

Diminishing Life-Sustaining Role of Water in Jaintia Hills of Meghalaya Due to Coal Mining

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The Jaintia Hills District of Meghalaya is a major coal producing area. Sutnga, Lakadong, Musiang-Lamare, Khliehriat, Ioksi, Ladrymbai, Rymbai, Bapung, Jarain, Shkentalang, Lumshnong and Sakynphor are the main coalfields of the area. Coal extraction is done by primitive method commonly known as 'rat-hole' mining. Most of the mining activities are small-scale ventures controlled by individuals who own the land. Though mining operation, undoubtedly, has brought wealth and employment opportunity in the area, but simultaneously has lead to extensive environmental degradation and disruption of traditional values in the society. Environmental problems associated with mining have been felt severely because of the region's fragile ecosystems and rich biological and cultural diversity. Large scale denudation of forest cover, scarcity of water, pollution of air, water and soil and degradation of agricultural lands are some of the conspicuous environmental implications of coal mining (Das Gupta and Tiwari, 2000; Swer and Singh, 2003). Besides, a vast area has become physically disfigured due to haphazard dumping of overburden, caving in of the ground and subsidence of land.

The problem of water quality degradation and its adverse impact on availability of potable and irrigation water, soil quality

and agricultural productivity, and biodiversity in the area has attracted increasing attention of major stakeholders particularly of users (rural folk and farmers), local administration, researchers and authorities. Recently, we have initiated a study on biomonitoring of water quality in the area and collected data pertaining to various physico-chemical and biological parameters in relation to benthic macroinvertebrate fauna. Here, we discuss some of our observations on coal mining in relation to water quality deterioration and associated problems including adverse impacts on aquatic biota. The article also summarises some environmental management initiatives that can be useful in mitigation of the environmental degradation and rehabilitation of degraded ecosystems of the area.

Coal Mining and Water Quality Degradation

The extraction of coal creates a variety of impacts on the environment before, during and after the mining operations. The extent and nature of impacts can range from minimal to significant depending on a range of factors associated with ongoing mining processes as well as post mining management of the affected landscapes. The sensitivity of the local environment also determines the magnitude of the problem. Usually, an ecologically fragile environment has been found highly vulnerable, subjected to long-term ecological impacts.

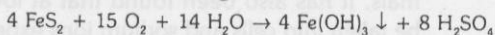
Studies done in Jaintia Hills suggest that unscientific coal mining is the primary cause of environmental degradation including deterioration of water quality and availability in the area. The influx of acidic water oozing out from mines or acid mine drainage (AMD) into the rivers and streams of the area is mainly responsible for degradation of water quality leading to degradation of aquatic habitat. The AMD contamination of water bodies has not only made water unfit for desired uses but also resulted into an environment devoid of most aquatic life. AMD contamination has adversely affected various uses of water including agricultural (irrigation and livestock) and domestic water supplies along with large scale degradation of cultivable land.

The severity and extent of degradation have spatio-temporal variations in the coal mining area. It varies in space and time depending upon climatic conditions and season, extent of

mining and other local factors including the quantity and quality of the acidic drainage, buffering capacity of the receiving stream and micro-hydrological conditions. Water bodies of the area have also been severely affected by leaching of heavy metals, organic enrichment, turbidity and silting.

Acid Mine Drainage

Acid Mine Drainage (AMD) is the biggest environmental threat from the coal mines, affecting the water resources particularly. The AMD is metal-rich acidic water formed from chemical reaction between water and coal/rocks containing sulphur bearing mineral—the pyrite. Mine drainage is generated when pyrite reacts with air and water to produce sulphuric acid and dissolved iron. During the process of pyrite oxidation, dissolved Fe^{2+} , SO_4^{2-} and H^+ , followed by the further oxidation of the Fe^{2+} to Fe^{3+} , are formed. Some or all of this iron can precipitate to cause turbidity of water (in the form of the red, orange, or yellowish colour), and sedimentation at the bottom of streams. The acid runoff or AMD aggravates the problem further by dissolving heavy metals such as aluminium, copper, lead, mercury etc. found in rocks and soil. As a result, the AMD contaminated surface water is not only acidic but also rich in different metals. The rate and degree of acid mine drainage formation can be increased by the action of certain bacteria found in nature. The overall chemistry of AMD formation is summarized in reaction given below:



(Pyrite + Oxygen + Water \rightarrow Yellow precipitate \downarrow + Sulphuric Acid)

The sulphuric acid on contamination lowers the pH level of water and makes water acidic. Whereas yellow precipitate of iron hydroxide gives characteristic yellowish or reddish colour to the water. The iron hydroxide commonly forms a reddish-yellow to yellowish-brown coating on rocks and other surfaces. The extent of AMD contamination varies greatly from site to site, as its formation is dependent on a variety of factors including the activity of bacteria, pH, pyrite chemistry and surface area, temperature, and O_2 concentration. AMD contamination is often characterised by one or more of the following five major components (mentioned below), which impair aquatic life either separately or in combination:

1. Low pH (high acidity),
2. High metal concentrations,
3. Elevated sulphate levels,
4. Excessive suspended solids (turbidity), and
5. Siltation.

Low pH (High Acidity)

The majority of AMD contaminations lead to acidity or low pH of the contaminated water bodies. Acidic water is a matter of primary concern since it can directly be injurious to aquatic organisms. It also facilitates leaching of toxic metals into the water that could be hazardous to aquatic life directly or can disturb the habitat after precipitation. The pH of waters in rivers and streams of Jaintia Hills has been found in range of 3–5. Although in some streams it has been recorded as low as 2.5 or even less. This indicates serious condition of the water bodies of the area that hardly can support any aquatic life such as fish, amphibians and insects.

In fact, most aquatic organisms have a well defined range of pH tolerance. Any substantial change in pH of the surrounding water leads to various physiological and ecological disturbances in affected organisms. If pH falls below the tolerance range, death occurs due to respiratory or osmoregulatory failure in the affected organisms (Kimmel, 1983). Low pH causes disturbance in the sodium and chloride ions balance in the blood of aquatic animals. It has also been found that at low pH hydrogen ions may be taken into cells and sodium ions expelled out of the cell (Morris *et al.*, 1989). Mayflies are one of the most sensitive groups of aquatic insects to low pH; stoneflies and caddisflies are generally less sensitive to low pH. Mayflies and stoneflies that normally live in neutral water experience a greater loss of sodium in their blood when exposed to low pH than do acid-tolerant species of stoneflies (Sutcliffe and Hildrew, 1989).

High Metal Concentrations

Layers of rock and earth above the coal seams removed during mining commonly contain traces of iron, manganese, and aluminium and can also contain other heavy metals. These

metals can be dissolved from mining sites through the action of acid runoff or can be washed into streams as sediment. Most of the water bodies in the coal mining areas of Jaintia Hills have been found containing high concentration of various metals. Many metals, though common, can be toxic to fish and other aquatic organisms when present in highly dissolved concentrations. Dissolved iron and iron precipitate, for example, can kill the aquatic biota that fish feed on, thus reducing the overall fish population.

Iron and aluminium are common components of mine drainage which can have a detrimental effect on aquatic life. Iron can be found in different forms that combine with a variety of other ions. The impact of mine drainage containing elevated iron and aluminum on aquatic ecosystems is complex and detrimental. Manganese is another metal that is widely distributed in mine drainage. Manganese can be present in a variety of forms and compounds and complexes with organic compounds. Manganese is difficult to remove from discharges because the pH must be raised to above 10.0 for its precipitation and removal. Manganese, therefore, is persistent and can be carried for long distances downstream of the source of mine drainage. Less information is available on the effects of elevated manganese concentrations on aquatic life than the effects of iron and aluminium. Trace metals such as zinc, cadmium, and copper, which may also be present in mine drainage, are toxic at extremely low concentrations and may act synergistically to suppress algal growth and affect fish and benthos (Hoehn and Sizemore, 1977).

Elevated Sulphate Levels

As pyrite wastes are chemically broken down, sulphate ions are produced in runoff water. Sulphates combine with water molecules and form sulphuric acid or can attach to calcium atoms to form gypsum sludge. Sulphuric acid is mainly responsible for acidity of the contaminated water. Higher sulphate levels have also been found in AMD contaminated rivers and streams of Jaintia Hills.

Suspended Solids and Turbidity

Dissolved iron and other metals precipitate at a specific pH. For instance iron precipitates at pH greater than 3.5 on coming in

contact with oxygen and forms ferric hydroxide. Precipitation of ferric hydroxide causes turbidity and deposition on the stream bottom that adversely affects macroinvertebrates, fish and other aquatic organism by altering their habitat and visibility (Hoehn and Sizemore, 1977). The severity is dependent on stream pH and the thickness of the precipitate. Generally, the effect of precipitated iron is less severe in less acidic or alkaline water (Haines, 1981).

Particles of iron precipitate often cover the bodies of macroinvertebrates and impair their normal life. Iron precipitate can also clog the gill structures of fish which eventually lead to death due to anoxia. Since precipitation of iron affects a wide range of aquatic animals in streams, it can also fragment or completely wipe out the aquatic food chains and thus adversely affects the populations of fish and others vertebrates. Koryak *et al.* (1972) found that ferric hydroxide greatly diminishes total biomass of benthic organisms and limits fish populations in streams with survivable pH levels. Hoehn and Sizemore (1977) have reported that precipitates of metals affect aquatic organisms by decreasing the oxygen availability due to forming a coating on gills and body surface. It also affects the reproduction of the animals by smothering eggs and killing sperms. Covering of stream bottom and filling of crevices in rocks by precipitates make the surrounding unfit for habitation by benthic organisms.

Excessive Siltation

In addition to the above-mentioned factors, siltation of rivers and streams of the mining area also plays a significant role in degradation of water quality and reduction of aquatic biota. Silting of clay, sand, gravels and fine coal particles is a common feature in most rivers and streams of the mining area. A significant threat to water quality and aquatic organisms comes from eroding soils at abandoned mining sites and deposition of unwanted material in the water bodies. It has been reported that small fly nymphs, insect larvae, and other organisms that form the base of aquatic food chains can be wiped out by heavy accumulations of soil and mine waste particles that wash into streams together with rain water (Hoehn and Sizemore, 1977). Suspended silt particles can clog the gills of fish and smother eggs on the stream bottom.

Effects of Acid Mine Drainage on Aquatic Organisms

Mine drainage is a complex of elements that interact to cause a variety of effects on aquatic life that are difficult to separate into individual components. Toxicity is dependent on discharge volume, pH, total acidity, and concentration of dissolved metals. pH is the most critical component, because lower the pH more severe the potential effects of mine drainage on aquatic life. The overall effect of mine drainage is also dependent on the flow (dilution rate), pH, and alkalinity or buffering capacity of the receiving stream. The higher the concentration of bicarbonate and carbonate ions in the receiving stream, the higher the buffering capacity and the greater the protection of aquatic life from adverse effects of acid mine drainage (Kimmel, 1983).

The acid mine drainage is one of the biggest environmental problems of the mining areas. Studies done to understand the adverse effects of mine drainage on aquatic biota (McKnight and Feder, 1984; Kelly, 1988) suggest that the acid mine drainage affects the aquatic biota mainly in three ways, viz. (1) acidity, (2) toxicity of dissolved metals, and (3) precipitation of metal hydroxides (mainly iron and aluminium hydroxides). Acid mine drainage with increased metal concentrations discharging into rivers and streams can have a devastating effect on the aquatic life. Secondary effects such as increased carbon dioxide tensions, oxygen reduction by the oxidation of metals, increased osmotic pressure from high concentrations of mineral salts, and synergistic effects of metal ions also contribute to toxicity. In addition to chemical effects of mine drainage, physical effects such as increased turbidity from soil erosion, accumulation of coal particles, and smothering of the stream substrate from precipitated metal compounds may also occur and has adverse impacts on aquatic ecosystem (Parsons, 1968; Warner, 1971).

AMD Contamination and Macroinvertebrates

Aquatic communities of unaffected rivers and streams comprise of phytoplanktons, periphyton, macrophytes, zooplanktons, invertebrates and vertebrate species which play important role in normal functioning of the aquatic ecosystem. Any physical or chemical or biological change in water bodies affects one or all

species and disturbs the normal functioning of the aqual ecosystem. The benthic (bottom-dwelling) communities of rive and streams consist of those organisms which grow in, on, otherwise in association with various bottom substrates. Benth macroinvertebrates are often used as indicators of water quali because of their limited mobility, relatively long residence time and varying degrees of sensitivity to pollutants.

Unaffected streams generally have a variety of species wi representatives of almost all insect orders, including a high dive sity of insects classed in the taxonomic orders of Ephemeropte: (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflie commonly referred to as EPT taxa. Like many other potenti pollutants, mine drainage causes a reduction in the diversity ar total numbers, or abundance, of macroinvertebrates and chang in community structure. Water bodies affected by AMD posse a lower percentage of EPT taxa. Moderate AMD contaminatic eliminates the more sensitive species (Weed and Rutschky, 1977) whereas severely contaminated conditions are characterised b dominance of certain taxonomic representatives of pollution-to erant organisms, such as aquatic worms (Tubificidae), midc larvae (Chironomidae), alderfly larvae (*Sialis*), fishfly larva (*Nigronia*), crane fly larvae (*Tipula*), caddis fly larvae (*Ptilostomis* and non-benthic insects like predaceous diving beetle (Dytiscidae) and water boatmen (Corixidae) etc. (Nichols an Bulow, 1973; Rosemond *et al.*, 1992). While these tolerat organisms may also be present in unpolluted streams, the dominate in affected stream sections. Mayflies are generally ser sitive to acid mine drainage, however, some stoneflies and cadd flies are tolerant of dilute acid mine drainage.

AMD Contamination and Fish Population

The fish in natural habitat often depend for their food o small aquatic organisms including macroinvertebrates. As consequence of depletion of aquatic invertebrates, the fishes d not get adequate supply of food and suffer indirectly from AMI contamination. AMD also has direct effect on fish by causing vari ous physiological disturbances. The primary cause of fish deat in acid waters is loss of sodium ions from the blood. Less avail ability of oxygen to the cells and tissues leads to anoxia and deat

as acid water increases the permeability of fish gills to water, adversely affecting the gill function (Brown and Sadler, 1989). Ionic imbalance in fish may begin at pH of 5.5 or higher, depending on the tolerance of the species. Severe anoxia occurs below pH 4.2 (Potts and McWilliams, 1989). Low pH that is not directly lethal may adversely affect fish growth rates and reproduction (Kimmel, 1983). It has been found that fish species are severely affected below the pH 5.5. Water pH below 4.5 in most of the rivers in Jaintia Hills is most likely responsible for complete elimination of fish from the natural water bodies of the area.

Biomonitoring of Water Quality in Jaintia Hills

Recently, we have undertaken a study on Biomonitoring of water quality in coal mining areas of Jaintia Hills District using benthic macroinvertebrates. The study revealed presence of only a few tolerant species namely *Chironomus* larvae, dragonfly larvae, water bugs, worms etc. in low abundance and species diversity. However, studies done on river away from the coal mining area (i.e. upstream of River Myntdu) show relatively higher abundance and species diversity of macroinvertebrates, including many sensitive species. The presence of only a few tolerant species of macroinvertebrates in low abundance, and absence of other commonly found aquatic organisms such as fish, frog and crustaceans in rivers and streams of the mining area indicate declining trend of diversity of aquatic fauna (Table 1).

The quality of water has degraded to the extent that rivers and streams are losing their life sustaining role and becoming devoid of aquatic life. Fish and many other sensitive species have already been eliminated from the streams due to acidity and high metal concentration. Organic enrichment of water bodies due to various anthropogenic activities is leading to lower Dissolve Oxygen (DO) and higher Biochemical Oxygen Demand (BOD) levels in water. This has further made the ambience unfit for survival of aquatic life. The polluted water has contaminated the agricultural fields, reduced drastically the agricultural productivity, and forced the farmers to abandon the agricultural activity. Besides, area is facing acute shortage of potable and irrigation water as many perennial rivers and streams have dried up or turned into seasonal due to percolation of water into the mine

Table 1. Occurrence of Macroinvertebrates in Rivers and Streams of Jaintia Hills

Benthic macro-invertebrates	Rivers/Streams							
	Myntdu As Control	Waikhyrwi (Sutnga)	Rawaka (Rymbai)	Kmai-Um (Rymbai)	Metyngka (Rymbai)	Um-Mynkseh (Lad Rymbai)	Thwai Kongor (Bapung)	Um Krypong (Khliehriat)
Plecoptera (stonefly nymph)	P	A	A	A	A	A	A	A
Ephemeroptera (Mayfly nymph)	P	A	A	A	A	A	A	A
Tricoptera (Caddis fly larvae)	P	A	A	A	A	A	A	A
Odonata (Dragon fly)	P	P	A	A	A	P	A	A
Hemiptera (Water bugs)	P	P	A	A	A	P	A	A
Diptera (chironomous larvae)	P	P	A	A	A	P	A	A
Crustacea	P	A	A	A	A	A	A	A
Other aquatic organisms (fishes, frogs and tadpoles)	P	A	A	A	A	A	A	A

P - Present; A - Absent

Note: The rivers Waikhyrwi, Rawaka, Kmai-Um, Metyngka, Um-Mynkseh, Thwai Kongor and Um Krypong affected by coal mining show presence of only a few species of benthic macroinvertebrates, whereas upstream of river Myntdu, which is not affected by coal mining shows presence of many macroinvertebrates including some pollution sensitive species.

pits. Hence, mining operation has proved detrimental to the fragile ecosystems of the area, in general and diminished the life-sustaining role of water, in particular.

Ecorestoration of Mining Affected Area

Under prevailing grave conditions of general environment and water quality and aquatic life in rivers and streams of Jaintia Hills, there is an urgent need for initiating activities for ecorestoration of the affected areas. Here, we describe some measures to mitigate the environmental problems of the area including the improvement of water quality. Filling of mine pits, channelling of acidic seepage for checking AMD contamination of water bodies and crop fields, extensive afforestation, neutralization of acidity, conservation of topsoil etc. coupled with scientific management of mining operation are some of the measures which can be helpful in ameliorating the environmental problems of the area.

Filling of Abandoned Mines

Abandoned mines are continuous source of AMD, as the exposed rocks come in contact with water and air, and generate acidic seepage for long time to come. Abandoned unfilled mines cause subsidence of land mass and development of cracks that promote percolation of surface water, erosion of topsoil and generation of AMD. Hence, it is very important to fill the mines with the same overburden material that was removed during the process of mining. Additional rocks, sand and soil can also be used to fill the mines.

Extensive Afforestation and Revegetation of the Mined Areas

Establishing vegetation on coal mined land is an important step in the process of ecorestoration. Vegetation helps in stabilizing the soil surface from erosion and controlling siltation. From the viewpoint of preventing acid mine drainage, vegetation is beneficial for reducing the amount of water and atmospheric oxygen entering the mine overburden. Some plants, particularly undergrowth helps in removal of dissolved metals and other toxic components

from the water and soil. Hence, extensive afforestation of the mined areas with local and tolerant plant species will be of great help in ecorestoration of the degraded ecosystems.

Neutralisation of Acidity

Various carbonate minerals such as limestone, calcite, dolomite etc. are found in nature in abundance. These materials produce alkalinity thus can reduce the effect of AMD in two ways. If alkaline water comes in contact with pyrite, the acid-generating reactions may be inhibited so that little or no AMD is formed. Alternatively, once AMD has formed, its interaction with alkaline materials may neutralize the acidity and promote the removal of Fe, Al and other metals from the water. Use of such alkaline materials in scientific manner may reduce the acidity of water and save agricultural fields and water bodies to some extent.

Conservation of Topsoil

Soil is essential for plant growth and agricultural productivity. Once lost, it takes decades in formation and regeneration. Hence, conservation of top soil is very important in the process of ecorestoration. Removal of topsoil prior to mining and its replacement as the final cover following coal mining is most beneficial method for assuring quick establishment of vegetation and ecorestoration. In addition to the benefits of topsoiling for improving vegetation and restoring pre-mining soil productivity, topsoil also helps in retention of water for plant growth. Further, topsoil limits the infiltration of water into the ground. It has been found that a final cover of topsoil on a mine backfill significantly reduces the infiltration rate of water. Limited infiltration of water means less production of AMD.

Management of AMD and Surface Water

Proper management of AMD and surface water in mining areas can be of great use in mitigation of water pollution and related environmental problems. Channelling of AMD and its prevention from contamination of agricultural fields and water resources can save agricultural land and water bodies from degradation. Use

of proper water management techniques to prevent AMD on mining sites can also control erosion and sedimentation, and surface water infiltration.

Conclusion

Water, a precious natural resource is vital for life of all organisms on the earth. Clean water is critical to the health, economic and social well-being, and quality of life. Any undesirable change in water quality affects not only the human beings and their activities but also a variety of flora and fauna of the area. As a result, the same life sustaining water turns into a life threatening substance that affects living organisms at different levels.

The rivers and streams of the Jaintia Hills, Meghalaya are the greatest victims of the coal mining. Contamination of acid mine drainage (coloured acidic seepage originating from mines and spoils), leaching of heavy metals, organic enrichment and silting are some of the major causes of water pollution. Degradation of water quality in the area is evidenced by low pH (in the range of 3-5), high conductivity, high concentration of sulphates, iron and other toxic metals, low DO and high BOD. Mine drainage is affecting aquatic life from elimination of all but the few tolerant species. As a result, the rivers and streams which had supported extremely rich biodiversity and traditional agriculture, and were sources of potable and irrigation water in the area, now carry polluted water. The level of pollution has reached to the extent that water has become unfit for human consumption and irrigation, and toxic to plants and animals. Consequently, the same rivers and streams that supported human life and activities, and rich biodiversity including many species of fish, amphibians, aquatic insects etc. have now lost their life sustaining role and become nearly devoid of aquatic life. Under prevailing grave conditions of water quality and aquatic life in rivers and streams of Jaintia Hills, there is an urgent need for initiating activities for ecorestoration of the affected areas. Filling of abandoned mines, extensive afforestation, neutralization of acidic seepage, conservation of top soil, scientific management of AMD and water resources etc. will go a long way in restoration of the lost environmental glory of the area.

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