & Chesnokov, M. (1969). *Safety in opencast mining*. Moscow: Mir Publishers.

Mukhopadhyay, S., & Maiti, S. K. (2011). Trace metal accumulation and natural mycorrhizal colonisation in an afforested coalmine overburden dump: a case study from India. *International Journal of Mining, Reclamation and Environment, 25*(2), 187–207.

Muthreja, I. L., Yerpude, R. R., & Jethwa, J. L. (2012). Application of geo-grid reinforcement techniques for improving waste dump stability in surface coal mines: numerical modeling and physical modeling. *International Journal of Engineering Inventions, 1*(1), 16–23.

Niroula, G. S., & Thapa, G. B. (2005). Impacts and causes of land fragmentation, and lessons learned from land rehabilitation in South Asia. *Journal Land Use Policy, 22*(4), 358–372.

Otte, M. L., & Jacob, D. L. (2008). *Mine area remediation [M]* (pp. 2397–2402). London: Academic.

Samanta, B. K. (2000). Environmental issues and management in coalfields of India. In: A. G. Paithankar, R. K. Jha, & P. K. Agarwal (Eds.), *Geoenviromental reclaimation, International Symposium* (pp. 67–73). Nagpur, India. ISBN 90-5809-219-4.

Schroeder, S. A. (1987). Slope gradient effect on erosion of reshaped spoil. *Soil Science Society of America, 51*(405), 409.

Shadhu, K., Adhikari, K., & Gangopadhyay, A. (2012). Effect of mine spoil on native soil of Lower Gondwana coal fields: Raniganj coal mines areas, India. *International Journal of Environmental Sciences, 2*(3), 1675–1687.

Singh, A. N., & Singh, J. S. (2006). Experiments on ecological restoration of coal mine spoil using native trees in a dry tropical environment, India: a synthesis. *New Forest, 31*(25), 39.

Singh, M. P., Singh, J. K., & Mhonka, K. (2007). *Forest environment and biodiversity* (p. 568). Richardson: Diya Publishing.

Taylor, T. J., Agouridis, C. T., Warner, R. C., & Barton, C. D. (2009). Runoff curve numbers for loose-dumped spoil in the Cumberland Plateau of eastern Kentucky. *International Journal of Mining, Reclamation and Environment, 23*(2), 103–120.

Wali, M. K. (1987). The structure dynamics and rehabilitation of drastically disturbed ecosystems. In T. N. Khoshoo (Ed.), *Perspectives in environmental management* (pp. 163–183). New Delhi: Oxford Publications.

Ward, A., Smith, A., & Caldwell, J. (1984). Surface erosion and sediment control at opencast mines in southern Africa. Challenges in African Hydrology and Water Resources. Proceedings of the Harare Symposium IAHS Publ. no. 144.