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Acid drainage from coal mining: Effect on paddy soil and productivity of rice

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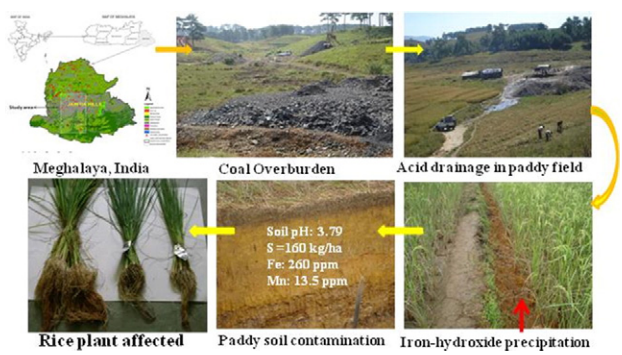
HIGHLIGHTS

- Mine drainage acidified paddy soil and increased exchangeable Al^{3+} saturation.
- Sulfur and extractable heavy metals increased in excess of critical limits.
- Paddy grain yield declined by 62% in contaminated than from unaffected fields.
- Concentration of excess sulfur significantly reduced biomass and grain yield.
- Paddy fields recovered some of their productivity 4 years after mining ceased.

GRAPHICAL ABSTRACT



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ABSTRACT

Overburden and acid drainage from coal mining is transforming productive agricultural lands to unproductive wasteland in some parts of Northeast India. We have investigated the adverse effects of acid mine drainage on the soil of rice paddy and productivity by comparing them with non-mined land and abandoned paddy fields of Jaintia Hills in Northeast India. Pot experiments with a local rice cultivar (*Myngoi*) as test crop evaluated biological productivity of the contaminated soil. Contamination from overburden and acid mine drainage acidified the soil by 0.5 pH units, increased the exchangeable Al^{3+} content 2-fold and its saturation on clay complexes by 53%. Available sulfur and extractable heavy metals, namely Fe, Mn and Cu increased several-fold in excess of critical limits, while the availability of phosphorus, potassium and zinc contents diminished by 32–62%. The grain yield of rice was 62% less from fields contaminated with acid mine drainage than from fields that have not suffered. Similarly, the amounts of vegetation, i.e. shoots and roots, in pots filled with soil from fields that received acid mine drainage were 59–68% less than from uncontaminated land (average shoot weight: 7.9 ± 2.12 g pot^{-1}; average root weight: 3.40 ± 1.15 g pot^{-1}). Paddy fields recovered some of their productivity 4 years after mining ceased. Step-wise multiple regression analysis affirmed that shoot weight in the pots and grain yield in field were significantly ($p < 0.01$) and positively influenced by the soil's pH and its contents of K, N and Zn, while concentration of S in excess of threshold limits in contaminated soil significantly ($p < 0.01$) reduced the weight of shoots in the pots and grain yield in the field.

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1. Introduction

The total coal reserve (mostly Tertiary) in the northeast India is estimated to be about 10^9 t. The northeastern states of Meghalaya have a reserve of about 640 Mt. (Indian Minerals Yearbook, 2012), and the Jaintia Hills district of Meghalaya alone has about 40 Mt of sub-bituminous coal. Mines from major coal belts in the district, namely Bapung, Sutnga and Khliehriat, produce nearly 40 million tonnes of coal per year; that is >80% of the total production of the state. The district has traditionally depended on agriculture, dominated by the production of paddy rice. However, with the introduction of opencast coal mining since 1970s there has been rapid degradation of the natural resources. In this form of surface mining, huge quantities of spoil, or overburden, in the form of gravel, rock, sand and soil are dumped on the arable land adjacent to the mines. These materials typically contain much sulfur (2 to 12%) in the form of metal sulfides (mostly iron pyrites), haematite and gibbsite (Dowarah et al., 2009; Nayak, 2013). Acid drainage and overburden from coal mines are acidic (pH: 2.0–3.0) and are rich in iron compounds, which on weathering and oxidation release sulfate, Fe^{2+} and other metallic ions. Due to heavy rain (>5000 mm $year^{-1}$), the influx of these highly acidic contaminants to the nearby otherwise fertile paddy fields are making the land unfit for cultivation (Swer and Singh, 2003; Sahoo et al., 2012). As a result, within the 5 years from 2007 to 2012 the production of rice in mine-affected paddy fields of Jaintia Hills declined from 1.80 t ha^{-1} to 1.50 t ha^{-1} (Anonymous, 2013).

The impacts of the mining, its wastes and acid drainage on the surrounding vegetation, water quality, biodiversity, eco-restoration, and re-vegetation strategies have been studied across India (Swer and Singh, 2003; Sarma, 2005; Dowarah et al., 2009; Nayak, 2013; Sahoo et al., 2012, 2013; Masto et al., 2015). However, the impact of acid mine drainage on the soil of paddy fields and rice productivity has not received equal attention. Therefore, we studied the effect of acid mine drainage from the major coal mining and over burden on soil properties of the paddy fields and rice productivity in the major coal belts across Jaintia Hills of Meghalaya, India. We also compared results with unaffected land and paddy soils where mining has ceased and land is recovering naturally. To complement the comparison we also did a pot experiment involving local rice genotype to evaluate the effect of acid drainage on paddy soils and its productivity for paddy rice. The findings should help in devising strategies to restore paddy fields that have suffered as a result of the mining and for sustaining their productivity in the future.

2. Material and methods

2.1. Location, soil and climate of the study area

Our study area is in the Jaintia Hills district of Meghalaya (between 25° 13′ and 25° 47′ N latitude and 91° 23′ and 91°56′ E longitude) (Fig. 1), with an elevation ranging from 1150 m to 1300 m above mean sea level (See Appendix A for details about study area). It is one of the most extensively mined districts of Northeast India. The district covers 3819 km^2. The topography is characterized by plateau incised by valleys with steep to gently sloping sides. The soil of the region developed on rocks of geological ages ranging from Pre-Cambrian to Recent. The parent material is composed of sandstones and shales with coal beds, and the Sylhet limestone. The valleys contain transported materials of shale origin and recent alluvium. Taxonomically, two soil orders, namely Cambisols and Alisols, dominate the region. The ground water table in the valley is approximately 3 m deep.

The climate is of the tropical monsoon type with an annual average rainfall exceeding 5000 mm, 77% is of which falls during Monsoon (May to September). August is the hottest month, with average minimum and maximum temperatures of 18.4 °C and 24.5 °C, respectively (see Appendix A). The coldest month is January when the average minimum and maximum temperatures are 8.7 °C and 16.6 °C, respectively. The average relative humidity varies from 85% in July to 61% in December.

2.2. Land use

The vegetation and land use in the region are varied. In 1975 forest occupied about 25% of the land, but by 2007 that cover had shrunk to only 12.5% (Sarma et al., 2010). Somewhat >55% of the land is dominated by scrub. The steeper slopes bear pine forest (*Pinus kesiya*). In the low-lying flat land in the valleys farmers grow rain-fed rice. They transplant the rice into puddled soil during the monsoon season (June to September or October) and harvest the crop in October or November. In winter; most of the land remains fallow. In the recent past, coal mining has led to major changes in land use: most of the productive arable land has gradually been affected by the mining. In the Jaintia hills the mined land increased from 3.26% to 11.2% of the total area between 1975 and 2007, while the land under agriculture decreased from 2.65% to 1.43% (Sarma et al., 2010). In two years (2005 to 2007) the area under paddy cultivation has declined from 16,593 ha to 12,195 ha in the district (Anonymous, 2013).

Coal mining in Jaintia Hills is done by surface (open-cast or open-pit) and sub-surface (rat-hole) methods. In the study area, coal is mined by open-cast methods with extensive surface excavation near both the forest and paddy fields. Overburden (mine spoil) from the mines is dumped in the nearby paddy fields (Fig. 2). During rainy seasons, acid drainage from the overburden and mines themselves spills on to the paddy fields, and in extreme cases yellowish precipitates of iron hydroxides form in the fields (Fig. 2) (Sarma, 2005). As a result, after 2 to 3 years of continued mining, the productivity in the fields influenced in this way declines drastically so that farmers are often forced to abandon those fields.

2.3. Site selection, soil sampling and analysis

With the help of a landuse map of the Jaintia Hills district, we traversed the region where mining had affected large proportions of the agricultural land (paddy field), and we chose to sample along a transect through the centre (Fig. 1). We distinguished three forms of land use, as follows.

1 Land where mining is current and has continued to pollute the land with overburden or acid drainage or both for at least 10 years.
2 Land where mining once contaminated the land but where mining ceased and has been allowed to recover for the last 4 years.
3 Land near to mines but which has not been contaminated by either overburden or acid drainage.

See Appendix A for detailed lists.

From class 1 we chose 60 fields at random, and from each we took some topsoil (0–15 cm) with a spade in February and March 2009 before the onset of the monsoon. From each of classes 2 and 3 we did likewise but from only 30 fields in each class. The soil from the contaminated fields contained some coarse debris. We removed the large stone sand also coarse plant litter (mostly crop residues from paddy). A proportion of each soil sample was used, without sieving, for a pot experiment, described below. Several undisturbed clods of soil (6–10 cm across) were collected at each site and used for the determination of aggregation (mean weight diameter) by wet sieving following standard procedures (Jalota et al., 1998). The remainder of each sample was dried in air, ground and passed through a 2-mm sieve (0.5 mm sieve for determination of organic carbon) for chemical and particle-size analysis. The last was done by the Bouyoucos hydrometer method (Jalota et al., 1998)

The air-dried, sieved samples were analysed for pH (1:2 soil: water), exchange acidity, cations Ca^{2+}, Mg^{2+}, K^+ and Na^+ extracted in ammonium acetate at pH 7.0, extractable available nitrogen (N) by alkaline potassium permanganate (Jackson, 1973), available phosphorus (P) by