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RESEARCH ARTICLE

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Study on assessment of slope stability and mixed disposal of overburden in voids of Singrauli Coalfield

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Abstract

The mining industry can be considered the backbone of the Indian economy as well as facilitating the power that drives most of the other industries in the company. The overburden and waste rocks produced during coal mining are major concerns in regard to the amount of land that is required for their disposal, as well as the stability of dumps for these materials, which are of increasing height. Land reclamation issues are also a concern. In this work the adverse impacts caused by the dumping of overburden on land and acidic mine water on water bodies is discussed. Remote sensing tools were used along with the laboratory experimentation to assess the various impacts. This study also shows that silt released from waste dumps, can affected the angle of repose of the overburden dump slope. The angle of repose of the overburden materials varies with particle size composition. Thus, use of in-pit crushers in large opencast mining operations can effectively reduce the area locked under the waste dumps. The acid neutralization potential of fly ash and overburden for the treatment of acid water was tested in the laboratory by using fly ash and waste rock materials on acidic coalfield water. The results are encouraging, and fly ash may prove to be a good acid neutralizer when used in conjunction of coal overburden material.

KEYWORDS
acidic mine water, fly ash, overburden materials, slope stability and opencast mines

1 | INTRODUCTION

The mining process disturbs all of the physical features of the environment. Large-scale mining and allied activities have caused severe damage to land resources, and mining operations produce a large quantity of overburden and ore materials (Chadwick, Highton, & Lindman, 1987). Mining activities are associated with major environmental problems involving air, water, and soil pollution, as well as land degradation. If done improperly, the removal of soil and rock overburden covering the coal resources causes the burial and loss of topsoil, which creates a vast infertile wasteland. This is why the mining industry has some negative environmental impacts on ecosystems; however, one cannot stop mining based on the cost of environmental protection (Carvalho, 2017).

Coal is a heterogeneous, carbon-rich material formed by biochemical and geological processes and the thermal alteration of organic debris, such as leaves and plants. The inorganic and organic constituents of coal play an active role in affecting the adjoining environment and in determining its quality (Zhang, Fan, Zhang, & Li, 2018).

Simultaneously, the combustion of coal in thermal power plant produces of large amount fly ash. The large amounts of fly ash and overburden create many problems, including the need for huge amounts of dedicated land for their disposal and the toxicity associated with heavy metals that can leach from these materials into groundwater. In coal mines, the main cause of water acidity is the occurrence of pyrite and other sulfide metals in the form of veins, granular, and crystallized forms in the coal and shale. In this paper, a case study involving the utilization of fly ash and overburden for the neutralization of acidic water generated from coal-mining operations is discussed.

1.1 | Physicochemical characteristics of fly ash

The physical and chemical properties of coal ash are determined by reactions that occur during the high-temperature combustion of the coal and the subsequent cooling of the flue gas. Fly ash is spherical particles that usually range from 0.5 microns in diameter to 100 microns, and it makes up from 10 to 85% of the total coal ash residue. Fly ash is a heterogeneous material primarily consisting of amorphous aluminosilicate spheres with minor amounts of iron-rich spheres, some

EXHIBIT 1 Typical ranges for geotechnical properties of fly ash

Property	Fly ash
Specific gravity	2.1–2.9
Bulk density (compacted), lbs/ft^3	65–110
Optimum moisture content, %	10–35
Hydraulic conductivity, cm/s	10.4–10.6
Porosity	0.40–0.50
Angle of internal friction, degrees	25–40

Note. Adapted from Electric Power Research Institute (EPRI, 2009).

crystalline phases, and small amounts of unburned carbon. It is usually tan to dark gray in color. Important geotechnical properties of fly ash are listed in the table in **Exhibit 1**.

1.2 | Chemical composition

The chemical composition of coal ash is determined primarily by the chemistry of the source coal and the combustion process. Because ash is derived from the inorganic minerals in the coal, such as quartz, feldspars, clays, and metal oxides, the major elemental composition of coal ash is similar to the composition of a wide variety of rocks in the Earth's crust. Oxides of silicon, aluminum, iron, and calcium comprise more than 90% of the mineral component of typical fly ash. Minor constituents, such as magnesium, potassium, sodium, titanium, and sulfur, account for about 8% of the mineral component, while trace constituents, such as arsenic, cadmium, lead, mercury, and selenium, together make up less than 1% of the total composition. The table in **Exhibit 2** provides the typical range of major and trace constituents concentrations in fly ash and bottom ash, along with the range for such constituents for rock and soil for comparison.

1.3 | Classification of fly ash

Fly ash generated by coal-combustion-based power plants typically falls within the American Society for Testing and Materials (ASTM) fly ash classes C and F (ASTM, 1987, Page, Elseewi, & Straughan, 1979). The differences between class F and class C fly ash are given in the table in **Exhibit 3**.

1.4 | Overburden associated with rock

During opencast mining, the overlying soil is removed and the fragmented rock is heaped in the form of overburden dumps. Dumped materials are left on the land in the form of overburden dumps. These dumps occupy large amounts of land, which loses its original use, with the quality of the soil underneath degraded. The dump materials are generally loose; as a result, fine particles from the dumps are highly prone to being picked up by the wind and dispersed. These particles are spread over the surrounding fertile lands and plants, disturbing their natural qualities and the growth of fresh leaves (Ghose, 2007; Ghosh, 2002).

1.5 | Physicochemical characteristics of overburden

The physicochemical properties of overburden dump materials are site-specific and differ from one dump to another due to differences among the geological deposits. Overburden is composed mostly of friable sandstone, a little shale, fired clay, and rarely, of conglomerate materials in a few places, with the particle sizes shown in the table in **Exhibit 4**.

1.6 | Nature and type of overburden dump

The overburden rocks in the study area are friable, loose, and non-cohesive in nature, and their sizes vary from boulders to the particles within clay. In the present study area, the mine has been divided into two sections, the east and the west with a central exit ramp. Both external and internal overburden dumping methods are used during the mining processes. Internal dumping involves placing overburden in parts of the mine where the minerals have already been extracted, and external dumping involves placing overburden in dumps outside the mineral exploration area. During external overburden dumping, contour strip benches are prepared to stabilize the overburden dumps. These benches improve dump stability against slope failure and reduce surface erosion by reducing slope length. The initial overburden dump of 97 million cubic meters has been removed as external overburden dumps on the east and the west side of excavations. These fill the southern boundary valley and extend over the plain to the south.

2 | METHOD AND METHODOLOGY

2.1 | Description about the study area

The Singrauli Coalfield is spread across the districts of Singrauli and Sonbhadra in the Indian states of Madhya Pradesh and Uttar Pradesh, mostly in the basin of the Son River. The Singrauli Coalfield is located between latitudes and longitude 23°45′-24°38′N and 82°30′-83°32′E. The north-eastern part of the coalfield sits on a plateau with an altitude of 500 meters (m) above mean sea level, well above the lower plains, with average altitudes of 280 m. The Singrauli Coalfield is divided into two parts by the Kachni River: the Moher sub-basin and the Singrauli main basin. Major parts of the Moher sub-basin lie within the Siddhi district of Madhya Pradesh and a small part lies in the Sonbhadra district of Uttar Pradesh. The Singrauli main basin lies in the western and southern parts of the coalfield and is largely unexplored.

2.2 | Description of Jayant Project

In the Jayant Blocks, rocks of Barakar formation that form a plateau are exposed. There are five coal seams: Kota, Turra A, Turra, Purewa Bottom, and Purewa Top. Kota and Turra A are thin seams (0.2–1.9 m), and they are not viable for commercial exploitation by opencast mining. The Turra seam occurs 3 to 5 m above the Turra A seam, and it is the thickest and best quality seam in the entire coalfield. The Turra seam's thickness varies from 13 m to 19 m. The thickness of the Purewa

EXHIBIT 2 Range (10th percentile–90th percentile) in bulk composition of fly ash, bottom ash, rock, and soil

Elements	Fly ash (EPRI, 2009) (mg/kg)	Bottom ash (EPRI, 2009) (mg/kg)	Rock (US Geological Survey [USGS], 2008) (mg/kg)	Soil (Shacklette & Boerngen, 1984; Smith et al., 2005) (mg/kg)
Aluminum	70,000–140,000	59,000–130,000	9,800–96,000	15,000–100,000
Calcium	7,400–150,000	5,700–150,000	6,000–83,000	1,500–62,000
Iron	34,000–130,000	40,000–160,000	8,800–95,000	7,000–50,000
Silicon	160,000–270,000	160,000–280,000	57,000–380,000	230,000–390,000
Magnesium	3,900–23,000	3,400–17,000	700–56,000	1,000–15,000
Potassium	6,200–21,000	4,600–18,000	4,000–45,000	4,500–25,000
Sodium	1,700–17,000	1,600–11,000	900–34,000	1,000–20,000
Sulfur	1,900–34,000	BDL–15,000	200–42,000	840–1,500
Titanium	4,300–9,000	4,100–7,200	200–5,400	1,000–5,000
Antimony	BDL–16	All BDL	0.08–1.8	BDL–1.3
Arsenic	22–260	2.6–21	0.50–14	2.0–12
Barium	380–5,100	380–3,600	67–1,400	200–1,000
Beryllium	2.2–26	0.21–14	0.10–4.4	BDL–2.0
Boron	120–1,000	BDL–335	0.2–220	BDL–70
Cadmium	BDL–3.7	All BDL	0.5–3.6	BDL–0.5
Chromium	27–300	51–1,100	1.9–310	15–100
Copper	62–220	39–120	10–120	5.0–50
Lead	21–230	8.1–53	3.8–44	BDL–30
Manganese	91–700	85–890	175–1,400	100–1,000
Mercury	0.01–0.51	BDL–0.07	0.1–2.0	0.02–0.19
Molybdenum	9.0–60	3.8–27	1.0–16	All BDL
Nickel	47–230	39–440	2.0–220	5–30
Selenium	1.8–18	BDL–4.2	0.60–4.9	BDL–0.75
Strontium	270–3,100	270–2,000	61–890	20–500
Thallium	BDL–45	All BDL	0.1–1.8	0.20–0.70
Uranium	BDL–19	BDL–16	0.84–43	1.2–3.9
Vanadium	BDL–360	BDL–250	19–330	20–150
Zinc	63–680	16–370	25–140	22–99

BDL, below detection limit; mg/kg, milligrams per kilograms.

EXHIBIT 3 Class of fly ash

Class F	Class C	Reference
Class F fly ash produced by burning of harder anthracite and bituminous coal.	Class C fly ash produced by burning of younger lignite or sub bituminous coal.	ASTM (1987); Page et al. (1979)
This class of fly ash contains less than 20% of lime.	This class of fly ash contains more than 20% of lime.	Obla (2008)
Alkali and sulfate contents are generally lower in class F.	Alkali and sulfate contents are generally higher in class C.	ASTM (1987); Page et al. (1979)
The quantities of Si, Fe, and K oxides are higher in Class F.	The quantities of Si, Fe, and K oxides are lower in Class C.	Murty and Narasimha Rao (1999)
The CaO, MgO, SO_3, and Na_2O quantities are lower in Class F.	While CaO, MgO, SO_3, and Na_2O quantities are higher in Class C.	Murty and Narasimha Rao (1999)
Class F fly ash has been rarely cementitious when mixed with water.	Class C fly ash usually has cementitious properties in addition to pozzolanic properties.	Shetty (2005, pp. 420–453)

Bottom and Purewa Top seams vary from 9 m to 12 m and from 5 m to 9 m, respectively. Detailed descriptions of the land use, coal seam details, and the size of overburden dump perimeters and area measurements for the Jayant Project appear in the tables in **Exhibits 5** and **6**.

IRS-1C satellite data and survey of India topographical map (63L/12) were used for the present study. The geo-coded sub-scene of the selected study area (path 102 and row 055) was acquired. The satellite image of the area had been procured in super structured

EXHIBIT 4 Overburden from surface mines

Particle size (micrometer)	Size fraction
>2,000	Gravel
50–2,000	Sand
2–50	Silts
<2	Clay

EXHIBIT 5 Project parameter of Jayant opencast plant

Particulars	As per sanctioned PR (10 MTY)	As per mine plan (12.5 MTY)
Mineable coal reserve (Mt) on 31.3.09	135.56	155.56
Balance life (years) as on 01.04.2009	14	14
Total lease area (Ha)	2,464	2,704
1. Forest land	1,162	1,162
2. Govt. land	467	467
3. Tenancy land	835	1,075
Stripping Ratio (m^3/t)	2.39	2.39
Ultimate working depth (m)	165	165
Particulars	**Value**	
Coal seam detail	**Thickness (m)**	**Reserve (Mt)**
1. Purewa top	5–9	40.06
2. Purewa bottom	9–12	91.60
3. Turra	13–19	217.27
Total reserve		348.93
Gradient (dip)		2–5
Average grade		C, E, F

Note. Exhibit data compiled by authors.

format. For the study, version 8.6 of Erdas Imagine software has been used.

3 | LABORATORY EXPERIMENT

For experiment number 1, samples of overburden materials were collected from the Jayant opencast project of Singrauli area. The area contains mostly the same type of material as overburden.

The experiment was performed to assess the impact of the removal of silt by water on the stability of overburden dumps. Overburden material is dumped at an angle less than the angle of repose of the material. The angle of repose of a material depends on several factors, such as the shape of the particles, the size of the particles, the dumping process, the angle of the base, and the like. In this experiment, the angle of repose of materials having different compositions (silt, clay, coarse gravel in the overburden) was measured by using an apparatus designed for this purpose. The arrangement for measuring the angle of repose was mounted on an iron frame as shown in **Exhibit 7**. The frame contained three platforms. On the uppermost platform a pipe with a diameter of 20 centimeters (cm) was fixed in conjunction with a funnel on its lower part to contain the material whose angle of repose was to be measured. The lowermost platform was also fitted with a 20 cm diameter pipe whose top was covered. The cover served as base for the formation of the heap of the material. A middle platform, which was movable, was set between the upper and lower platforms. The middle platform was also outfitted with a 20-cm hole and a funnel. The middle platform was added to maintain a smooth flow of material onto base (bottom platform). As the height of the material

EXHIBIT 6 Measured perimeters and areas of overburden dump of Singrauli Coalfield

Sl. no. of polygon	Mine block	Perimeter (m)	Area (m^3)
1	Amlohri	687.2	2,262.8
2		879.4	9,761.5
3		556.6	9,916.5
4	Nigahi	246.5	5,441.2
5		826.7	9,939.2
6		757.6	9,835.3
7		1,314.2	9,741.5
8		617.0	9,379.3
9	Jayant and Dudhichua	1,237.9	9,762.8
10		988.6	9,371.5
11		1,150.7	9,712.8
12		659.9	7,790.3
13		337.2	2,824.2
14		592.0	9,485.3
15		1,065.9	9,771.6
16		1,320.7	9,652.8
17		681.6	8,814.1
18	Khadia	428.5	3,139.6
19		994.7	8,896.5
20		845.1	9,772.8
21	Bina and Kakri	520.1	2,777.8
22		482.8	3,295.3
23		880.9	9,777.8
24		509.1	5,536.6
25		690.0	5,594.0
26	Jhingurdah	1,078.2	9,750.3
27		880.0	9,211.5
28	Gorabi B OCP	591.0	9,855.3
29		1,642.6	10,166.6
30		936.9	9,870.3
31	Gorbi	993.9	9,814.3
32		631.0	9,842.8
33		1,197.8	4,546.6
34		1,065.3	7,956.6
Sum total		28,287.6	273,267.4

Note. Data compiled by authors.

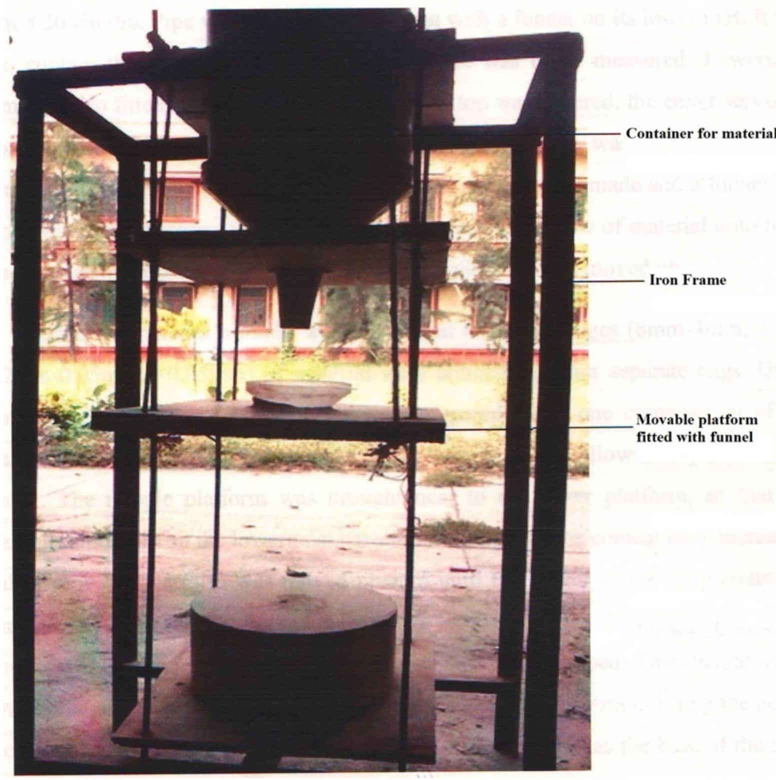


EXHIBIT 7 Apparatus designed to measure angle of repose [Color figure can be viewed at wileyonlinelibrary.com]

increased, as it is released from the top, the middle platform was moved upward.

The overburden material used in the experiment was sieved into four size ranges (i.e., 8 millimeter (mm) to 4 mm; 4 mm to 2 mm; 2 mm to 0.05 mm; and <0.05 mm). These materials were stored in four separate bags. For the experiment, the angle of repose was measured for each size of overburden individually. The material was placed into the pipe fixed in the top platform and allowed to pass through the funnel. The middle platform had been adjusted so it was near the bottom platform, which allowed the material to fall smoothly onto the base at the bottom. As the height of the conical heap increased, the middle platform was moved upward until the heap reached its maximum height. Once the maximum height was attained, the movable platform was fixed into place and the flow of the material was stopped. The height of the heap was then measured. Readings were taken to record the height of each heap formed from each size of overburden material. Using the height of the conical heap, the angle of repose of the material was calculated, as the base of the heap was constant and already known. This experiment was run several times with each size of overburden material (see the table in **Exhibit 8**).

Experiment number 2 involved determining the extent to which overburden and fly ash, when added to acidic mine water, could increase the pH to a number approaching neutral and over what period of time. For this experiment, samples of 1,000 milliliters (ml) in volume of mine water (pH 2.54) were collected into containers. Amounts of 70 grams (g) of overburden and 30 g of fly ash were added to each water sample and mixed. The pH values were taken of the treated mine water over time. The data of pH versus time of interaction were plotted as shown in the graph in **Exhibit 9**. As the graph shows, over time, the reaction between the overburden and fly ash with the mine water resulted in an increase in the pH of the mine water ranging between 2.54 and 5.8.

4 | RESULTS AND DISCUSSION

To measure the impact caused by mining in general, and overburden dumping in particular, remote sensing tools were used. A satellite image of the Singrauli area from 1998 has been procured from the geology department of Banaras Hindu University, Varanasi, and with this, a sheet methodology was developed to characterize the land pattern and natural features of the area.

The findings regarding overburden dump size perimeters and areas are given in the table in **Exhibit 10**, and the delineated overburden dumps are shown in **Exhibit 11**. As shown in Exhibit 10, the whole area was divided into 16 classes:

- water,
- fly ash pond,
- scrub land,
- dense forest,
- haul roads,
- moderately dense forests,
- grassland,
- colony,
- cultivated land,
- permanent roads,
- barren land,

EXHIBIT 8 Impact of particle size on the angle of repose

	Particle size (composition of material) %				Height of heap formed (based constant = 20 cm diameter)				Observations			
Sl. no.	4 mm–8 mm	2 mm–4 mm	0.05 mm–2 mm	<0.05 mm	h1 (cm)	h2 (cm)	h3 (cm)	h4 (cm)	Maxium height (cm)	Average value (cm)	Least (cm)	Average angle of repose (in degree)
1.1	100	0	0	0	6.9	7	7.2	7.2	7.2	7.1	6.9	35.37
1.2	0	100	0	0	7.9	8.1	7.8	7.9	8.1	7.9	7.8	38.3
1.3	0	0	100	0	9.3	9.6	9.4	9.3	9.6	9.3	9.3	42.92
1.4	0	0	0	100	9	9.1	8.9	9	9.1	9	8.9	41.98
2.1	40	50	10	0	7.9	7.8	7.6	8	8	7.8	7.6	37.95
2.2	40	40	20	0	8.2	8.1	8.3	8.2	8.3	8.2	8.1	39.35
2.3	40	30	30	0	8.5	8.8	8.8	8.6	8.8	8.7	8.5	41.02
2.4	40	20	40	0	9	8.9	8.8	8.9	9	8.9	8.8	41.66
2.5	40	10	50	0	9.1	8.9	9	9	9.1	9	8.9	41.98
2.6	40	0	60	0	9.1	8.9	9	9.1	9.1	9	8.9	41.98
3.1	30	60	10	0	7.9	8	8	8	8	8	7.9	38.65
3.2	30	50	20	0	8.2	8.1	8.1	8.3	8.3	8.2	8.1	39.35
3.3	30	40	30	0	8.6	8.9	8.4	8.4	8.9	8.5	8.4	40.36
3.4	30	30	40	0	8.9	8.9	8.9	8.8	8.9	8.9	8.8	41.66
3.5	30	20	50	0	9	9.1	9.1	9.2	9.2	9.1	9	42.3
3.6	30	10	60	0	9.3	9.1	9.1	9.2	9.3	9.2	9.1	42.61
3.7	30	0	70	0	9.2	9.2	9.3	9.2	9.3	9.2	9.2	42.61
4.1	47	20	30	3	8.9	8.7	8.8	8.8	8.9	8.8	8.7	41.34
4.2	45	20	30	5	8.9	8.8	9	8.9	9	8.9	8.8	41.66
4.3	40	20	30	10	9.2	9.1	9	9	9.2	9.1	9	42.3
4.4	35	20	30	15	9.1	9.2	9.2	9.1	9.2	9.2	9.1	42.61
4.5	30	20	30	20	9.2	9.3	9.3	9.3	9.3	9.3	9.2	42.92
4.6	25	20	30	25	9.4	9.5	9.5	9.5	9.5	9.4	9.4	43.22
4.7	20	20	30	30	9.5	9.4	9.3	9.3	9.5	9.3	9.3	42.92

- rural settlement,
- stone/hilly area,
- coal benches,
- wetland, and
- overburden dump.

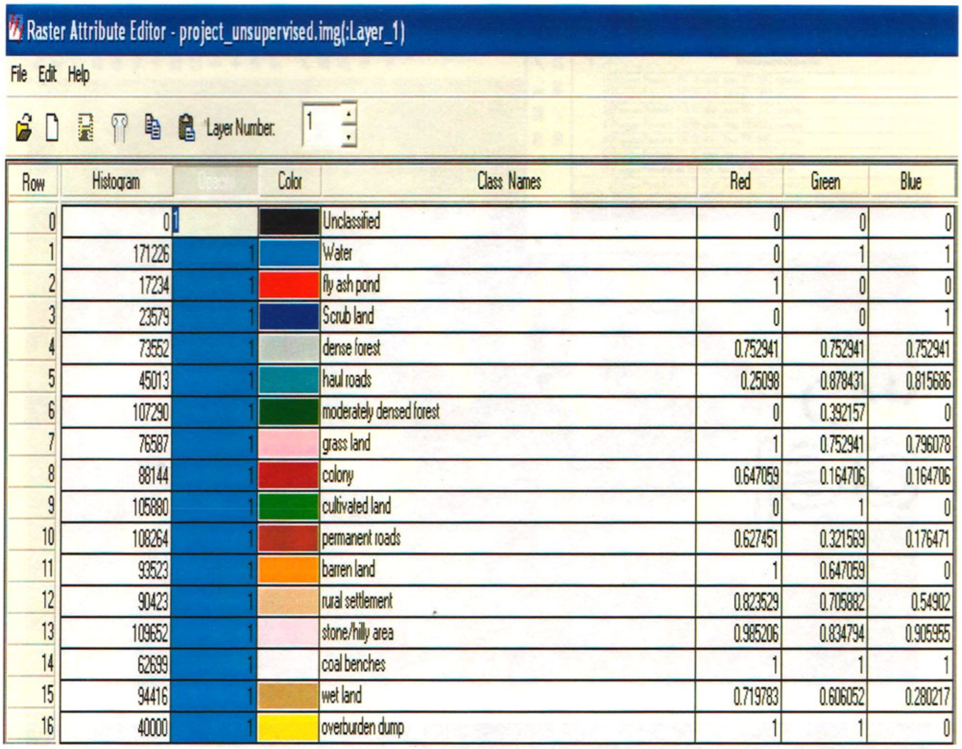
The remaining lands were unclassified. Using this technique, the total area of overburden dumping has been calculated. The perimeters of different overburden dumps have also been measured. Thirty-four polygons (overburden dump spoils), their perimeters, and areas are given in the table in Exhibit 11. It may be observed from the table in Exhibit 11 that in 1998, the total area occupied by waste was 271,264.4 square meters (m^2).

The impact of particle size on the angle of repose of overburden materials was examined through experimental means, using overburden sieved into four different size ranges as shown in the table in Exhibit 8. As this table shows, the value of the angle of repose for materials of different sizes varied from 35.37° to 43.22°. Initially, the height of the heap increased with the increasing percentage of fine materials and showed a rise in the value of angle of repose. However, after attaining a maximum value, the height began to decline. The maximum values of angle of repose were observed based on the material compositions:

Size	4 mm–8 mm	2 mm–4 mm	0.05 mm–2 mm	<0.05 mm
%Composition	25	20	30	25

As a result of experiment number 2, the analysis of data in respect to overburden mixed with fly ash disposal in voids of acidic mine water bodies are discussed as follows:

It can also be observed from Exhibit 9 that the pH value of acidic water (2.54) increases after overburden material and fly ash is added to samples of acidic mine water. The range of pH is increased from initial 2.5 to 5.8 after traveling number of times. The pH value after 7.2×10^2, 1.4×10^3, 2.9×10^3, 2.2×10^4, 4.3×10^4, and 1.3×10^5 min were found 2.5, 3.5, 3.7, 3.9, 4.0, and 5.8, respectively (Exhibit 9). It indicates the rate of increase in pH with reference to increasing time.



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Row	Histogram	Opacity	Color	Class Names	Red	Green	Blue
0	0	1		Unclassified	0	0	0
1	171226	1		Water	0	1	1
2	17234	1		fly ash pond	1	0	0
3	23579	1		Scrub land	0	0	1
4	73552	1		dense forest	0.752941	0.752941	0.752941
5	45013	1		haul roads	0.25098	0.878431	0.815686
6	107290	1		moderately densed forest	0	0.392157	0
7	76587	1		grass land	1	0.752941	0.796078
8	88144	1		colony	0.647059	0.164706	0.164706
9	105880	1		cultivated land	0	1	0
10	108264	1		permanent roads	0.627451	0.321569	0.176471
11	93523	1		barren land	1	0.647059	0
12	90423	1		rural settlement	0.823529	0.705882	0.54902
13	109652	1		stone/hilly area	0.985206	0.834794	0.905955
14	62639	1		coal benches	1	1	1
15	94416	1		wet land	0.719783	0.606052	0.280217
16	40000	1		overburden dump	1	1	0

EXHIBIT 9 Image classified into 16 classes [Color figure can be viewed at wileyonlinelibrary.com]

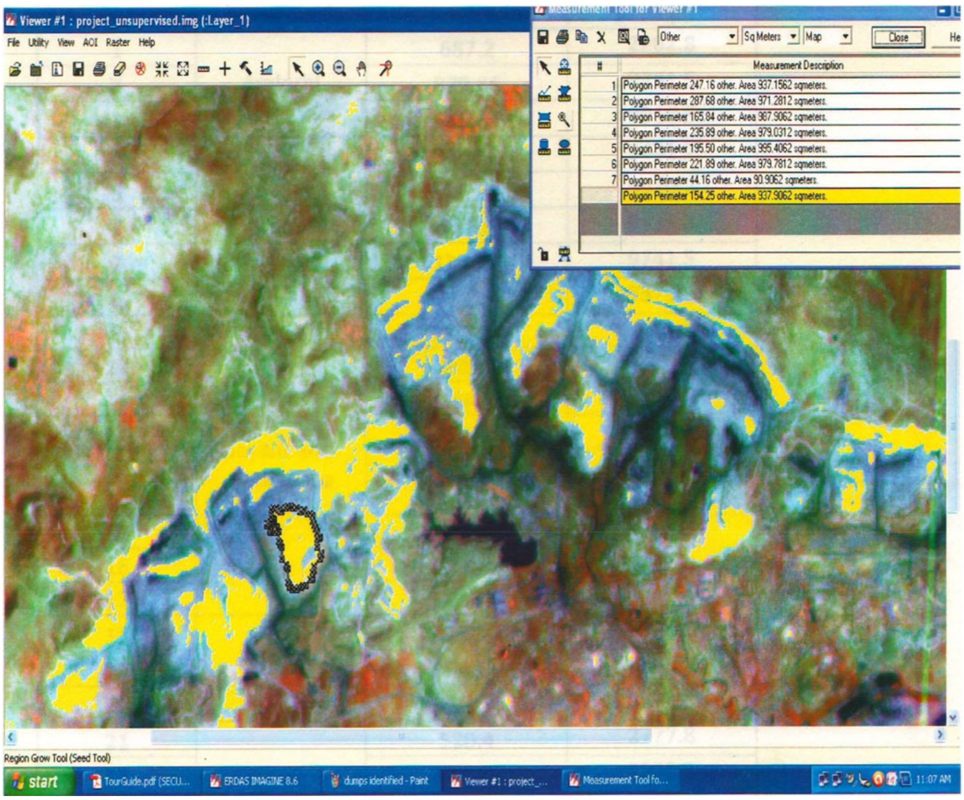

EXHIBIT 10 Using the measurement tool with region grow property to measure the area and perimeter of overburden [Color figure can be viewed at wileyonlinelibrary.com]

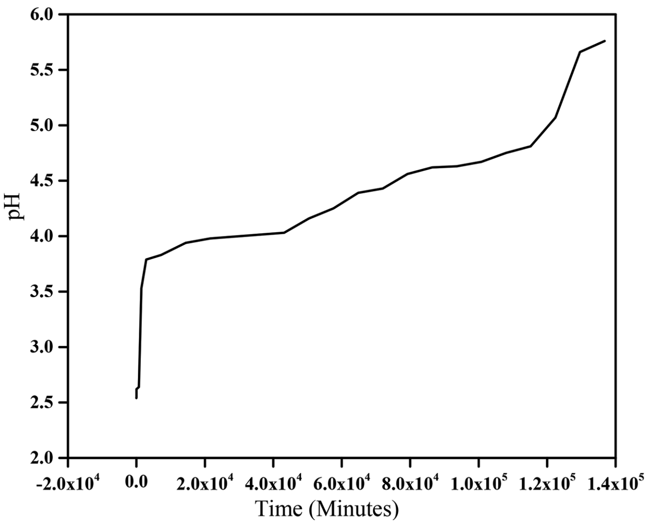

EXHIBIT 11 Time v/s pH value of acidic water putting mixed overburden and fly ash

5 | CONCLUSION

In the present study, it can be deduced that overburden dumps are affecting the land use pattern of Singrauli. The total area of land locked under the overburden dumps as of 1998 was 271,264.4 m^2. Thus, the need to consider methods for reducing the area of land covered by overburden is important both to facilitate mine operations and to protect the environment. This present study suggests that the particle size of overburden materials affects its angle of repose. Hence, it is possible that pit crushers can be used to process overburden materials into a uniform size to achieve a maximized angle of repose.

Successful management of acid water drainage can play a significant role in improving the ecosystem of the environment surrounding the mines as well as assisting in the long-term sustainability of mine sites.

The laboratory investigation of the R-pH value of overburden indicates that the overburden is alkaline in nature. We can say that the overburden can be used for the treatment of acidic water. Fly ash and overburden both have appreciable neutralization potential and may be used effectively for acid neutralization. The use of fly ash and waste rock will further improve the gainful utilization of fly ash and overburden for the improvement of water quality. The present study, which was performed on a laboratory scale, suggests that the acid neutralizing properties of fly ash and overburden will be assets to coal mines suffering from slight to moderate acidic drainage problems, both at the exploitation and the abandoned stages.

6 | SCOPE FOR FUTURE WORK

Other percentages of fly ash can be mixed with overburden to obtain a detailed study of the variation of geotechnical parameters as well the factor of safety of the resulting dumps. The method of mixing of fly ash with overburden, such as adding them in alternate layers, can be further explored. As the dumps were modeled in dry conditions, the effects of groundwater and rainfall on the slopes can also be examined.

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