ACID-MINE DRAINAGE AND ITS ENVIRONMENTAL CONSEQUENCES

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Metals and minerals are essential for the development of a country. The industrial revolution towards the end of 21st century necessitated expansion of mining of metals on a large-scale. The extraction of minerals involves several steps like excavation, removal of top soil, dumping of overburden material and tons of tailings are released as a result of the above processes which is one of the major sources of acid-mine drainage (AMD) in mining areas. AMD is a global environmental issue and natural resources have been seriously damaged by contamination from AMD, affecting the region's agricultural productivity and putting human health at risk.

ACID-MINE DRAINAGE CONCEPT

Globally several thoughts are prevailing on acid-mine drainage. Acid-mine drainage can be described as the acidic sulfur-rich wastewaters generated as the by-products during numerous industrial operations like flue gas scrubbing at power plants, galvanization etc. (Johnson, 2003). According to Johnson and Hallberg (2005) "acid mine drainage, acid and metalliferous drainage (AMD), or acid rock drainage (ARD) is the outflow of acidic water from metal mines or coal mines". "Mine-acid drainage (MAD) is the run-off produced when water comes into contact with exposed rocks containing sulfur-bearing minerals that react with water and air to form sulfuric acid, dissolved Fe and Al, and other chemical elements" (Moncur et al., 2009). However, according to the United States Environment Protection Agency (USEPA) AMD is metal-rich water formed from chemical reaction between water and rocks containing sulfur-bearing minerals.

Among the rock forming minerals, sulfide is one of the main mineral components (particularly FeS_2) responsible for generation of AMD due to its ease of oxidation when exposed to oxygen, water, and microorganisms which converts the sulfide to sulfuric acid by chain of chemical reactions (Eq. 1-4) and resulted red or orange precipitation of ferric hydroxide (Figure 1).

$$2FeS_2\,(s) + 7O_2\,(g) + 2H_2O\,(l) \rightarrow 2Fe^{2+}\,(aq) + 4SO_4^{2-}\,(aq) + 4H^+\,(aq) \text{.................(1)}$$

$$4Fe^{2+}\,(aq) + O_2\,(g) + 4H^+\,(aq) \rightarrow 4Fe^{3+}\,(aq) + 2H_2O\,(l) \text{.......................................(2)}$$

$$Fe^{3+}\,(aq) + 3H_2O\,(l) \leftarrow\rightarrow Fe(OH)_3 + 3H^+\,(aq) \text{...(3) *}$$

$$FeS_2\,(s) + 14Fe^{3+}\,(aq) + 8H_2O\,(l) \rightarrow 15Fe^{2+}\,(aq) + 2SO_4^{2-}\,(aq) + 16H^+\,(aq) \text{...........(4)}$$

* $Fe^{3+}\,(aq) + 3H_2O\,(l) \leftarrow\rightarrow Fe(OH)_3\,(ppt.) + 3H^+\,(aq) \text{.............(3)}$

ACID-MINE DRAINAGE CHARACTERISTICS

Acid-mine drainage can be ranged from highly acidic to alkaline in pH based on the dissolved ions, source of mine-drainage and oxidation state. However, the general features of AMD are extreme acidity with elevated concentration of sulfate. Furthermore, this acid dissolves heavy metals present in tailings and waste rock, for instance copper (Cu), mercury (Hg), cadmium (Cd), arsenic (As), lead (Pb), selenium (Se) and zinc (Zn) and contaminates ground and surface water. Heavy metals cause the plants to decrease water and nutrient uptake, decrease root respiration, constrain cell mitosis in root meristematic regions, and decrease enzymatic activity and microbial communities in soil. Additionally, unregulated release of dust from the mines contaminates surface waters and negatively affects crop growth as pores of the plant are blacked. Nonetheless the methods and process used for extracting metallic or non-metallic minerals, mining always results in massive land disturbance which covers large scale. The waste produced due to mining activities affects the overall land productivity on a long-term basis. As a result, productive land that could have been used for other economically attractive areas such as agriculture is left barren. The concentration of metals in soil, water and plants depends on the distance of the area from the mine and the form in which the ore is transported. The spatial variation of the contaminants in the topsoil in the mining site indicates their dispersion through wind and erosion. Metals dispersed from mine waste are generally retained in the lower areas used for agriculture.

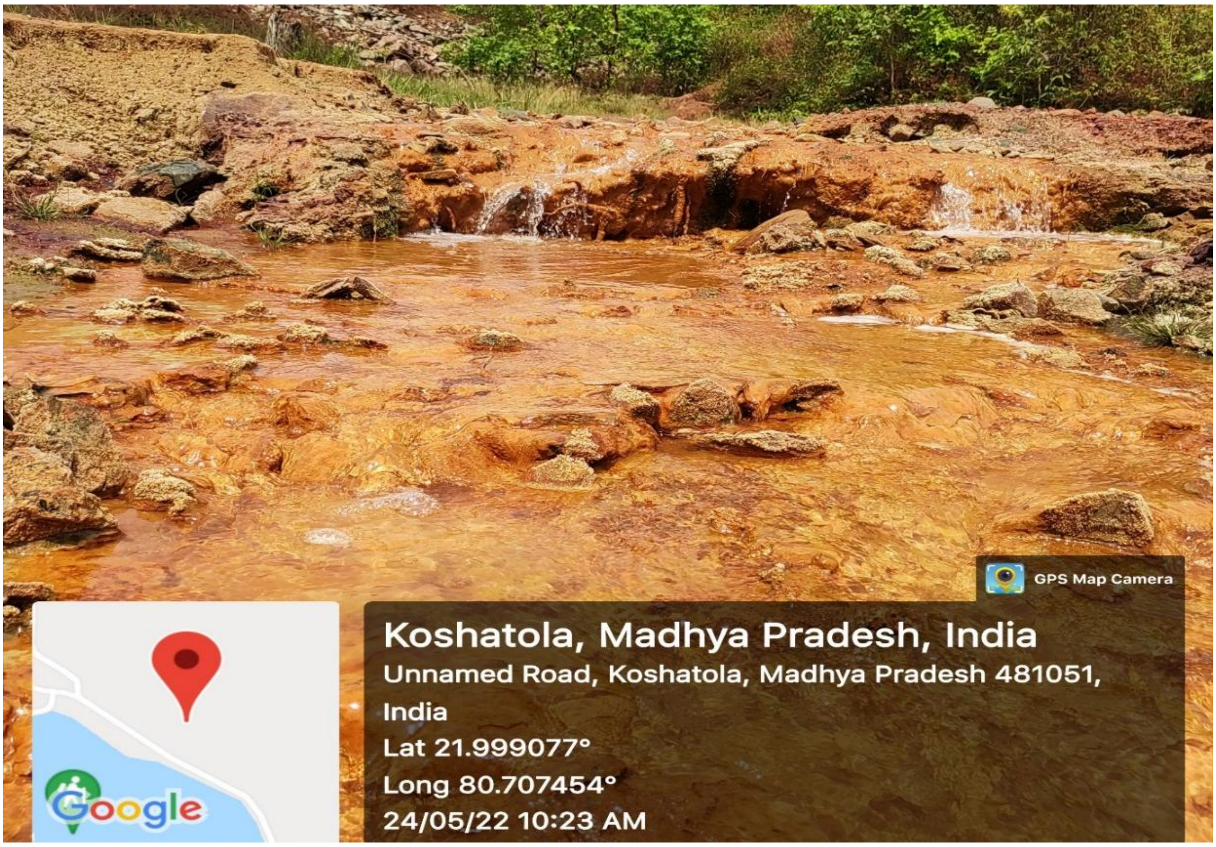

Figure 1. Precipitation of ferric hydroxide [$Fe(OH)_3$] in the tailing channel of Malanjkhand Copper mine area

ENVIRONMENTAL CONSEQUENCES OF ACID-MINE DRAINAGE

Water Pollution and Aquatic Life: Many studies reported that AMD can pollute water and hamper aquatic life due to very high acid pH, soluble toxic ions and high salt concentrations. Water samples nearest to the AMD are highly acidic and may have high concentration of dissolved sulphate (as high as 1.3×10^5 mg SO_4^{2-} L^{-1}) and ferrous ions (as high as 1×10^3 mg Fe^{2+} L^{-1}). Naidu et al.

(2019) documented that wastewater released as AMD from metal mines has very high concentration of metals like Zn, Al, Cu, Mn and Ni. Acidic pH of AMD triggers metalssolubility and resulted very concentration of metals in the water released from the mines. Water draining at Malanjkhand mine in India is highly acidic (pH 2.7) and rich in SO_4^{2-}(2800 mg L^{-1}) and Cu(65.2 mg L^{-1}), and contains smaller concentrations of other metals such as Fe, Mn, Cd and Zn (Equeenuddin et al., 2017). In South-West Spain, the Tinto Santa Rosa mine field generate AMD that has very high concentration ferrous (694-845 mg L^{-1}) and sulphate (2853-3622 mg L^{-1}) ions; even wastewater released from the North-eastern coalfield of India are highly acidic and contained very high amount of sulphate due to 3 - 3.5% sulfur content in the coals (Asta et al., 2010; Dutta et al., 2017).

Heavy Metals and Soil Pollution: Acidified mine drainages often increased exchangeable Al^{3+} in soil, which subsequently generate soil acidity during hydrolysis. On the other hand, metals having good solubility acidic pH range; similarly heavy (relatively high density than the water) metals and metalloids are become more soluble in acidic pH range. Lin et al. (2005) reported that surface mining affected streams and agricultural land of Dabaoshan mine region of Sothern China has pH 2.79 in waste mine soil, whereas, AMD affected water varies from 2.15 to 3.78. Due to high acidity Cd contamination has also been reported. Garrido et al. (2009) found that acid mine drainage affected irrigation waters has contaminated agricultural soils and reported high concentrations of ecotoxic metals (Cd, Pb and Zn) in potatoes which may potentially risk the health of the local communities in Potosoi, Southern Bolivia. Based on the geo-accumulation index results, soils from and near the tailings impoundments, as well as sediments of the downstream fluvial system, are highly enriched and contaminated by Pb, while the As, Cu, Cd and Zn contamination is bounded in the tailings piles area (Azhari et al., 2017). On the other hand, Pandey et al. (2016) assessed that mining activities (40%), crustal source (24%), and windblown dust (23%) are the chief contributors of soil pollution in Jharia coalfield of Dhanbad. In addition, coal mining activities are the main contributing source to soil Ni, Cu, and Cr, while crustal input was mainly represented by Mn and Zn and wind-blown dust by Pb, Fe, and Cd.

Human Food-chain Contamination: Local people suffer from various illness due to the degradation of the natural sources of food and water. The generated AMD water elevates the level of dissolved metal in the receiving surface water stream and sediments which negatively affects the stream biota. Further, the problem does not end with small aquatic life; it has also a negative impact on the food chain. Nevertheless, an accurate assessment of the economic scale and environmental liability caused by AMD remains challenging. A conceptual pathway of acid-mine drainage associated to human food-chain contamination is presented in Figure 2.

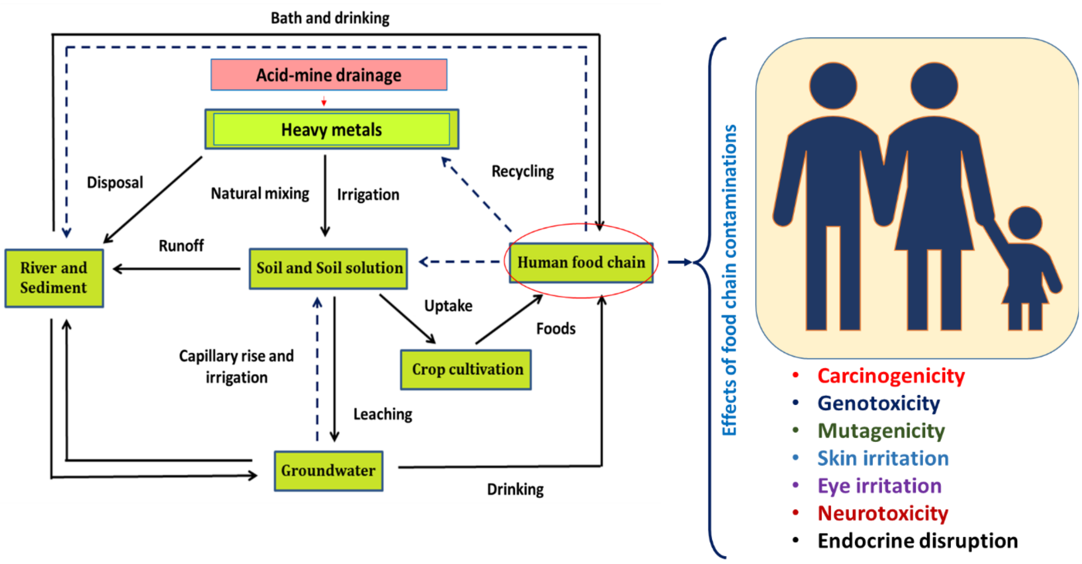

Figure 2. Pathways of human food-chain contamination from heavy metal rich wastewater (acid-mine drainage)

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