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Research paper

Environmental assessment and nano-mineralogical characterization of coal, overburden and sediment from Indian coal mining acid drainage

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A B S T R A C T

The deterioration of environmental conditions is the major contributory factor to poor health and quality of life that hinders sustainable development in any region. Coal mining is one of the major industries that contribute to the economy of a country but it also impacts the environment. The chemical parameters of the coal, overburden, soil and sediments along with the coal mine drainage (CMD) were investigated in order to understand the overall environmental impact from high sulphur coal mining at northeastern coalfield (India). It was found that the total sulphur content of the coal is noticeably high compared to the overburden (OB) and soil. The volatile matter of the coal is sufficiently high against the high ash content of the soil and overburden. The water samples have a High Electrical Conductivity (EC) and high Total Dissolve Solid (TDS). Lower values of pH, indicate the dissolution of minerals present in the coal as well as other minerals in the mine rejects/overburden. The chemical and nano-mineralogical composition of coal, soil and overburden samples was studied using a High Resolution-Transmission Electron Microscopy (HR-TEM), Energy Dispersive Spectroscopy (EDS), Selected-Area Diffraction (SAED), Field Emission-Scanning Electron Microscopy (FE-SEM)/EDS, X-ray diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), Raman and Ion-Chromatographic analysis, and Mössbauer spectroscopy. From different geochemical analysis it has been found that the mine water sample from Ledo colliery has the lowest pH value of 3.30, Tirap colliery samples have the highest electrical conductivity value of 5.40 ms cm^{-1}. Both Ledo and Tirap coals have total sulphur contents within the range 3–3.50%. The coal mine water from Tirap colliery (TW-15B) has high values of Mg^{2+} (450 ppm), and Br^{-} (227.17 ppm). XRD analysis revealed the presence of minerals including quartz and hematite in the coals. Mineral analysis of coal mine overburden (OB) indicates the presence both of pyrite and marcasite which was also confirmed in XRD and Mossbauer spectral analysis. The presented data of the minerals and ultra/nano-particles present shows their ability to control the mobility of hazardous elements, suggesting possible use in environmental management technology, including restoration of the delicate Indian coal mine areas.

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1. Introduction

Coal mining is one of the major industries that contribute to the economy/economic development of a country; however it causes noticeable deterioration to the environment (Hower et al., 1998; Tiwary, 2000). As a primary source of energy, coal has become essential to meet the energy demand of a country. Out of 861 billion tons of the world's total coal reserves (World Coal Association, Coal facts 2015), 60 billion tons are Indian coal, out of which the northeastern region of India has a deposit of about 1.597 billion tons (Ministry of Coal, Provisional Coal Statistics, 2014–2015). These northeastern coals are characterized by high sulphur content and occur in the states of Assam, Meghalaya, Sikkim, Nagaland and Arunachal Pradesh (Saikia et al., 2015a). These coals are bituminous coal in rank. In the northeastern coalfield, Coal India Limited is operating in five working collieries namely Ledo, Baragolai, Tirap, Tikak and Tipong. While the underground coal mining is a more environment friendly method, the open cast mining operations cause major damage to the environment. In the Ledo colliery in Assam, open cast mining is the main method being used.

1.1. Northeastern coalfield and coal mine drainage

The sulphur in the coal is found to be present in five forms – mainly sulphate sulphur, pyritic sulphur, organic sulphur, elemental sulphur and secondary sulphur (Baruah and Gogoi, 1998) with no elemental sulphur been reported in the Assam coals (Baruah, 1992). The occurrence of another type of sulphur has been established in Assam coals (Baruah, 1984, 1992). This sulphur has been reported as secondary sulphur containing Fe–S functional groups associated with coal organic matter (Baruah, 1992).

The major part of the inorganic sulphur in coals consists of pyrite (FeS_2) which occurs both in macroscopic and microscopic forms (Baruah et al., 2006). Coal mining leads to extensive environmental degradation which has an adverse and hazardous effect on human health (Sahoo and Bhattacharjee, 2010). The coal mining activity in the northeastern coalfield, Margherita, has resulted in significant ecological degradation surrounding the Ledo area and exerts a long lasting impact on the landscape, ecosystem and socio-cultural-economic conditions (Baruah and Khare, 2010; Giri et al., 2014). Coal mining is accompanied by the generation of mine waste, dust, land subsidence, deforestation, spontaneous combustion of coal etc. (Equeenuddin, 2010). A large volume of overburden (OB) materials accumulated during the mining of coal is subsequently exposed to the environment (Baruah et al., 2006) and their removal results in significant forest and top soil loss. This leads to a major ecological and environmental degradation especially when the materials contain sulphur (Saikia et al., 2015a,b). Due to its high sulphur content (2–11%) (Chabukdhara and Singh, 2016) the mine OB from the northeastern coalfields also tends to produce highly acidic leachates in a pH range of 2.0–3.0 (Baruah et al., 2006; Dowarah et al., 2009). Mining affects the water regime of the area in different ways, disturbing the natural drainage pattern, lowering the water table and polluting of surface and sub-surface water bodies (Sheoran and Tholia, 2011). Coal mine drainage (CMD) is enhanced by physical, biological and chemical factors. It is an unavoidable by-product of the mining industry which is generally characterized by a high concentration of dissolved heavy metal sulphates; low pH and high electrical conductivity (Somerset et al., 2005). The heavy metals released during coal mining are elements with metallic properties and specific weights higher than 5 g/cm^3, which do not degrade (Gorhe and Paszkowski, 2006). The elevated concentrations of trace metals have an adverse effect on humans as well as plants and animals (Singh et al., 2012, 2015). In humans the elevated intake of trace metals can cause allergic problem as these elements enter the food chain consequently forming complex toxic compounds leading to detrimental effect on biological functions (Jarup, 2003). These toxic substances are the heavy metals like Fe, Hg, As, Pb, Zn, Cd etc. (Guha Roy, 1991; Singh et al., 2012).

Open cast coal mine spoils are deficient in plant nutrients due to biologically rich top soil being removed and cause a serious problem for revegetation and restoration (Maharana et al., 2015). As the mining has been continued over a long period, huge excavations exist and other environmental problems including air, water, noise pollution and deforestation occur (Dutta et al., 2004; Dkhar and Rai, 2005; Borpujari and Saikia, 2006; Sarma and Barik, 2011).

Pyrite present in the coal and overburden (OB) materials are leached to form low pH drainage due to the metabolic activity of some acidophilic bacteria such as *Thiobacillus ferroxidans* (Baruah and Khare, 2010). These microbes are capable of surviving in low pH and catalyse the pyrite oxidation where it obtains energy by the oxidation of either Fe or S. The oxidation of iron sulphides resulting in formation of CMD is a significant environmental hazard, faced by a large number of coal mining industries all over the world. CMD refers to the outflow of acidic water from coal mines, often abandoned mines where ore or coal mining activities have exposed rocks containing the sulphur-bearing mineral pyrite, which reacts with air and water to form sulphuric acid and dissolved iron and as water washes through the mines, this compound forms a dilute acid, which can wash into nearby rivers and streams (Coal mining and environment, 2010). The common characteristics of CMD are low pH, high concentration of sulphates, total dissolved solids and the drainage also includes hazardous elements (HEs). The influx of untreated CMD into water bodies can severely degrade the water quality by producing an environment devoid of most aquatic life and unfit for use. The severity and extent of damage depends upon a variety of factors including the frequency, volume and chemistry of the drainage and the size and buffering capacity of the receiving stream (Kimmel et al., 1983). Once acid drainage is created, HE's are released into the surrounding environment and become readily available to biological organisms. When fishes are exposed directly to metals and H^+ ions through their gills, impaired respiration may result from chronic and acute toxicity (Giri et al., 2014). If acid producing mines located in permeable formation, water with low pH percolates into the aquifers and gets spread over a wide area through ground water movement (Lottermoser, 2003). The contaminants from mine drainage can persist for a long time after closer of mine (Demchak et al., 2004).

According to a study conducted by Tiwary (2001) on the quality of the acidic and non-acidic mine water and leachate characteristics of the open cast mining overburden dumps it reveal that the pollutants such as Total Suspended Solids (TSS), Total Dissolved Solids (TDS), oil, grease and heavy metals are present in coal mining areas and the waste effluents in coal mine drainage leads to water quality deterioration. The increasing trends of open cast mining leads to production of huge quantities of dust and thereby cause air pollution in work zone and the surrounding areas (Ghose and Majee, 2000). The iron hydroxide [e.g. $Fe(OH)_3$] precipitate was found a long distance away in streams affected by CMD. The hydroxide may physically coat the surface of the stream sediments and stream beds destroying habitat, diminishing availability of clean gravels used for spawning and reducing fish food items such as benthic macro invertebrates (Hoehn and Sizemore, 1977; Giri et al., 2014). The