Surface Runoff Assessment due to Opencast Coal Mining and Its Management

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ABSTRACT

Energy security is essential for development of a nation, and coal is contributing to 55% of the total production of energy resources in India. Opencast mining, accounts for 86% of India's coal production and is the preferred method of mining. Opencast coal mines make excavation activities on the natural surface of earth and thereby affect the hydrology of the area. Hydrological impact assessment due to opencast coal mines is one of the major concerns for each mine. The situation needs to be studied and analyzed particularly for rainy season, as proper understanding is required regarding scale of generation of surface runoff from the extensive area of mine excavation, overburden dump, coal stock yard, railway siding etc. so that it can be managed properly. On the other hand, there is huge water demand in the mining area to fulfill the daily requirement during non monsoon period. Therefore, it is essential to have a proper plan for management of surface runoff for each mine in order to avoid the surface runoff being discharged to the nearby areas. In this paper, the findings of surface runoff assessment for a large opencast coal mine in the state of Odisha have been presented. Suggestions for effective management of the huge quantities of surface runoff have also been discussed.

INTRODUCTION

In order to meet the ever-increasing demands of the modern society, the mineral production is continuously increasing in our country, along with the scale of mining operations. Mining being a site-specific activity, there are a large number of environmental concerns as well. Impact of mining on land environment gets reflected in land-use pattern of the respective area because the more the land gets exposed to erosion by loosing its green cover or by getting disturbed otherwise due to mining (excavation, overburden dumping etc.) and related activities, Successful environmental management in the mining sector is dependent on recognising, and avoiding or minimising the adverse environmental impacts. Opencast mines of Mahanadi Coalfields Ltd. (MCL) are large excavations on the surface and thickness of coal seam extracted is more than the thicknesses of overburden in all the mines. The coal from these mines is mostly supplied to power plants. Once the coal is excavated and transported out of the mine, the overburden and the waste materials including the material obtained from the partings are left in the mine. Due to the low stripping ratio, it is not always possible to carry out complete backfilling, and so a lot of void spaces are always present in these mines. During monsoon season, rain water falls in the entire quarry area, external OB dump, coal stock and siding etc. The runoff flows into or out of the mine depending upon its topographical profile. Like any land disturbance, the mining and water interact during the flow. The effects depend on the location of the mine, the hydrology and climate of an area, and the physical and chemical properties of the coal, associated strata, and residual materials. The quality and quantity of surface and groundwater may be affected, both within a mine and in the surrounding areas, if no mitigating measures are incorporated. The mine drainage may or may not be acidic, depending upon the minerals present in the excavated rock. It may affect the aquatic life vary widely, from elimination of all but the few most tolerant algae, macro-invertebrates, and fish. The most severe effects are caused by high volume, acidic discharges with high concentrations of dissolved metals that drain into lightly buffered streams and produce accumulations of precipitated iron or aluminium. Little or no effect may occur from low volume or alkaline discharges with relatively low concentrations of metals that drain into moderate or highly buffered streams. The major source of acidity is oxidation of pyrite (FeS_2) in freshly broken rock that is exposed by mining or highway construction. Pyrite oxidation can be rapid upon exposure to humid air or aerated water, particularly above the water table. Therefore, throughout the mine life, the mining activities must be designed to ensure the protection of the quality of the surface and groundwater resources. The mine management has to ensure that surface and groundwater availability and utility by local landowners is not compromised and that contingencies are in place to counter the occurrence of any adverse impacts. They should ensure that appropriate control systems are established prior to mining and additional systems are progressively implemented in advance of mining activities so that the generation of contaminated water is minimised and to maintain effective measures for their control and isolation; and surface water use and surface water discharges comply with all relevant legislation.

SURFACE RUNOFF IN MINE A

Mine A is a large opencast mine of MCL with a production capacity of 20 million tonnes per year. The mining lease falls in the Angul-Talcher region, which was identified as one of the critically polluted areas. The main drainage of the mine is Brahmani River which flows at a distance of about 10 Km from the lease boundary. A small nallah flows adjacent to the mine and ultimately ends up in Brahmani river. The overburden (OB) thickness in the coalfield is very low. The volume of coal seam extracted is much more compared to the volume of OB. Initially, OB is stored in external OB dumps and once sufficient space is created for construction of haul roads and coal transportation roads with pliable gradient for movement of OB and coal from face to surface. Once the bottom most coal seam is extracted, the OB generated thereafter is utilized for backfilling of the opencast mine void. However, the quantity of OB generated in these coalfields is usually less than the void created and about 40 to 50% of the initial land remains as the void. Attempt is made in most of the mines to channelize the runoff into the mine voids. These voids can be categorized into two types, viz. abandoned mine voids and voids available in active quarries. Since overburden removal, coal seam exposure, backfilling of overburden in the de-coaled void, extraction of coal and associated transportation activities are continuous process, and require a lot of space, the active quarry voids are not fixed or stationary.

However, during the entire course of mining operations, mine sumps are always present to accommodate the surface runoff, although its position may keep on changing from year to year due to the advancing coal face and backfilling front. Thus, the assessment of sump capacity of the active quarry is indicative of the status during the study period only. The surface runoff generated within the mine area and the sump capacity have been estimated based on the present topographic condition, field investigations and the data provided by the mine authorities.

During monsoon season, the rain water that falls in the entire quarry area, external OB dump, coal stockyard etc accumulates in the mine void. It was observed that there is accumulation of water in all the mine sumps. However, in a few cases where the water is accumulating in the coal face in dip side of the mine. Pumping of water is being carried out to obtain a dry face for production operations. The water is discharged to a sedimentation pond, the overflow of which goes to nearby nallahs or rivers.

Around the periphery of the quarry area, garland drains have been provided which diverts rain water into the mine sumps. The water in the mine sumps, mainly collected during the rainy season, is being utilized for dust suppression, fire-fighting, plantation activities, washing of HEMMs in the Mine Workshop etc., and in some places, these are being used for supplementing the drinking water supply through IWSS. Also on the demand of nearby villagers, the water is being supplied to nearby areas to support agriculture.

The mine has its own workshop and effluent treatment plant (ETP). The heavy earth moving machineries (HEMMs) like dumper, grader, crane, water tankers etc. are being washed at washing platform located in the HEMM workshop. The effluent generated during washing mainly contains TSS (Total Suspended Solids) and oil & grease (O&G), these are directed to the workshop effluent treatment plant (WETP) or Oil & Grease Trap. Oil and grease is recovered from the effluent through O&G Trap and is auctioned to the authorized agencies. TSS is removed regularly from the primary settling tanks. The treated/clean water is collected in the clean water tank and then it is re-utilised for vehicle washing purpose. Thus the ETPs are operating in close circuit and there is no discharge of the effluents outside.

The railway sidings have been located in a low lying area. There is no surface runoff from the railway sidings in any other season except monsoon, because the water used for sprinkling for dust suppression, is absorbed/evaporated. Sedimentation tanks have been constructed in most of the coal mines for settling of the suspended solids.

In order to calculate the surface runoff, updated mine and contour plans were obtained from the mine. The digital elevation models (DEMs) were prepared using ArcGIS 10.1 in order to segregate the area into different zones based on flow direction. A digital terrain model (DEM) represents the topography of the terrain surface for specific location on the Earth. This terrain surface can be represented as a combination of mathematical function, vector-based triangulated irregular network (TIN) mesh or raster with height as its pixel value (Li et. al., 2005; Toppe, 1978). The quarry area was determined from the scanned maps which were geo-referenced and digitized. Also, the boundaries of the existing drainage networks and water bodies were digitized.The different layers of the digitized maps, water bodies and drainage network were overlaid in ArcGIS10.1 environment leading to the determination of the locations and areas of the water bodies. The DEM of the mine has been presented in Figure 1. Depending upon the flow patterns the area has been divided into 8 zones (R1 to R8). The location of important surface features in the mining area have also been presented Figure 1.

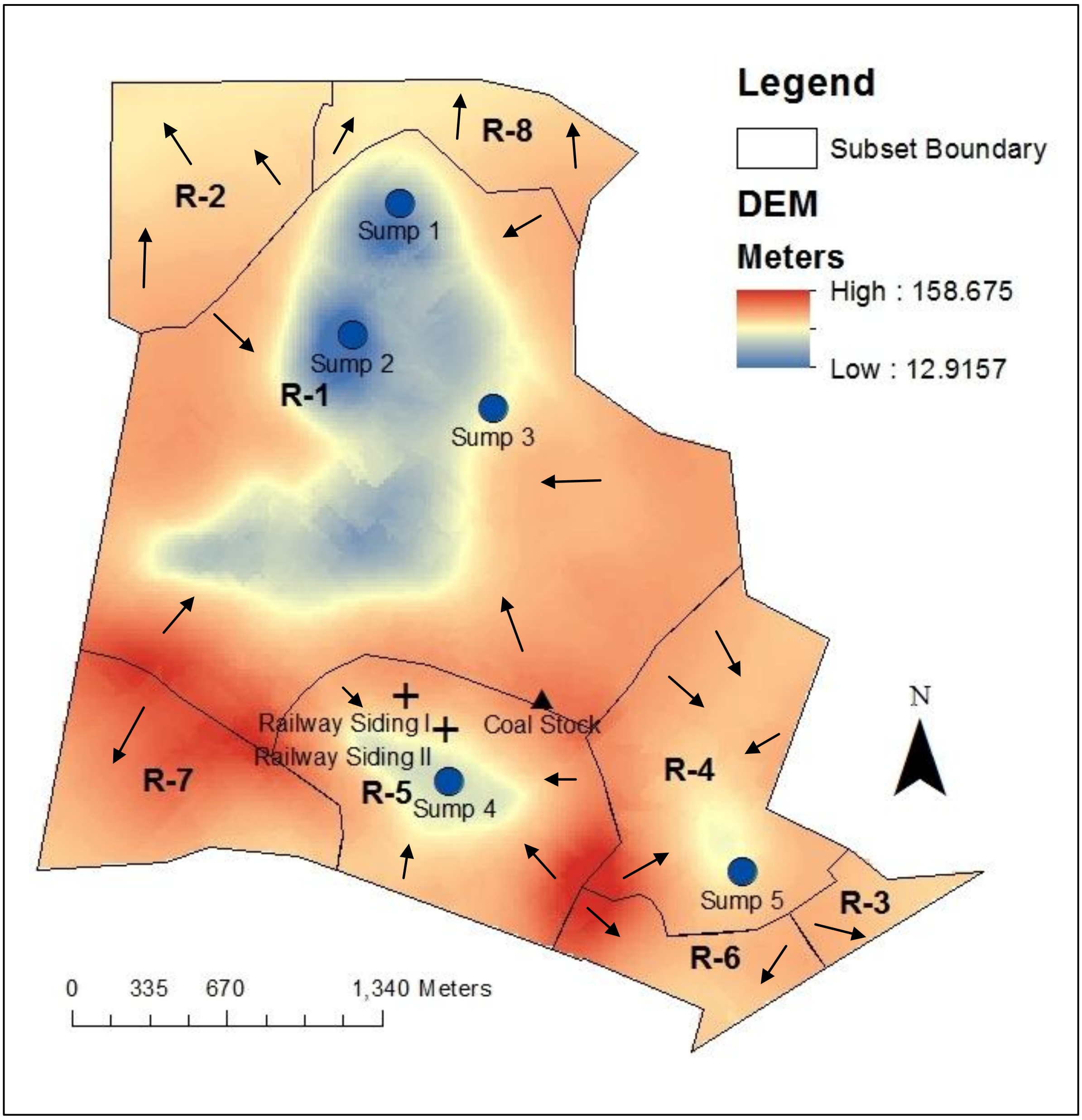

Fig. 1: Digital elevation model (in meter) of Mine A with arrows denoting the flow direction of water and Location of important features

The surface runoff for each mine were determined by using the rationale method which is quantified based on the following relationship:

Surface Runoff = Area x Total Rainfall during monsoon x Runoff Coefficient

The runoff coefficient was determined based on land-cover, topography, whether in natural or disturbed state and soil type within the study area. Generally, areas with permeable soils, flat slopes and dense vegetation are expected to have the lowest values of coefficients. Areas with dense soils, moderate to steep slopes and sparse vegetation should have highest values. Furthermore, if the types of soil cover are homogeneous for the entire watershed, then the average of the runoff coefficients is used. In a situation where there is multiple soil cover type in a watershed, the watershed was divided into sections and the area calculated for each section (Kuichling,1889; Harlan, 2007; and Idowu et al., 2013).Once the runoff is collected in the sumps, evaporation takes place throughout the year. Evaporation losses from the sumps for the monsoon period were taken into account to calculate the net quantity.

Table 1: Surface runoff from each region in Mine A

Name	Area (m^2)	Rainfall (m)	Net Quantity (Lakh m^3)
R1	4447208.2	1.21	42.51
R2	732195.98	1.21	3.50
R3	160142.41	1.21	1.60
R4	1035176.07	1.21	9.82
R5	1130166.73	1.21	9.52
R6	338145.94	1.21	3.30
R7	715481.48	1.21	6.90
R8	440527.59	1.21	2.10
Total	**8999044.40**		**79.25**

A large quantity of water is required in each mine for dust suppression, fire fighting, washing of HEMM etc. The water stored in the sumps during monsoon is used for these activities throughout the year. The water demand for each mine for the monsoon period was therefore deducted from the Net Runoff Quantity to determine the required sump capacity for the monsoon period. The annual water demand for the mine was found out to be 14.34 lakh m^3, where as the monsoon consumption is 4.78 lakh m^3. Therefore, provision of storage of at least 74.47 Lakh m^3 is required for the monsoon period.

It is difficult to estimate the exact capacity of any sump. Hence, this was done by obtaining the area of each sump from the mine plans and Google Earth imagery, and the depth information was obtained from MCL officials. Currently, there are 5 sumps in the mine. However, sump 4 has been allocated for fly ash filling by NALCO. The depth of the each sump and the total sump capacity is presented in Table 2.

Table 2: Capacity of sumps in the mine

Sump Name	Volume (Lakh m^3)
Sump 1	25.65
Sump 2	19.08
Sump 3	6.22
Sump 4	143.83
Sump 5	19.12
Total =	**213.9**

WATER QUALITY ANALYSIS

Water quality analysis was carried out to ascertain the quality of water in the mine sumps as well as the mine discharges. Samples were collected during March 2015 to know the pre-monsoon status; and again in August 2015, to know the status in monsoon. Water samples were analyzed following the APHA (2012) and CPCB guidelines. Some of the parameters viz. pH, Conductivity, Total suspended solids (TSS), Conductivity etc. was measured at the site by using a multi-parameter water quality analyzer (Figure 2). The results of the analysis are presented in Table 3.

Fig. 2: Measurement of water quality parameters for mine discharge

In general the water quality of the mine sumps were found to be within acceptable limit for utilization in industrial activities like dust suppression, fire fighting, irrigation of plantation, washing of HEMMs etc and after some treatment these can also be used for supplementing the drinking water supply. Wherever the sump water is discharged in the surface water bodies, the discharge water quality conforms to the relevant standards for coal mines prescribed by CPCB.

It was observed that there is increase in concentration of parameters like TSS, Oil and Grease in the water samples collected in the monsoon season compared to the pre-monsoon quality, which is on the expected lines. Most of the mine sump water is near neutral to alkaline in nature. However, the mine water from sump 4 shows strongly acidic characteristics. Proper scientific study may be carried out for control of acidic drainage in these areas. It was also observed that concentrations of selenium in some of the water samples were above the permissible limit.

Water Quality Analysis results

Sl. No.	Parameter	South Quarry	Central Quarry		Water discharge point for industrial use		Standards Prescribed under Env. Protection Rules, 1986	
							Into inland surface water	Onland for irrigation
1.	pH	**3.87**	5.35	5.18	8.10	5.98	5.5-9.0	5.5-9.0
2.	Temperature (^{o}C)	31.55	26.13	31.58	31.04	31.39	Shall not exceed 40^{0}C in any section of the stream within 15m downstream from the effluent point	
3.	TDS (mg/L)	695	266	350	412	589	2100	2100
4.	TSS (mg/L)	100	9	**184.75**	23	**219.5**	100	200
5.	BOD_3 (mg/L)	2.28	0.8	2.67	4.4	2.34	30	10
6.	Chloride content (mg/L)	17.04	40.2	24.14	39.6	19.88	1000	600
7.	Residual chlorine (mg/L)	0.32	BDL	0.18	0.22	0.14	1.0	-
8.	COD (mg/L)	18.9	15.8	21.3	16.2	17.4	250	-
9.	Fluoride (mg/L)	0.1	0.2	0.2	0.2	0.5	2.0	-
10.	Sulphate (mg/L)	257.2	377.9	274.1	420.0	260.1	1000	-
11.	Zinc (mg/L)	0.25	0.202	0.18	0.291	0.21	5.0	-
12.	Copper (mg/L)	0.06	BDL	0.04	0.015	0.01	3.0	-
13.	Cadmium (mg/L)	0.007	0.005	0.004	0.004	0.005	1.0	-
14.	Lead (mg/L)	BDL	BDL	BDL	BDL	BDL	0.1	-
15.	Selenium (mg/L)	**0.083**	**0.068**	**0.052**	**0.059**	**0.061**	0.05	-
16.	Arsenic (mg/L)	0.026	0.066	0.073	0.031	0.034	0.2	0.2
17.	Mercury (mg/L)	BDL	BDL	BDL	0.002	BDL	0.01	-
18.	Chromium (mg/L)	BDL	BDL	BDL	0.014	BDL	2.0	-
19.	Cyanide (mg/L)	BDL	BDL	BDL	0.023	BDL	0.2	0.2
20.	Nickel (mg/L)	0.61	0.408	0.47	0.513	0.32	3.0	-
21.	Phenol (mg/L)	BDL	BDL	BDL	0.077	BDL	1.0	0
22.	Oil and Grease (mg/L)	2.97	3.78	2.88	7.88	6.41	10	10
23.	Sodium (mg/L)	23.07	21.08	22.93	27.27	43.1	-	60
24.	Boron (mg/L)	BDL	BDL	BDL	BDL	BDL	2.0	2.0

SUGGESTIONS FOR MANAGEMENT OF SURFACE RUNOFF

The sumps have adequate capacity to store the surface runoff generated in the mine at the moment.

R2 and R8 zones are in virgin land and the surface runoff can be allowed to take its natural course. If future as the mining proceeds in these zones, the runoff may be directed back to the mining sumps.

The Railway sidings are in a low lying area in R5. Surface runoff is being channeled to the Sump 4 (Fig.3).

Fig. 3: A view of arrangements in railway siding to channel the runoff into South Quarry Sump via a culvert.

Surface runoff from R7, which is external overburden slope, well vegetated, should be channelized into the Sump 4.

Surface runoff from R3 and R6 can be routed to the nearby Sump 5 or to the sumps of nearby mines.

The overflow of the sedimentation pond is released to the nearby paddy fields (Fig. 4), which ultimately mixes with the nearby nallah and then in Brahmani river. This overflow should be redirected back into mining sumps. Moreover, the dimension of the sedimentation pond is inadequate to provide a detention time of 3hrs for the suspended particles to settle with alum dosing.

It is recommended to construct a sedimentation pond for the railway siding with a dimension of 1529m^2 having a depth of 3m.

Fig. 4: Overflow of the sedimentation pond is released to the nearby paddy fields

Since the South Quarry sump which has a capacity to store 143.83 lakh m^3 of water, will not be available for storing the runoff in future. Therefore, the capacity of the active sumps should be increased in due course of mining.

All the existing mine sumps, garland drains, sedimentation ponds created on the surface should be de-silted before monsoon and wherever possible, the sumps may be deepened to accommodate more surface runoff quantity. Attempt should be made to increase the consumption of water from the mine sumps. The mine authorities may explore the possibility for construction of a number of recharge pits beyond the zone of influence.

Plantation, grassing and soil water conservation measures like contour trenches (continuous or staggered), bunds (2 ft high), agave plantation, silt arrestors, check dam etc should be carried out in all the external o/b dump slopes to minimize siltation during monsoon, otherwise the capacity of garland drain to carry the surface runoff will decrease and will lead to flooding and discharged to nearby areas instead of being channeled to the sump(Caribbean Agricultural Research and Development Institute, 2010). Where the slope is very steep, coir mats or geo-synthetic material along with grass seeding should be practiced to securely protect the slope.

Proper retaining wall or gabion wall or catch drain (1.5m x 1.5m cross section) should be provided at the toe of the ob dumps to arrest the siltation during heavy rains and these catch drains should be cleaned before onset of monsoon each year.

The mine management should have the provision of flexible pipe and small capacity sumps, which can be utilized to pump water to deal with fire affected areas and plantation activities within the mine premises.

CONCLUSION

Most of the opencast coal mines these days occupy a large area. Since the land area progressively gets disturbed by mining activity, the rate of percolation is very low, and the quantity of surface runoff generated is very high. This runoff, if not managed properly may cause serious environmental impact on the nearby surface water bodies. The common parameters which are likely to have a significant effect on water quality of nearby water bodies are pH, total suspended solids, BOD, COD and oil and grease. The management of each mine therefore should make adequate provision to store the water within mine sumps. In areas, where the water flows outwards from the mine, provision should also be made to divert the water into the mine sumps through garland drains, culverts etc. However, if due to any reason, it is not possible to make such provisions, then sedimentation ponds of adequate dimension must be constructed, so that the suspended solids get settled, and removed periodically. Artificial rainwater harvesting techniques, such as recharge pits can be created to replenish the groundwater of the surrounding mining area. In order to maintain the sump capacity in the mines, the utilization of water from the sumps may be increased. The water may be supplied to the nearby areas for irrigation purposes.

ACKNOWLEDGEMENT

The authors thank MCL authorities for sponsoring the scientific study. The authors express their thankfulness to Sri R. K. Srivastav, General Manager (Environment) and Dr. S. Jha, Sr. Manager (Environment), MCL for their help during the study. The authors thank Sri Bishnu Prasad Sahoo, Ph.D. Scholar; and Dhruti Sundra Pradhan, M.Tech student; for their help in conducting the experiments.

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