Mining: Friend or Foe?

Economic, Environmental & Social Impacts- An Overview

Golam Kibria Ph.D; March 2013

Summary

Economic impacts*:** Mining is a key sector that leads to economic development, employment, supply of essential raw materials for society, and for production systems. Mining has historically served as a viable route to national development in resource-rich countries like Australia, Canada, and the United States where mining was the main driver of growth and industrialisation. Artisanal and small-scale mining (ASM) (subsistence miners) in Africa have been identified as an important economic opportunity for people in rural areas. ***Environmental impacts: Mining and mineral exploration can impact on the environment via generation of hazardous wastes (wastes that threats to public health or the environment). Some of the negative environmental impacts are contamination of air, soil, water, plants and food with sulfate, metalloids (arsenic), metals (cadmium, copper, lead, mercury), radioactive substances (uranium, radon), fly ash (residues generated in combustion of coal), acids (sulfate), mining processed chemicals (cyanides). Acid Mine Drainage (AMD) waters can have high sulfate, iron and aluminium, and elevated copper, chromium, nickel, lead and zinc and elevated calcium, magnesium, sodium and potassium. AMD containing high metal and salt concentrations may impact on the use of the waterways in the downstream for irrigation, fisheries, raw town supply, livestock watering, drinking water supplies and industry water usage. Metal and metalloid concentrations and acidity levels in AMD if exceeds toxicity threshold values of aquatic ecosystem can lead to sub-lethal and lethal effects on aquatic life (fish, invertebrates). Some of the metalloids and metals (arsenic, cadmium, mercury, uranium) are known to bio-accumulate in fish, crops, livestock, therefore the transfer of toxic metals to human via the food chain is easily possible (note: arsenic, cadmium and uranium are carcinogenic to humans). Irrigation of crops with stream water that is affected by AMD effluents could be phytotoxic to crops. High concentrations of bioavailable metals and metalloids can cause a reduction of biodiversity, changes in species diversity, depletion of numbers of sensitive species, and even fish kills and death of other species. During coal mining operations, methane and other toxic gases are released; the exposure of methane and other toxic gases may cause "pneumoconiosis" (a disease of the lungs) to coal miners. Coal combustion also releases toxic chemicals such as arsenic, mercury. Salt levels particularly chloride concentrations, can be extreme in the coal mine sites. ***Social impacts:*** Mining may cause several negative effects on the quality of life and lifestyle of the communities. The rapid influx of people into mining areas can lead to price inflation of local goods (food, fuel, land/housing etc.). Furthermore, social ills such as alcohol abuse, prostitution, spread of communicable diseases, namely, HIV/AIDS often increase in mining areas.

Contents

1. Introduction
2. Mining operations
3. Economic impacts
4. Environmental impacts
    4.1: Mining waste- physical and chemical characteristics
    4.2: Acid mine drainage (AMD)
        4.2.1: Chemistry of oxidation of pyrites
        4.2.2: Some facts about AMD
        4.2.3: Impacts of AMD
    4.3: Mine water and its impact
        4.3.1: Toxic heavy/trace metals (Arsenic, cadmium, lead and mercury)
        4.3.2: Other environmental impacts
    4.4: Coal mining impacts
    4.5: Climate change and mining chemicals
    4.6: Some examples (Australia, Tanzania, Papua New Guinea, USA)
5. Social impacts
6. Reducing mining impacts
7. Conclusion
8. References

1. Introduction [1,2,4,5,6,7,8,9,10].

Mining can be defined as "an area of land or sea upon or under, which minerals or metal ores (Table 1) are extracted from natural deposits in the earth by any methods, including the total area upon which such activities occur or disturb the natural land surface'' [1]. It is a global industry (Figure 1 on page 2) that underpins (strengthen) industrial development in many regions. It is a key sector that leads to economic and social development, employment, supply of essential raw materials for society, and for production systems (section 3), and has the potential to bring economic, social and infrastructure development to remote and poorly developed areas [1,2]. Though there are significant economic benefits, however, mining can also cause severe negative environmental impacts (contamination of air, soil, water, plants and food and pollution of rivers, creeks) as well as social impacts (migration, spread of HIV/AIDS).

Table 1: Main groups of minerals [1].

Metallic	Precious metals	Gold, platinum, silver
	Base metals	Copper, lead, iron, nickel, zinc
Non-metallic		Asbestos, gravel, gypsum, limestone, salt, sand
Fuels		Coals, natural gas, peat, petroleum, uranium

2. Mining operations [1,3].

Mining operations consist of four steps Exploration, Mining, and Mineral processing & dressing and Metallurgic processing (Figure 2). *(a) Exploration* is to locate deposits of economic interest; *(b) Mining* is the extraction of material from the ground in order to recover one or more parts of the mined material. Mining consists of surface mining, underground mining, and *in situ* (place where it occurs) mining. Surface mining is used to excavate ores at or close to the earth's surface, and it includes open pit mining and dredging. Underground mining removes mineral by extracting under the surface and removing the ore. *In situ* mining

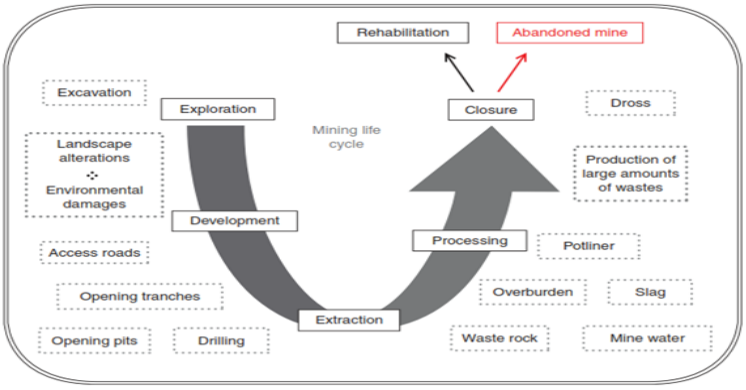

Figure 2. Schematic representation of the main steps taking place in mining life cycle with the consequent impacts in the environment. Also represented are the several wastes produced in each step [1].

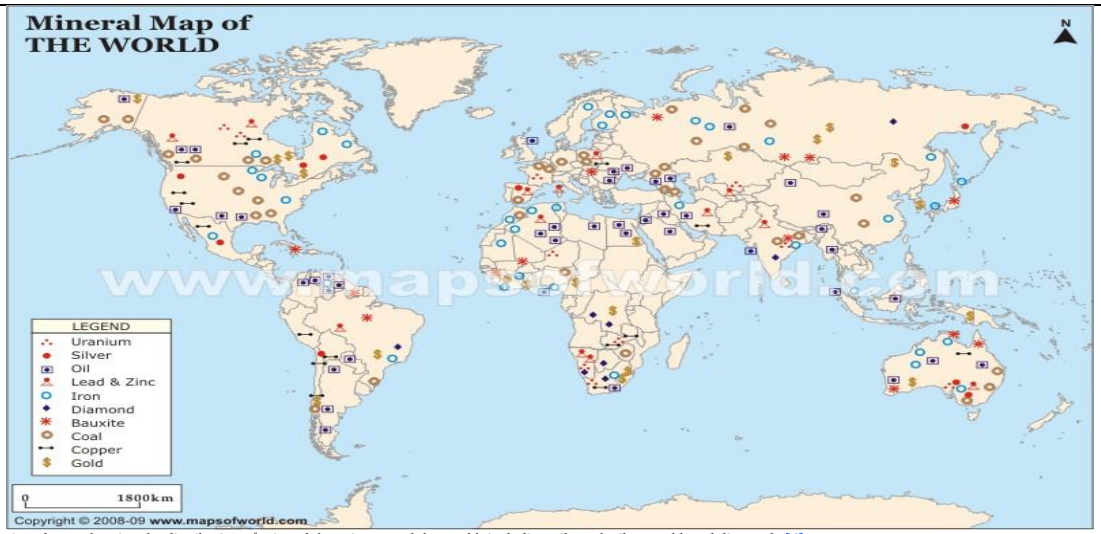

Figure 1.1: The World mineral map showing the distribution of mineral deposits around the world, including oil, coal, silver, gold, and diamonds [4].

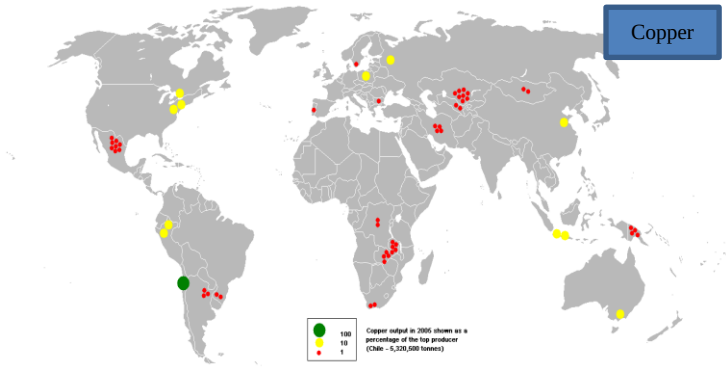

Figure 1.2: The bubble map showing the global distribution of mined output of **copper** in 2005 as a percentage of the top producer (Chile - 5,320,500 tonnes) [5].

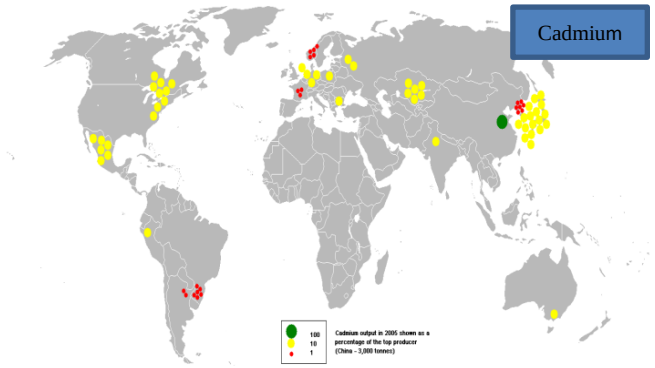

Figure 1.3: The bubble map showing the global distribution of **cadmium** output in 2005 as a percentage of the top producer (China - 3,000 tonnes) [6].

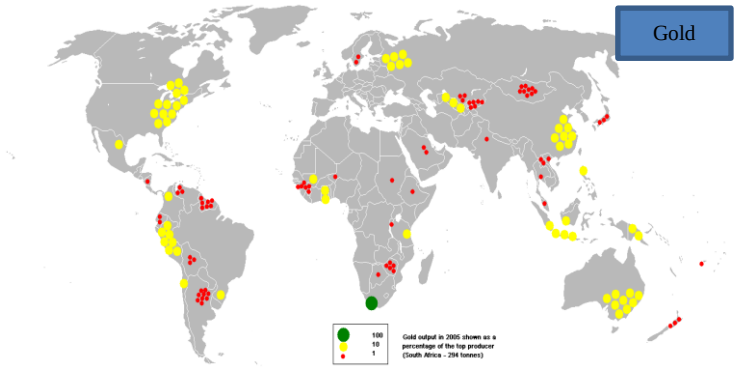

Figure 1.4: The bubble map showing the global distribution of mined output of **gold** in 2005 as a percentage of the top producer (South Africa- 294 tonnes [7].

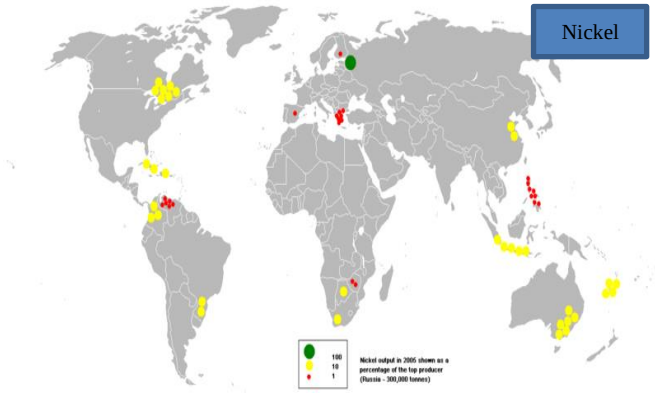

Figure 1.5: World **nickel** production in metric tons, in 2005. The Russian Federation is the largest producer, followed by Canada [8].

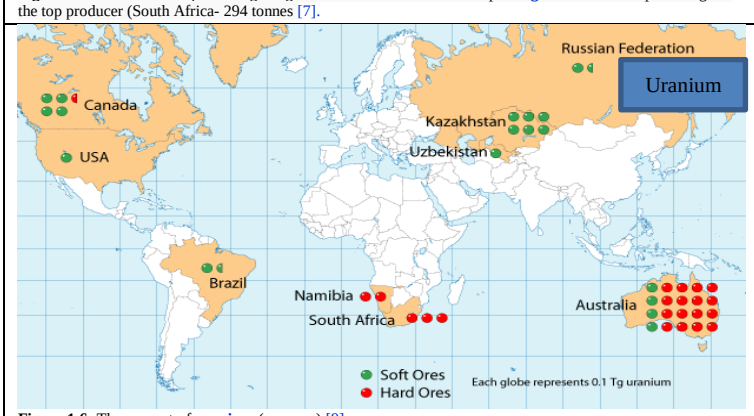

Figure 1.6: The amount of **uranium** (reserves) [9].

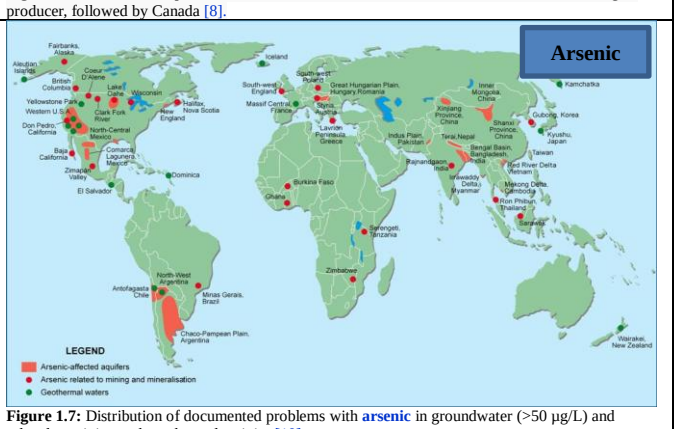

Figure 1.7: Distribution of documented problems with **arsenic** in groundwater (>50 µg/L) and related to mining and geothermal activity [10].

removes minerals by sinking injection and extraction wells, and leaching the ore in place; *(c) Mineral processing and dressing* includes all mechanical, physical, and chemical methods to separate minerals from the gangue (valueless and undesirable material) and to partially treat them. This is generally the most polluting stage (Figure 2) and the one that generates the highest number of health risks. It includes three types of operations: preparation, concentration, and conditioning. At the end of these three stages, the ore will be more concentrated but the purity achieved is relatively low; *(d) Metallurgic processing* refer to melting and refining operations to produce pure metals or to prepare alloys (mixture of two or more metals). The process includes several operations, such as pyrometallurgical operations (e.g., smelting, refining, and roasting), hydrometallurgic operations (e.g., digestion of phosphate in producing phosphoric acid), and electrometallurgic operations (e.g., electrolytic refining) [3].

3. Economic impacts

3.1: Employment [11,12,13,14].

Mineral resources are a potentially great source of wealth for poor countries. Minerals resources, such as copper, diamonds, gold and tin, can provide with large revenues that can be used to alleviate poverty (for example, economic growth can contributes to poverty reduction via creating jobs, therefore, generate income for workers and their families). According to World Bank, small scale mining can provide employment for about 13 million workers across the world whereas large-scale mining provides direct employment for about 203 million workers [11]. Artisanal and small-scale mining (ASM) (note:) in Africa have been identified as an important economic opportunity for people in rural areas [Table 2; 12]. In fact, artisanal mining is largely driven by poverty; and may complement more traditional forms of rural subsistence earning (Table 2).

Mining----⇒Job Creation----⇒Income Generation----⇒Poverty Reduction

Table 2: People engaged in artisanal and small-scale mining (ASM) in selected countries in Africa [12].
***NA**=not available; **Artisanal miners and small scale miners:** An artisanal miner or small-scale miner is a subsistence miner, are not officially employed by a mining company, but rather work independently, mining or panning for gold using their own resources. Small-scale mining includes enterprises or individuals that employ workers for mining, but generally working with hand tools. Artisanal miners often undertake the activity of mining seasonally (e.g. crops are planted in the rainy season, and mining is pursued in the dry season).*

Country	Artisanal and small-scale mining population	Main mineral(s) extracted on a small scale	% population residing in rural areas (2003) data	% population with less than US$2	Adult literacy (%)	HDI rank* * (2011)
Burkina Faso	60,000	Gold	82.2	81	87.2	181
Ethiopia	>100,000	Gold	84.3	80.7	58.5	174
Ghana	200,000	Gold, diamonds	54.6	78.5	46.7	135
Guinea	40,000	Gold, diamonds	65.1	NA	NA	178
Madagascar	10,000	Gold, gemstones	73.4	85.1	29.4	151
Mali	200,000	Gold	67.7	90.6	81	175
Nigeria	10,000-20,000	Industrial minerals	53.4	NA	33.2	156
*Papua New Guinea	60,000-80,000	Gold	86.8	NA	36.1	153
Sierra Leone	30,000-40,000	Diamonds	61.2	74.5	70.4	180
Tanzania	450,000-600,000	Gold	64.6	59.7	30.6	152
Uganda	5000-10,000	Diamonds	87.7	NA	31.1	161
Zambia	30,000	Gemstones	64.1	87.4	32.1	164
Zimbabwe	50,000-350,000	Gold	65.0	64.2	10	173

**Not in Africa, located in the south-western Pacific Ocean (Oceania)*
***Human development index (HDI)= is a comparative measure of life expectancy, literacy, education, standards of living, and quality of life for countries worldwide. It is used to distinguish whether the country is a developed, a developing or an underdeveloped country, and also to measure the impact of economic policies on quality of life. The index was developed in 1990 by Pakistani economist Mahbub ul Haq and Indian economist Amartya Sen. Countries fall into four broad human development categories: Very High Human Development, High Human Development, Medium Human Development and Low Human Development. HDI rank (2011): Norway 1; Australia 2; Netherlands 3; USA 4; New Zealand 5, Canada 6; Japan 12; Hong Kong 13; Israel 17; UK 28; UAE 30; Saudi Arabia 56; Brazil 84; Iran 88; Sri Lanka 97; Fiji 100; China 101; Philippines 112; Indonesia 124; Vietnam 128; Iraq 132; India 134;Cambodia 139; Pakistan 145; Bangladesh 146; Myanmar 149; Papua New Guinea153; Nepal 157; Afghanistan 172; Burundi 185; Niger 186; Congo 187.*

According to a case study conducted in Tanzania [13], the socioeconomic benefits from ASM includes rural employment (major), improvement of rural road networks, water and school construction, subsistence (petty) business (sale of food crops). In general, wages earned by employees at mining operations are spent on goods and services produced by local people, which, in turn, increases the incomes of local populations. Though there are some economic benefits of mining for rural poor in third world countries, however, an analysis of 57 developed and developing countries from 1967 to 1997 found no reliable link between the level of or change in mineral and energy production and unambiguous changes in poverty during a given growth spell [14]. Despite the above findings, mining has historically served as a viable route to national development in resource-rich countries like Australia, Canada, and the United States where mining was the main driver of growth and industrialization over more than a century (see section 3.2).

3.2: Mining contribution in Australia [15,16].

Mining is a significant primary industry and contributor to the Australian economy. The mining sector represents 10% of GDP; whereas the "mining-related economy" represents 9% of GDP– the total mining sector is therefore of 19% of GDP [15,16]. The industry employs about 2.2% of the total labour force. Large quantities of minerals and resources are extracted in Australia such as: (a) ***Bauxite/aluminium*** (the world's largest producer in 2011); (b) ***Coal*** (the world's largest exporter of coal and fourth largest producer of coal behind China, USA and India); (c) ***Copper;*** (d) ***Diamond*** (the third largest commercially-viable deposits after Russia and Botswana); (e) ***Gold*** (the second largest producer after China); (f) ***Iron ore*** (the world's third largest supplier in 2008 after China and Brazil); (g) ***Natural gas*** (world's third largest producer of Liquefied Natural gas or LNG and forecast to be world leader by 2020); (h) ***Nickel*** (the world's second largest producer in 2006 after Russia); (i) ***Oil shale;*** (j) ***Opal*** (the world's largest producer of opal, being responsible for 95% of production); (k)

Petroleum (the twenty-eighth largest producer of petroleum); (l) ***Rare earth elements;*** (m) ***Silver;*** (n) ***Uranium*** (the world's third largest producer in 2010 after Kazakhstan and Canada); (o) ***Zinc*** (second to China in production in 2008). Much of the raw material mined in Australia is exported overseas such as China for processing into refined product (energy and minerals constitute about two thirds of Australia's total exports to China including more than half of Australia's iron ore exports) [15].

3.3: Uses of minerals [16,17,18,19].

The minerals extracted (metallic, non-metallic or industrial minerals- see Table 3) are used for a wide a range of purposes including electrical generation, production of cement, steel, agricultural lime, commercial and residential building materials, asphalt (bitumen), and medicines, jewellery, as well as countless household, electronic, and other manufactured products. Key uses of minerals are as follows: ***Antimony (Sb)***- Flame retardants, semi-conductors; ***Bauxite ($Al(OH)_3$)***- Aluminium production; ***Borates*** (salts such as sodium metaborate, sodium borate)- Fiberglass insulation, textile ore continuous-filament glass fibres, glass, detergents and bleaches, enamels and frits (ceramic), fertilisers, and fire retardants; ***Chromite ($FeCr_2O_4$)*** - Stainless steel production, superalloys; ***Coal*** *(fossilised carbon)*- Energy (electricity) generation; making iron and steel, and manufacturing chemicals; ***Cobalt (Co)***- Metal alloys (*note: An alloy is a substance made by melting two or more elements together, at least one of them is a metal);* ***Copper (Cu)***- Electrical applications, construction; communications equipment, electric cables and wire, switches, plumbing, heating, chemical and pharmaceutical machinery, alloys, alloy castings, and protective coatings for other metals; ***Crushed rocks***- Highways, paint, plastics, medicines, glass, concrete sidewalks, bridges, wallboard, vinyl, brick and stone buildings and homes, concrete block, roofing tile, asphalt shingles, minerals for agriculture; ***Diamonds***- Jewellery, abrasives; ***Gold (Au)***- Jewellery, investments; satellites, electronic circuits, medicines, arts, coins, ingots (nuggets), scientific and electronic instruments, electrolyte in electroplating industry; ***Iron ore (Fe)***- steel industry; steel products (kitchen utensils, automobiles, ships, buildings); *powdered iron* (used in metallurgy products; magnets; high-frequency cores; auto parts; catalyst); *radioactive iron* (in medicine; tracer element in biochemical and metallurgical research; *iron blue* (in paints, printing inks, plastics, cosmetics, paper dyeing); *black iron oxide* (as pigment; in polishing compounds; metallurgy; medicine); ***Lead (Pb)***- Motor vehicle batteries, chemical; military tanks, seals or bearing, electronics; TV tubes and glass, construction, communications, and protective coatings; in ballasts or weights; ceramics or crystal glass; X-ray and gamma radiation shielding; soundproofing material in construction industry; and ammunition; ***Manganese (Mn)***- FerroAlloys; ***Molybdenum (Mo)***- FerroAlloys; ***Nickel (Ni)***- Stainless steel, batteries, fuel cells; ***Palladium (Pb)***- Motor vehicle catalysts, electronic; ***Phosphates (PO^{3-}_4)***- Fertiliser applications (plants); feed additives for livestock, elemental phosphorus, variety of phosphate chemicals for industrial and home consumers; ***Platinum (Pt)***- Motor vehicle catalysts, jewellery; ***Potash***- used as a fertilisers, in medicine, and in the chemical industry; ***Silver (Ag)***- Electronics, photographic, jewellery; coins, jewellery, photo film, chemistry, in lining vats and other equipment for chemical reaction vessels, water distillation, catalyst in manufacture of ethylene, mirrors, silver plating, table cutlery, dental, medical and scientific equipment, bearing metal, magnet windings, brazing alloys, solder; ***Soda ash***- glass, chemicals, soap, and detergents, pulp and paper, agriculture, brine treatment, corn syrup, drilling mud additives, dyes and pigments, enamels, flue gas desulfurisation, food processing, leather tanning, metal refining, perfume, pharmaceuticals, and textiles; ***Tantalum (Ta)***- Electronic components; alloys; ***Tin (Sn)***- Packaging, alloys; ***Titanium (Ti)***- Pigments and alloys; ***Tungsten (W)***- FerroAlloys, filaments; ***Uranium (U)***- nuclear power generation, medical, dating, fertilisers; ***Vanadium (V)***- FerroAlloys; ***Zinc (Zn)***- Galvanising brass and bronze, alloys; protective coatings on steel, chemical compounds in rubber and paints, used as sheet zinc and for galvanizing iron, electroplating, metal spraying, automotive parts, electrical fuses, anodes, dry cell batteries, nutrition, aluminium products, chemicals, roof gutter, engraver's plates, cable wrappings, organ pipes and pennies. Zinc oxide used in medicine, paints, vulcanizing rubber, sun block. Zinc dust used for primers, paints, precipitation of noble; ***Zirconium (Zr)***-Foundry applications, alloys [17,18].

Table 3: Mining Profiles of some selected countries [16,17,19].

Country	Mining contribution (% of GDP)	Mining	Comments
Australia	10	**Major:** bauxite (aluminium), diamonds, ilmenite (titanium oxide or FeTiO3) and zircon. **Others:** coal, iron ore, gold, uranium, zinc, lead and silver	-World's third largest producer of commodities.
Botswana	34.2	**Major**: diamonds. **Others:** copper, nickel, cobalt, gold, soda ash and coal	
Brazil	2	**Major:** bauxite, Kaolin, iron ore, niobium, and nickel **Others**: gold, coal and phosphates.	-Iron ore is the most important of mineral exports, (annual revenue of around $ 2.3 billion). -Brazil is the world's largest exporter of niobium, tin, lithium, tantalum and gemstones. Bauxite, gold, manganese.
Canada	3.7	**Major:** gold, nickel, copper, zinc, lead, iron ore and, more recently, diamonds.	-Canada is one of the world's leading mining nations. -Gold reserves have more than trebled over the last 20 years, currently estimated at 1 500t gold.
Chile		**Major:** Copper. **Others:** gold, silver, molybdenum, zinc, manganese and iron ore.	-Most important mining countries in Latin America. -World's largest copper producer.
China		production statistics are sketchy	-Mining industry ranks third in the world.
India		**Major**: chromite, coal, iron ore and bauxite.	-Major mineral producer in Asia and globally.
Indonesia		**Major:** tin, coal,, copper, gold and nickel. **Others:** bauxite, phosphates, iron sand, alluvial diamond.	-One of the world's largest producers of tin and coal.
Kazakhstan	27	**Main:** uranium, manganese and chromium ores, iron, coal.	
Mexico		**Major**: silver, base metals (zinc, lead), gold, celestite ($SrSO_4$ or strontium sulfate) and bismuth. **Others:** barite, manganese, salt, lead and zinc.	-Leading producer of silver, celestite and bismuth, respectively. -Ranked among the world's top ten in barite, manganese, salt, lead and zinc production.
Morocco	6	**Major:** phosphate. **Others:** anthracite, antimony, barite, cobalt, copper, fluorspar, iron ore, lead, manganese, salt, silver, and zinc.	-Phosphate mining is the world's third largest produce.

Peru	6.5	**Major**: Gold, silver, tin, copper, lead and zinc.	-Major producer of gold (largest producer in Latin America).
Papua New Guinea	17.3	**Major:** gold, copper and silver.	-World's largest copper producer.
Russia		**Major:** diamonds, nickel, copper, coal, gold, PGE's, tin and bauxite.	
South Africa	6.5 (2000) 8.4 (1991)	**Major:** chrome, gold, vanadium, manganese and PGM's.	-Africa's most important mining countries. -80% of the world's known manganese reserves. -72% of the world's known chromite ore reserves.
USA		**Main:** gold, copper, silver, lead, zinc, molybdenum and coal.	-World's leading mining nation.
Zambia		**Major:** copper, cobalt. **Others**: lead, zinc, silver, gold, minor-platinum.	-World's seventh largest producer of copper. -World's second largest producer of cobalt.
Zimbabwe	8	**Major:** gold, asbestos, chromite, coal and base metals.	

***Note**: **Australasia** is a leading producer of iron ore, gold and base metals; **Africa** is a major producer of cobalt, gold, Platinum Group Element (PGE's) and diamonds; **South America** is a major producer of base and ferrous metals, in particular copper and iron ore; **Asia** is a major producer of base metals, PGE's, ferrous metals and coal; **Europe** is not a major mining centre; **North America** is the major producer of gold and silver [19] (accessed 15 Dec 2012).*

4. Environmental impacts [1,3].

Though mining is a major economic activity in many developing and developed countries, however mining operations, whether small- or large-scale, are inherently disruptive to the environment, producing enormous quantities of waste that can have deleterious impacts for the environment.

4.1: Mining wastes- physical and chemical characteristics [1,3].

The mining industry is the most significant industrial producer of solid, liquid and gaseous wastes (Table 4; Figures 2 and 3). Mining wastes can be categorised into mining, processing and metallurgical wastes (Table 4). For example, *mining wastes* (e.g. open pit and underground mining) can contain waste rocks, overburden, spoils, mining water, atmospheric emissions; *mineral processing* (e.g. coal washing, mineral fuel processing) can contain tailings, sludge's, mill water (water used to crush and the size the ore) and atmospheric emissions and, *metallurgical wastes* (e.g. residues of the leached or smelted ores) can contain slags (stony waste), roasted ores, flue dust (finely divided metal or metallic compound), ashes, leached ores, process water and atmospheric emissions [3].

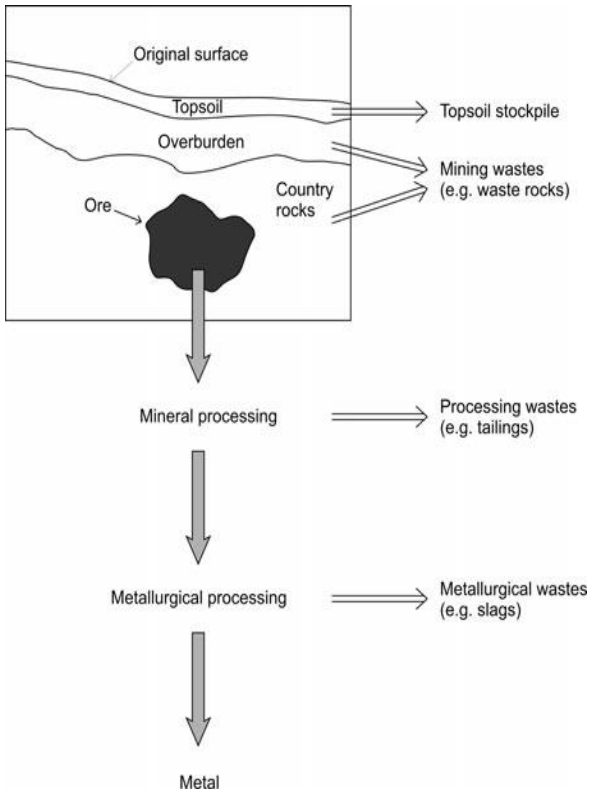

Figure 3: *Schematic product and waste streams at a metal mine* [3]. *[**Note: Metallurgical:** refer to melting and refining operations to produce pure metal; **Overburden**: rock, soil, and ecosystem that lies above a coal seam or ore body; **Slag**: waste product of the process of smelting; **Tailings:** the gangue and other refusal material resulting from washing, concentration, or treatment of ground ore].*

Mining and mineral exploration can impact on the environment (air and water pollution) via generation of wastes (hazardous substances such as heavy metals, metalloids, sulfate, radioactive substances (uranium), fly ash (residues generated in combustion of coal), acids (sulfate), and processed chemicals (cyanides). In addition, mining may produce noise pollution, dust pollution and visual pollution and may cause destruction and disturbance of ecosystems and habitats, erosion, formation of sinkholes, loss of biodiversity and contamination of soil, groundwater and surface water. Acid mining drainage (AMD) from waste rocks, tailings, and other mine components, is the single most important environmental concern in the mining industry (see section 4.1.1). In most metal ores, the metals are found in chemical combination with other elements forming metal-bearing ore minerals such as oxides or sufides.

Table 4: Mine wastes [1,3].

Mining	Wastes	Remarks
Mining (open pit, underground)	Mining wastes (overburden, mining water, waste rocks, atmospheric emission)	May contain heavy metals and low pH water (acidic)
Mineral processing & dressing	Processing wastes (tailings, sludges, mill water, leaching wastes, atmospheric emissions)	Sources of contamination of groundwater, surface water and soil; may contain pyrite, metals and reagents used in processing of metals; possibilities of acid drainage
Metallurgic processing (pyrometallurgy, hydrometallurgy, electrometallurgy)	Metallurgical wastes (slags, roasted ores, flue dusts, ashes, leached ores, process water, atmospheric emissions)	Produce large amounts of acidic material; may contain heavy metals, sulfates, cyanides

***Note: Leachate**- mine water that has percolated through or out of solid mine wastes**; Mill water**- water that is used to crush and size the ore; **Mine water**- any surface or groundwater present at a mine site; **Mining water**- water that had contact with any of the mine workings; **Mine drainage water**- surface or ground water that actually or potentially flows from the mine site a mineral treatment **Overburden**- rock, soil, and ecosystem that lies above a coal seam or ore body; **Slag**- the waste product of the process of smelting; **Tailing**- the gangue and other refuse material resulting from washing, concentration or treatment of ground ore [1,3].*

4.2: Acid mine drainage (AMD) [3,20,21,22]

Acid mining drainage (AMD) is produced when sufide bearing material is exposed to oxygen and water. For example, the AMD occurs naturally in iron sulfide-aggregated rocks (sulfidic mine wastes, especially those which contain high concentrations of pyrite (FeS_2), are the major sources of AMD)). Mining can promote AMD through increasing the quantity of sulfides exposed. Naturally occurring bacteria can accelerate AMD production by assisting in the breakdown of sulfide minerals. Upon exposure to oxidizing conditions, the sulfde minerals oxidize in the presence of oxygen and water to form acidic, sulfate-rich drainage. The primary ingredients for acid generation are: (a) sulfide minerals; (b) water or humid atmosphere; (c) an oxidant such as oxygen from the atmosphere or from chemical sources. In most cases, acidophilic bacteria (bacteria that thrive in a relatively acid environment such as *Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans)* accelerate the rate of acid generation; therefore, the inhibition of bacterial activity can impede the rate of acid generation. Although a host of chemical processes contribute to AMD, however pyrite oxidation is the main contributor for AMD and the chemistry of oxidation of pyrites is very complex (as illustrated in section 4.1.1.1)

$$\underset{\text{Pyrite}}{4FeS_2} + \underset{\text{Oxygen}}{15O_2} + \underset{\text{Water}}{14H_2O} \rightarrow \underset{\text{iron hydroxide (yellow boy)}}{4Fe(OH)_3} + \underset{\text{Acid}}{8\,(SO_4)^{-2}} + \underset{\text{Sulfate}}{16H^+}$$

[3,21]

[note: the dissolved Fe^2, $SO^{2-}{}_4$ and H^+ represent an increase in the total dissolved solids and acidity of the water and, induce a decrease of pH) [20]; the precipitation of Iron (III) hydroxide, a yellow-orange solid colloquially known as yellow boy [21,22] (see Figures 4 and 5)].

4.2.1: Chemistry of oxidation of pyrites [3,20,22].

Pyrite is the most abundant of the sulfide minerals, occurs in nearly all types of geological environments, and is commonly associated with coal and metal ore deposits. Pyrite oxidation takes place when the mineral is exposed to oxygen (abiotic). Oxidation which occurs in the presence of microorganisms such as bacteria is known as biotic. Pyrite oxidation may also occur without microorganisms as an abiotic or inorganic chemical oxidation process. Biotic and abiotic degradation can be caused by oxygen (i.e. direct oxidation) or by oxygen and iron (i.e. indirect oxidation). Iron, both in its divalent and trivalent state, plays a central role in the indirect oxidation of pyrite. These different pyrite oxidation mechanisms according to Lottermoser, 2010 [3] can be summarized as follows:

Oxidation by oxygen (abiotic direct oxidation);
Oxidation by oxygen in the presence of microorganisms (biotic direct oxidation);
Oxidation by oxygen and iron (abiotic indirect oxidation);
Oxidation by oxygen and iron in the presence of microorganisms (biotic indirect oxidation).

The oxidation of pyrites and the production of ferrous ions (Fe^{2+}) and ferric ions (Fe^{3+}) is a complex process as shown in following three steps [3,22].

Step 1: Oxidation of pyrite by oxygen

$$FeS_{2(s)} + 7/2O_{2(g)} + H_2O_{(l)} \rightarrow Fe^{2+}{}_{(aq)} + 2SO^{2-}{}_{4(aq)} + 2H^+{}_{(aq)} + \text{energy}$$

In the initial step (step 1 which is a direct oxidation process), pyrite (iron sulfide) is oxidized by oxygen to produce dissolved ferrous iron (Fe^{2+}), sulfate and hydrogen ions. The dissolved iron sulfate ions cause an increase in the total dissolved solids of the water. The release of hydrogen ions with the sulfate anions results in an acidic solution unless other reactions occur to neutralize the hydrogen ions.

Step 2: Oxidation of ferrous iron to ferric iron

$$Fe^{2+}{}_{(aq)} + 1/4O_{2(g)} + H^+{}_{(aq)} \rightarrow Fe^{3+}{}_{(aq)} + 1/2H_2O_{(l)} + \text{energy}$$

In the second step, the oxidation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) by oxygen occurs at a low pH. Either of the above two reactions (step 1 and 2) can occur spontaneously or can be catalysed by bacteria that derive energy from the oxidation reaction.

Step 3: Oxidation of pyrite by ferric iron

$$FeS_{2(s)} + 14Fe^{3+}{}_{(aq)} + 8H_2O_{(l)} \rightarrow 15Fe^{2+}{}_{(aq)} + 2SO^{2-}{}_{4(aq)} + 16H^+{}_{(aq)} + \text{energy}$$

In the third step, pyrite is oxidized with the help of Fe^{3+} generated in the previous step (step 2). Here, Fe^{3+} acts as the oxidizing agent of pyrite. The oxidation of pyrite by Fe^{3+} in turn generates more Fe^{2+}. The net effect of these reactions is to release H^+, which lowers the pH and maintains the solubility of the ferric ion.

4.2.2: Some facts about AMD [3,23].

- Iron sulfides (e.g. pyrite, marcasite, pyrrhotite) or sulfides having iron as a major constituent (e.g. chalcopyrite, iron-rich sphalerite) generate the most acidity *(note: Chalcopyrite is a copper iron sulfide mineral ($CuFeS_2$); Sphalerite ((Zn,Fe)S) is a mineral that is the chief ore of zinc).*
- Sulfides constitute a major proportion of rocks. In particular, metallic ore deposits (Cu, Pb, Zn, Au, Ni, U, Fe), phosphate ores, coal seams (bed of coal), oil shales, and mineral sands may contain abundant sulfides. Mining of these resources can expose the sulfides to an oxygenated environment.
- Mining, crushing and milling of pyrite-bearing rock to fine particle sizes for the purpose of metal extraction, vastly increase the pyrite surface area and potentially expose more pyrite to oxidation and weathering.
- AMD waters can have high sulfate (> 1000 mg/L), high iron and aluminium (>100 mg/L), elevated copper, chromium, nickel, lead and zinc (>10 mg/L) and elevated calcium, magnesium, sodium and potassium (Table 5).

Table 6: *Classification of mine waters based on pH* [3].

Classification	Examples and remarks
Extremely acid **[pH <1]**	Rocks enriched in pyrite; depleted in acid buffering materials.
Acid **[pH <5.5]**	Base metal, gold and coal mines
Neutral to alkaline **[pH 6-10]**	High levels of alkalinity generated through dissolution of carbonates, alkali oxides, hydroxides and silicates; generally found in diamond, base metal, gold, uranium, iron, coal and mineral sand mines.
Saline **[pH highly variable]**	Associated with the mining of coal and industrial minerals, including evaporates (a natural salt or mineral deposit left after the evaporation of a body of water) such as potash, halite and borate.

[1]Oxidation of pyrite and other sulfides is the major contributor of hydrogen ions in mine water;
[2] The oxidation of sulfide minerals does not only create acid, but it also liberates metals and sulfate into waters and accelerates the leaching of other elements from gangue minerals. As a consequence, AMD is associated with the release of sulfate, heavy metals (Cd, Co, Cr, Cu, Fe, Hg Ni, Pb, Zn), metalloids (As, Sb), and other elements (Al, Ba, Ca, F, K, Mg, Mn, Na, Si).
[3]AMD waters from coal mines typically contain much lower concentrations of heavy metals and metalloids than waters from base metal or gold deposits;
[4] pH in AMD water is generally < 3 [3].

- Indicators of AMD are increasing waste temperature, decreasing oxygen concentration, low pH, increasing EC (Electrical conductivity), increasing sulfate, metal (Cu, Zn) and major cations (Na, K, Ca, Mg). In some acid mine drainage systems (e.g. Richmond mine, USA, mined for gold, silver, copper, zinc, and pyrite) temperatures reached 47 °C, the pH was as low as -3.6, total dissolved metal concentration as high as 200 g/L, sulfate concentrations as high as 760 g/L [Table 5; 23].

Table 5: Composition of acidic mine waters in the Richmond Mine, Iron Mountain, California, USA during September 1990 [23].

pH	T (°C)	As (g/L)	Cd (g/L)	Cu (g/L)	Fe (total) (g/L)	Fe (II) (g/L)	Pb (g/L)	$S0_4$ (g/L)	Zn (g/L)
+1.51 to -3.6	29.9 to 47.1	0.003-0.340	0.0004-0.211	0.290-4.76	2.67-141	2.47-79.7	0.0001-0.012	110-760	0.058-23.5

- AMD is associated with the release of sulfate, heavy metals (Fe, Cu, Pb, Zn, Cd, Co, Cr, Ni, Hg), metalloids (As, Sb) and other elements (cations and anions) (Al, Mn, Si, Ca, Na, K, Mg, Ba, F) (Tables 5 & 8).
- Some of the common indicators of sulfide oxidation can be recognized by abundant yellow to red staining on rocks and flocculants (clumping of particles) in seepage points, streams and ponds due to the formation of secondary iron minerals and colloids (Figures 4 and 5).
- Bacteria isolated from AMD environments are numerous and include *Acidithiobacillus thiooxidans*, *Acidithiobacillus ferrooxidans*, *Leptospirillum ferrooxidans*, and *Thiobacillus thioparus.* These bacteria function best in an acid, aerobic environment (pH < 4). There are other life forms apart from bacteria and algae identified in AMD environments. For instance, a species of Archaea, *Ferroplasma acidarmanus*, has been found to thrive in exceptionally acid (pH 0).
- Algae are common organisms in AMD waters.
- AMD waters can form rapidly, with evidence such as iron staining or low pH (Table 6).
- AMD waters produce sulfurous odours.
- AMD process produces additional hydrogen ions, which can further decrease pH (Table 6).

Figure 4: Acidic lake waste water at Northland Mine in Temagami, Ontari, Canada [24].

Figure 5: Iron hydroxide precipitate (orange/yellow boy) in a Missouri stream receiving acid drainage from surface coal mining in USA [25].

4.2.3: Impacts of AMD [3].

AMD (with low pH) (Table 6) can contain high levels of **heavy metals** (e.g. Cd, CO, Cr, Cu, Hg, Fe, Ni, Pb, Zn), **metalloids** (As, Sb) and **other elements** such as Al, Mn, Si, Ca, Na, K, Mg, Ba, F)) that may exceed water quality standards and results in toxic effects to aquatic life of receiving aquatic ecosystems (Table 7). The release of Acid mine drainage (AMD) containing high metal and salt concentrations may impact on the use of the waterways (creeks, rivers, channels) in the downstream for irrigation, fisheries, raw town supply, livestock watering and drinking water supplies and industry water usage. Metal and metalloid concentrations and acidity levels in AMD if exceeds toxicity threshold values (LC_{50}, EC_{50}) of aquatic ecosystem can lead to sub-lethal and lethal effects on aquatic life (fish, invertebrates). Some of the metals (Cd, Hg) are known to bio-accumulate in living organisms such as in fish, crops, livestock, therefore, the transfer of toxic metals to human via the food chain is easily possible if metal and metalloid contaminated water is used for irrigation or fish farming/aquaculture or stock drinking (note: As, Cd, Hg are as well carcinogenic to humans). Irrigation of crops with stream water that is affected by AMD effluents could be phytotoxic to crops. If waterways are contaminated with high concentrations of bioavailable metals and metalloids it may cause a reduction of biodiversity, changes in species diversity, depletion of numbers of sensitive species, and even fish kills and death of other species. Drinking water supplies can also be affected by AMD, for example, significant concentrations of sulfate, metals, metalloids, and other contaminants have been found in ground water plumes migrating from mine workings and waste repositories and impoundments at metal sulfide mines. Poor water quality due to contamination with AMD can also limits its reuse as process water at the mine site and may cause corrosion to and encrustation of the processing circuit.

Table 7: Impacts of AMD on agriculture, biodiversity and water quality [3].

Sectors	Subsectors	Main impacts
Agriculture	Irrigation	High sodium levels in AMD may prevent the use of waters for irrigation.
	Irrigation, fisheries & livestock	AMD waters with high metal and salt concentrations can impacts on the use of the waterways downstream for fisheries, irrigation, stock watering.
	Irrigation	Irrigation of crops with stream water that is affected by AMD effluents containing metal and metalloid concentrations well above threshold values could be phytotoxic to crops.
Biodiversity	Plant and animal life	AMD can smother plant and animal life on the streambed, disrupting stream ecosystems (offense under the Fisheries Act in Canada).
	Vegetation	The contaminated sites with AMD can be devoid of vegetation. Most aquatic and bankside plant communities may disappear
	Aquatic life	Metal and metalloid concentrations and acidity levels in AMD may exceed aquatic ecosystem toxicity limits, leading to diminished aquatic life.
	Aquatic life	The high acidity of AMD waters can destroy photosynthetic aquatic organisms that use bicarbonate as their inorganic carbon source.
Bioavailability and toxicity of metals	Leaching of metals	The AMD (acid) can leach metals from surrounding rocks to produce drainage containing high amounts of dissolved metals, since solubility of metals increases with increasing acidity.
	Toxicity of metals	The toxicity of heavy metals increases with acidity and therefore there is likelihood of lethal and sub lethal effects on aquatic organisms.
	Aquatic life and human health	AMD containing elevated heavy metals and metalloids (at higher bioavailable concentrations), can be lethal to aquatic life and of concern to human and animal health (see Table 9).
	Biodiversity/ Aquatic life/Fish kills	The contaminated waters and sediments, containing high concentrations of bioavailable metals and metalloids may cause a reduction of biodiversity, changes in species, depletion of numbers of sensitive species, or even fish kills and death of other species are possible.
Water quality	Water colour	AMD can discolour the receiving water bodies (see Figures 4 and 5).
	Stream pH	Where AMD enters streams, there is high possibility in drop of pH of water.
	Drinking water	AMD waters with their high metal and salt concentrations can impacts on the use of the waterways downstream for drinking water supplies.
	Potable water	Potable water supplies can be affected when national drinking water quality guidelines are not met.
	Process water	Poor water quality due to AMD may also limits its reuse as process water at the mine site and may cause corrosion to and encrustation of the processing circuit.

4.3: Mine waters and its impact [3,26,27]

Mine waters are highly variable in their composition (Table 8), some waters contain nitrogen compounds (nitrite, nitrate, ammonia) from explosives used in blasting operations and processed chemicals- cyanide used for the extraction of gold. Other mine waters possess chemical additives from mineral processing and hydrometallurgical operations. For instance, metallurgical processing of many uranium ores is based on leaching the ore with sulfuric acid. Spent process waters are commonly released to tailings repositories, so the liquids of uranium tailings dams, for example, are acid and sulfate rich. Major cations (Al^{3+}, Si^{4+}, Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (Cl^{-}, SO_2^{4-}, CO_2^{3-}, HCO^{3-}) are important constituents of any mine water (see Tables 5 and 8)

4.3.1: Toxic trace/heavy metals [3,26,27,28,29,30,31,32,33,34,35,36,37].

Two of the most toxic heavy metals that can be found in mine waters are arsenic and cadmium, in addition, mercury, lead and uranium can also be found.

Arsenic is a carcinogenic (IARC-group 1; see Table 9) and metalloid that bioaccumulates in food plants, algae, crustacean, and fish. People can be exposed to arsenic in mining areas mainly through consumption of contaminated water and food [1]. Chronic poisoning of arsenic may result in anemia, leucopenia, skin cancer, and other internal cancers, leading in severe cases to death [3, 26].

Cadmium is also carcinogenic (IARC group 1; see Table 9), a metal with high toxic effects, which bioaccumulates in human kidney and liver. Acute inhalation exposure to high levels of cadmium may result in adverse effects on lungs, such as bronchial and pulmonary irritation. Chronic inhalation or oral exposure to cadmium results in severe effects on the kidney, liver, lung, bone, immune system, blood, and nervous system. Mining processes can also result in the contamination of sediments in streams when dissolved pollutants are discharged to surface waters. For example, fine grain waste materials eroded from mines can become sediments. Sediments, resulting from increased soil erosion, cause siltation or the smothering of streams beds. This siltation affects fisheries, swimming, domestic water, irrigation, and other uses of streams [3, 26].

Table 8: Chemical composition of some mine waters from mine sites in Australia [3, 27].

Parameters	Tailing pond water (Jumna tin mill)	Mine site drainage water, Montalbion silver mine	Tailing dam seepage water, Mary Kathleen uranium mine	WHO guidelines
General parameters				
pH	2.5	3.59	5.55	
Conductivity (mS cm^{1})	2.74	1.39	5.11	
TDS (mg/L)	1860	1091	4550	
Major ions (mg/L)				
Cations (positively charged ions)				
Al	129	47	0.01	
Ca	27	85	503	
Fe	148	11.63	302	
K	<1	3.8	10	
Mg	23	34	465	
Mn	7.2	11	219	0.4
Na	1	13	204	
Anions (negatively charged ions)				
Cl	<1	14	147	
F	1.9	Na	Na	1.5
HCO_3	<1	<0.1	13	
SO_4	1530	780	4110	
Trace elements (µg/L)				
As	772	50	3	10
Ba	6	50	17	700
Cd	291	623	Na	3
Co	192	289	Na	-
Cr	68	3	Na	50
Cu	30,800	21,700	4	2000
Mo	2	0.2	Na	70
Ni	257	236	93	70
Pb	607	36	<1	10
Se	20	22	Na	10
U	36	Na	319	15
Zn	63,700	79,000	17	-

Lead and mercury: Some other toxic constituents associated with discharges from mining operations are lead and mercury that may be found at elevated levels in water and sediments (see Tables 5, 8 and 9 for environmental and human health effects from various metals). Contamination of sediments can affect human health through the consumption of fish or other biota that bio-accumulate toxic substances. Sediment contamination provides a long-term source of pollutants through potential redissolution in the water column. This may lead to chronic contamination of water and aquatic organisms [3, 26].

Uranium: A very important source of environmental contamination is the extraction of uranium in particular tailings may contain radionuclides species that are disposed in open- air piles. Exposure to these substances may increase the risk of developing several cancers (Table 9). Tailings release radioactive radon gas into the environment. There are several studies demonstrating that the exposure to these substances may increase the risk of developing several cancers [3].

4.3.2: Other environmental impacts [1,3,26,38,39]

Particulate matter: Particulate matter can be released during surface mining when overburden is stripped from the site and stored or returned to the pit. For example, during mining the soil is removed causing the vegetation to be removed, thereby expose the soil to the weather, causing particulates to become airborne through wind erosion and road traffic. Particulate matter can be composed of toxic materials such as heavy metals like arsenic, cadmium, and lead. In general, particulates affect human respiratory tract, such as emphysema (a condition in which the air sacs of the lungs are damaged and enlarged), but they can also be ingested or absorbed into the skin [1,3].

Gaseous emissions: Some metals like arsenic, zinc, mercury, and cadmium vaporise when heated in pyrometallurgical processes. If they are not captured and condensated during these processes, they will escape to the surrounding environment [1,3].

Physical disturbances: mining can cause physical disturbances to the landscape, such as waste rock piles and open pits. These disturbances may contribute to the decline of wildlife and plant species in the area. Furthermore, mining subsidence (i.e., ground movements due to the collapse of overlying strata into voids by ground mining) can cause damage to buildings, pipelines, and roads [1,3].

Table 9: Toxic metals found in mining and other environments, their sources, and effects on environment, human health and guideline values to assess risks to different receptors.

Toxic metals	Environmental sources	Environmental effects	Human effects IARC group 1= carcinogenic to humans; IARC group 2A= probably carcinogenic to humans; IARC group 2B= possibly carcinogenic to humans; IARC group 3= Not classifiable as to its carcinogenicity to humans; IARC group 4= probably not carcinogenic to humans.	Guideline values* Bq – Becquerel; FW=freshwater; dw=dry weight; NA=not available; SW=Saltwater; TV=trigger values * toxicity of Cd, Cu, Pb, Zn depends upon hardness
Arsenic (As) **$_{33}$As** Arsenite (As^{3+}) (trivalent arsenic) is more acutely toxic than Arsenate (As^{5}) (pentavalent) [26].	Natural (Parental rock material), naturally found in association with coal, gold, iron, lead, silver, zinc ores; mining (mine tailings) & smelting, volcanoes, pesticides fertilisers, treated wood/wood treatment sites, industrial effluents, sewage sludge, tanneries, coal (fly & bottom ash), animal farms, incineration and incineration ash, detergents, petroleum combustion, air, land and water can be contaminated via windblown dust, water runoff; natural contamination (groundwater) reported from Bangladesh, West Bengal, Vietnam, China, Taiwan (see Figure 1.7) [26,28].	Soil and water close to mines can be contaminated with As. Terrestrial plants can absorb As via root or adsorption of air borne arsenic deposited on the leaves; As is phytotoxic to plants (bean, soybean, rice, are highly sensitive to As), rice and vegetables grown in contaminated soil & irrigation water can contain elevated levels of As; As toxicity on rice includes delayed seedling emergence, reduced plant growth, yellowing, wilting of leaves, reduced grain yields; freshwater fish can bio-accumulate As in different organs; phytoplankton are among the most sensitive organisms to arsenic [1,26].	As can cause cancer to humans from consumption of elevated level of As via drinking water and food or exposure from air, soil or water. IARC group 1 [1,26,30].	*Drinking water*: WHO: 10 µg/L, Asia and Bangladesh: 50 µg/L; *Freshwater aquatic ecosystems protection TV* (As^{3+}): 24 µg/L; *Marine aquatic ecosystems protection TV*: NA; *Irrigation:* 100-2000 µg/L; *Aquaculture* (FW): <50 µg/L; *Aquaculture* (SW): <30 µg/L; *Livestock drinking:* 500 µg/L; *Food (seafood)*: 1-2 mg/kg; *Sediment:* 20-70 mg/kg dw [28,29,30].
Cadmium (Cd) **$_{48}$Cd**	Parental rock material, phosphate fertilizers, farmyard manures, sewage sludge, mine tailings, batteries, industrial processes (electroplating, non-ferrous metal, iron and steel production), burning of fossil fuel and waste combustion, minor component in most zinc ores (by product of Zn), coal contain significant amounts of cadmium (flue dust), discharge from refineries, lead and zinc smelting, pigments for plastics and paint residues, plastic stabilizers [26,28,31].	Acidified soils enhance cadmium uptake by plant which may cause a threat to animals which feed on them and to the rest of the food chain. Earthworms and other essential soil organisms are extremely susceptible to cadmium poisoning. Cadmium may bioaccumulate in freshwater aquatic organisms (mussels, oysters, shrimps, lobsters, and fish) is highly toxic to plants and animals. Cd toxicity can damage nervous and reproductive systems and can reduce the ability of aquatic organisms to osmoregulate [1,26].	Human uptake of cadmium can occur through food ingestion (liver, mushrooms, shellfish, mussels, cocoa powder, dried seaweed), inhalation of fine dust and fumes; people can be exposed from highly soluble cadmium compounds, tobacco smoke, living near the hazardous waste sites or factories; Cd can damage the lungs, kidney, liver, and may cause reproductive failure and infertility; Cd is also carcinogenic to humans, IARC group 1; an endocrine disrupting chemicals (EDCs) [1,26,28,32].	*Drinking water:* 3 µg/l; *Freshwater aquatic ecosystems protection TV*: 0.2 µg/L; *Marine aquatic ecosystems protection TV*: 0.7 µg/L; *Irrigation:* 10-50 µg/L; *Aquaculture (FW):* <0.2-1.8 µg/L; *Aquaculture (SW):* <0.5-5.5 µg/L; *Livestock drinking:* 10 µg/L; *Food (seafood):* 2 mg/kg; *Sediment:* 1.5-10 mg/kg dw [28,29,30].
Copper (Cu) **$_{29}$Cu**	Parental rock material, copper fungicide, algicides, copper mining (mine tailings), fertilizers, farmyard manures, sewage sludge, copper dust, drinking water pipes, antifouling paints, coal and wood combustion, iron and steel production industrial processes, incineration ash [26,28,33].	Cu can accumulate in plants and animals,Cu is more toxic to freshwater fish and invertebrates than any other heavy metals except mercury. Cu can cause gill damage, reduce growth and kidney damage of aquatic organisms [1,26].	Cu is essential to all living organisms as a trace dietary mineral; it is not classified as carcinogenic to humans; high uptake of copper may cause liver and kidney damage; IARC group 3 [1,26,28,32].	*Drinking water*: 2000 µg/l; *Freshwater aquatic ecosystems protection TV*: 1.4 µg/L; *Marine aquatic ecosystems protection TV*: 1.3 µg/L; *Irrigation:* 200-5000 µg/L; *Aquaculture (FW & SW):* < 5 µg/L; *Livestock drinking- sheep:* 400 µg/L; cattle: 1000 µg/L; , pigs: 5000 µg/L; poultry: 5000 µg/L; *Food:* 0.5-2 mg/kg; *Sediment:* 65-270 mg/kg dw [28,29,30].
Lead (Pb) **$_{82}$Pb**	Natural (parental rock material), farmyard manures; mining; sewage sludge, batteries, lead ore mine wastes, lead smelters, sewage discharge, storm water runoff, lead pipes, fossil fuel combustion (lead petrol), corrosion of household plumbing usually found in ore with zinc, silver and (most abundantly) copper, pesticides, batteries, paint pigment, steel mill residues [26,28].	High lead levels can damage gill epithelium of fish and affected fish may die from suffocation [1,26].	Lead is a poisonous to animals and humans; it damages the nervous, kidney and brain system and can cause brain disorders; excessive lead also causes blood disorders in mammals; may decline fertility of men through sperm damage; probably carcinogenic to humans; IARC group 2A and 2B (inorganic), IARC group 3 (organic); EDCs [1.,26,28,32].	*Drinking water:* 10 µg/l; *Freshwater aquatic ecosystems protection TV*: 3.4 µg/L; *Marine aquatic ecosystems protection TV*: 4.4 µg/L; *Irrigation:* 200-5000 µg/L; *Aquaculture (FW & SW):* < 1-7 µg/L; *Livestock drinking:* 100 µg/L; *Food (seafood):* 0.5-2 mg/kg; *Sediment:* 50-200 mg/kg dw [28,29,30].
Mercury (Hg) **$_{80}$Hg** Organic mercury (methyl mercury-MeHg) is 4-31 time more toxic than inorganic mercury	Parental rock material, fertilizers; pesticides; lime; manures; sewage sludge; mercury used in gold production/gold separation may enter into water bodies via mine tailing; barometers, thermometers and fluorescent light bulbs, coal combustion, metallurgy, Mercury occurs in deposits throughout the world mostly as cinnabar (mercuric sulfide) [34].	Mercury bio- accumulates in fish and can enter in to the human food chain in the form of methyl mercury, etc.; mercury compounds can damage vital tissues and organs (gills, liver, kidney, brain and skin) of fish and may reduce reproductive success [26].	Hg exposure can occur via inhalation of mercury vapour, or eating seafood contaminated with mercury, mercury poisoning in humans causes incurable severe retardation of brain functions, disruption of the nervous system, DNA, chromosomal, sperm damage, birth defects and miscarriages, possibly carcinogenic to humans; IARC group 3, biomagnify up the food chain, EDCs, [1,26,28,32,35].	*Drinking water*: 1µg/l (Hg total); *Freshwater aquatic ecosystems protection TV*: 0.06 µg/L; *Marine aquatic ecosystems protection TV*: 0.1 µg/L; *Irrigation:* 2 µg/L; *Aquaculture (FW & SW):* < 1 µg/L; *Livestock drinking:* 2 µg/L; *Food (seafood):* 0.5 mg/kg (for most fish); 1 mg/kg (for large fish, such as shark); *Sediment:* 0.15-1 mg/kg dw [28,29,30].
Nickel (Ni) **$_{28}$Ni**	Parent rock material, fertilizers, fuel and residual oil combustion, alloy manufacture, nickel mining and smelting, sewage sludge, incineration and incineration ash, electroplating, batteries [28].	Released into the air by power plants and trash incinerators, most nickel released is adsorbed by sediment or soil particles, in acid soils, it becomes more mobile and often runs off to groundwater, high concentrations of Ni on sandy soils can severely damage plants, can reduce the growth rates of algae in waterways, though Ni is an essential element for animals at low concentrations but extremely harmful when the maximum tolerable amount is exceeded (can cause different kinds of cancer, in those organisms living near refineries) [1].	Humans can be exposed by breathing contaminated air, drinking contaminated water, eating contaminated food, or smoking cigarettes or dermal exposure via contaminated soils and waters or eating chocolate and fats, Ni is an essential element in small amounts but too high uptake can cause lung, nose, larynx, and prostate cancer, lung embolism, respiratory failure, birth defects, asthma and chronic bronchitis, and heart disorders, Ni exposure through breathing can cause pneumonitis; IARC group 1 [1,28].	*Drinking water:* 20 µg/l; *Freshwater aquatic ecosystems protection TV:* 11 µg/L; *Marine aquatic ecosystems protection TV:* 7 µg/L; *Irrigation:* 2 µg/L; *Aquaculture (FW & SW):* < 1 µg/L; *Livestock drinking:* 1000 µg /L; *Food:* NA; *Sediment:* 1000 mg/kg dw [28,29,30].
Uranium (U) **$_{92}$U** Persist many years (half-life): U-238: 47 billion years; U-235: 704 million years.	Found naturally (U-238 : 99.28%, U-235: 0.72%, U-234:.006%) in very small amounts in all rock, soil, and water, erosion of tailing from mines and mills could be main source in the environment, exist as dust that falls into surface water, plants and soils through rainfall, uranium compounds in soil combine with other compounds and persist in soil for many years. [3,36].	Plants absorb uranium through their roots, therefore, root vegetables may contain higher amounts of this element but washing can remove uranium [3].	People can be exposed to uranium (or radioactive daughters such as radon) by inhaling dust in air or by ingesting contaminated water and food, and working in the phosphate fertilizers industry and living or working near a coal-fired power plant; uranium can affect the kidney, brain, liver, heart, and other systems; radon gas can cause lung cancer and deaths from inhalation; IARC group 1 (Radon 222) [1,28,37].	*Drinking water:* 2 µg/l; *Freshwater aquatic ecosystems protection TV*: NA; *Marine aquatic ecosystems protection*: NA; *Irrigation (U):* 10- 100 µg/L; *Irrigation (U238):* 0.2 Bq/L; *Aquaculture:* NA; *Livestock drinking:* 200 µg/L; *Livestock drinking:* 0.2 Bq/L; *Food:* 0.5 mg/kg (for most fish); 1 mg/kg (for large fish, such as shark); *Sediment:* NA.[28,29,30].
Zinc (Zn) **$_{30}$ZN**	Parental rock, fertilizers, pesticides, coal and fossil fuel combustion, non-ferrous metal smelting, galvanized iron and steel, alloys, brass, rubber manufacture, oil tires, sewage sludge, batteries, brass, rubber production, mine tailings, urban run-off, waste incineration [26,28].	Zn can cause gill damage, reduced growth and kidney damage in fish [26].	Zinc is an essential mineral for humans but too much can cause health problems such as stomach cramps, skill irritations, and can damage the pancreas, respiratory disorders [26].	*Drinking water:* NA; *Freshwater aquatic ecosystems protection TV*: 8.0 µg/L; *Marine aquatic ecosystems protection*: 15 µg/L; *Irrigation:* 2000-5000 µg/L; *Aquaculture (FW & SW):* < 5 µg/L; *Livestock drinking:* 20,000 µg/L; *Food (seafood):*NA; *Sediment:* 200-420 mg/kg dw [28,29,30].

Agricultural soils: Agricultural fields (soils) which are close by mines (e.g. abandoned mines) may be contaminated by the dispersion processes (dust) resulting elevated metals and metalloid concentrations in food crops grown on such contaminated soil. The food grown in contaminated soil may not be safe for human consumption and may exceed permitted standards for metals, thus posing a health risk to humans. Grazing animals (beef cattle) may also consume metal-rich plants and soils and bio-accumulate metals in tissues. Mine waters are a significant source of metals and metalloids and cations and anions (Tables 5 and 7) [1,3].

Dispersion of mine wastes and waterways contamination: as indicated above, soils surrounding mine waste piles and mine sites are well known for their elevated metal and metalloid concentrations. The dispersion of mine wastes may lead to the contamination of stream systems, floodplains and coastal environments as well as drinking water supplies. Element concentrations in soils, sediments and waters may exceed environmental quality guidelines and impact on ecosystem health. Metals and metalloids originally contained in waste particles may be released to ground, surface and pore waters and become bioavailable to plants and animals [1,3,26].

Phytotoxic effects: Plants colonizing metal mine sites and waste repositories commonly accumulate metals and metalloids into their biomass relative to concentrations of plants growing in adjacent uncontaminated areas. The uptake and accumulation of metals into plants may reach phytotoxic levels and subsequent plant death [1,3]. Arsenic is reported to be highly toxic to beans, rice and can reduce growth and grain yields in rice [26].

Tailing dams (mine dumps): Drainage water including AMD from tailings dams, mine waste dumps etc. may contain suspended solids and dissolved contaminants such as acid, salts, heavy metals, metalloids, and sulfate. Such waters should not be released from a mine site without prior treatment. Tailings/mine dumps would continue to leach residual chemicals into the environment, and if weather conditions allowed, the finer fraction would become windborne and may affect the close by areas. Several major environmental disasters have been caused by tailings dam failures. The uncontrolled discharge of mine waters with elevated contaminant concentrations into the environment may impact on surface waters, aquatic life, soils, sediments, and ground waters. Therefore, investigations of the environmental impacts of mine waters require an assessment of the concentration of elements in waters of background and contaminated sample populations [3]. ***Common minerals and elements*** found in tailings include: (a) Arsenic (found in association with gold ores), (b) Barite, (c) Calcite, (d) Cadmium, (e) Fluorite, (f) Hydrocarbons (introduced by mining and processing equipment (oils & greases)), (g) Mercury, (h) Radioactive materials (Naturally present in many ores), Sulfur (many sulfide compounds / pyrites), and ***common additives*** found in tailings includes: (h) Cyanide (as both sodium cyanide (NaCN), hydrogen cyanide (HCN)), (i) SEX - Sodium Ethyl Xanthate (flotation agent), (j) PAX - Potassium Amyl Xanthate. (flotation agent), (k) MIBC - Methyl Isobutyl Carbinol (frothing agent), (l) Sulfamic acid (Cleaning / descaling agent), (m) Sulfuric acid (used in large quantities in the pressure acid leaching process), (n) Activated Carbon (used carbon in pulp and carbon in leach processes and (o) Calcium (different compounds, introduced as lime to aid in pH control) [38].

Cyanides: Cyanides (contains the cyano group, -C≡N) are other environmental contaminant sourced from activities such as gold and silver extraction. Cyanides are used to dissolve these metals and their ores. Finely ground high-grade ore is mixed with the cyanide (concentration of about two kilogram NaCN per tonne); low-grade ores are stacked into heaps and sprayed with a cyanide solution (concentration of about one kilogram NaCN per ton). The precious metals are complexed by the cyanide anions to form soluble derivatives, e.g. $[Au(CN)_2]^-$ and $[Ag(CN)_2]^-$ [3,39]. Hydrocyanic acid is the most toxic of the simple compounds, and penetrates quickly in the organism and acts by attaching itself to ferric iron (Fe^{++}). As this ion plays an active role in various enzyme systems, deactivation by cyanide of some of those systems would cause important adverse effects in the organism. Ingestion or inhalation causes headache, chest pain, and vomiting. Ingestion of a fatal dose is followed by respiratory difficulty, arrhythmia, and coma.

4.4: Coal mining impacts [3,21,40,40,41,42,43]

During coal mining operations, methane may be released into the air *[note: methane is also called coal bed methane, coalbed gas, coal mine methane, coal seam gas (CSG)- is a natural gas extracted from coal beds (300-1000 meters), an important source of energy in the United States, Canada, and Australia; CSG is a mixture of a number of gases, but is mostly made up of methane (generally 95-97 per cent pure methane]*. The coal miners can suffocate from the release of methane and other toxic gases; as a consequence miner's lungs can be damaged via inhalation, which may cause "pneumoconiosis". Pneumoconiosis was responsible for about 10, 000 deaths in the USA until 2009 *(note: pneumoconiosis is a disease of the lungs, a result of continued or prolonged inhalation of mineral dust or particles)* [40,41,42]. Coal combustion releases toxic chemicals such as arsenic, mercury, fluorine, cadmium, lead, selenium and zinc. It is known that over a third of all mercury emissions attributable to human activity come from coal-fired power stations. Mercury enters the environment and accumulates in the food chain, particularly in fish. Burning of coal emits many pollutants that can harm human health including causing respiratory symptoms such as cough, aggravated asthma, the development of chronic bronchitis and decreased lung function; arrhythmias, nonfatal heart attacks and premature death in people with heart or lung disease. In China, (Guizhou province) about 3,000 people are suffering from severe arsenic poisoning from consumption of chilli pepper dried over fires fuelled with high arsenic coal [21]. In 2010, coal seam gas operations in Queensland resulted in contamination of groundwater with a potentially dangerous combination of benzene, toluene, ethylbenzene and xylene (BTEX). The Queensland government has recently banned BTEX chemicals from coal-bed fracturing fluids [40]. Coal mine tailing dumps produce acid mine drainage, which can seep, into waterways (most coal deposits contain pyrite (FeS_2), arsenopyrite and other sulfur) [21]. The pH of coal mine waters can have near neutral pH to low pH values. In addition, high electrical conductivity, total dissolved solids, sulfate, nitrate, iron, aluminium, sodium, calcium and magnesium values can

be found. Individual mine sites may have waters with elevated manganese and trace elements (Cd, Co, Cr, Cu, Li, Ni, Pb, Sr, Zn) and metalloids (As, B, Se) [3].. In general, AMD waters from coal mines typically contain much lower concentrations of heavy metals and metalloids than waters from base metals (copper, lead, iron, zinc, nickel) or gold deposits. Substantial concentrations of manganese have been documented for some near-neutral coal mine waters. Salt levels, particularly chloride concentrations, can be extreme in the coal mine sites. These saline waters originate from saline aquifers as dewatering of mine may intersect deep saline formation waters. In rare cases, coals have significant concentrations of uranium, thorium, and radioactive daughter products of uranium and thorium decay series [3]. Coal-fired power stations are potent emitters of greenhouse gases and are important contributors to climate change (coal produces 84% of Australia's power supply).There is overwhelming evidence that coal mining and the burning of coal is harmful to physical and environmental health, and can have a significant impact on local communities [40] . In Bangladesh, there has been a public outcry against a proposed open pit coal mining project (Phulbari, Dinajpur) if implemented, the mine would have devastating environmental impacts, displacing about 220,000 people including indigenous people**,** and harming livelihoods of the local people (access to drinking water and food could have been at risk) (see Figure 6 and 7).

Figure 6: Demonstrators hold placards and banners outside Global Coal Resources AGM in London, UK, against the open-cast coal mine project proposal in Phulbari (Dinajpur) in Bangladesh. Image by James Melik [43].

Figure 7: In the Phulbari area of Northwest Bangladesh (Dinajpur), communities have come together to raise their voices against the proposed Phulbari Coal Project--which threatens to turn fertile agricultural region (rice, wheat) region into an open-pit coal mine. If implemented, the mine would have devastating environmental impacts and ultimately displace up to 220,000 people.

4.5: Climate change and mining chemicals [3,26,49]

There could be a link between climate change and chemicals, for example, where intense rainfall is expected to increase due to climate change, as a result, run-off of pollutants such as pesticides (insecticide, herbicide and fungicide); trace/heavy metals (Cd, Cu, Hg, Pb, and Zn), dioxins, furans and PCBs, and other chemicals (EDCs, human and veterinary pharmaceuticals) into water bodies will increase and contaminate waters [26]. Furthermore, the predicted increase in global temperature is expected to increase the rates of mine waste weathering (changes & breakdown) about 1.3-fold higher than present by the year 2100. Moreover, longer dry spells and more intense rainstorms have been predicted for particular regions. Such changes in evaporation rates, as well as rainfall patterns, and events will impact on the chemistry of mine waters, in particular first flush events. Prolonged weathering will lead to the formation of a greater abundance of soluble salts. Flushing of mine sites and waste repositories will lead to larger sudden increases in contaminant concentrations and higher average concentrations during longer low-flow periods [3, 26]. Alternate floods and droughts (which are projected, to increase due to climate variability and climate changes) have been found to be associated with the release arsenic and contamination of groundwater in Bangladesh. It is also expected that uptake and toxicity of metals in fish may be enhanced with increasing temperatures/global warming [26, 49].

4.6: Some examples [3,13,44,45,46]

Australia (zinc, lead and silver): McArthur River mine is one of the world's largest zinc, lead and silver mines, situated about 70 kilometres southwest of Borroloola, near the Gulf of Carpentaria in the northeastern Northern Territory, Australia. Seepage monitoring conducted (2005, 2007, and 2010) found that soluble sulfate, zinc, lead and cadmium are seeping into natural creeks such as Surprise Creek. Dust from operations at the run of mine pad, crushing plant, and Tailings Storage Facility (TSF) contaminated stream sediments (Barney Creek and Surprise Creek) adversely impacting the macro-invertebrates in Surprise Creek. The Environmental monitoring report for 2010 identified two main environmental issues that may pose extreme risks are: overtopping of TSF cells leading to an embankment failure and acid leachate migration from the TSF into Surprise Creek [44].

Papua New Guinea (PNG) (copper-gold): Chemicals from the tailings of Ok Tedi mine (copper-gold mines) killed fish as well as contaminated fish with metals. Alluvial sediments of the Fly River flood plain had a copper concentration of 620 mg/kg compared to regional background of 40 mg/kg; average dissolved copper content in waters of the inner flood plain was recorded as 9 µg/L compared to unpolluted plain with < 2 µg/L. The background gold concentrations in the Fly River flood plain was 7 µg/kg (ppb) Au compared to 140-275 µg/kg (ppb) in mine derived material [45,46].

Tanzania (gold and gemstone): The mining caused were pollution of natural waterways with mercury and cyanide. The local people have reported approximately 52 cases of housing collapse resulting from mine-induced explosions. The mining caused destruction of agricultural and grazing lands (abandoned pits, excavated materials) impacting livestock production and associated manure (fertiliser), milk and meat production. Artisanal mining activities also caused diversion of rivers, water siltation, landscape degradation, deforestation, destruction of aquatic life habitat, and widespread mercury pollution. In addition, the dust pollution from gold and gemstone mining has been reported to increase the rate of female miscarriage and air borne infections [13].

USA (coal and metal): In the United States, it has been estimated that 19,300 km of streams and 72,000 ha of lakes and reservoirs have been seriously damaged by mine effluents from abandoned coal and metal mines [3].

5. Social impacts [1,11,12,13,45,46]

Communities living close by mines can be impacted from environmental exposure to contaminated air, water, soil, and noise pollution and non-environmental effects such as mining disasters and pit closure [1]. For example, small-scale gold and artisanal miners can inhale noxious mercury fumes and dust where stringent occupational health and safety practices are not followed and information concerning the risks associated with mercury exposure is not readily available. These people may be working without safety gloves and may consume contaminated water or fish containing elevated concentrations of mercury. Once in the body, inorganic mercury is transformed into toxic methylmercury, which poses a serious threat to humans. Overexposure of mercury can cause a variety of illness, including dizziness, fatigue, and a loss of appetite, headaches, convulsions and even death. Workers of deep mines are exposed to more hazardous situations (compared to open cast mines) due to the risk of collapse, poor air quality, and underground explosions. Major impacts on workers' health are cancer and respiratory diseases such as asbestosis, silicosis, and pneumoconiosis. Long-term effects are particularly prominent in miners who have worked in asbestos, coal, and uranium mines, or in miners who have been exposed to a mixture of different silica and other dusts (copper, gold, and zinc mines) [1,11,12,13].

Mining may cause several negative effects on the quality of life and lifestyle of the communities. The negative social effects include appropriation of lands belonging to the local communities, alteration of social relationships and destruction of forms of community subsistence and life. Mining requires migration of people from other areas, for instance, in South Africa; gold mining involves workers coming from neighbouring countries. Such population influxes can contribute to social tensions and new forms of poverty in local areas. The rapid influx of people can lead to price inflation of local goods (food, fuel, land/housing etc.). Furthermore, social ills such as alcohol abuse, prostitution and, spread of communicable diseases, namely, human immunodeficiency virus / Acquired immunodeficiency syndrome (HIV/AIDS) often increases in mining areas [11,13]. Migration of young ladies into mining centres in search of non-existent jobs has also increased prostitution and the spread of venereal diseases including HIV and AIDS in mining region. Kituala *et al*. (2006) [13] reported that in Tanzania, the under aged children (18 and below) generally involve in small-scale mining operations and such activities exposes children to dust that can cause silicosis (lung disease caused by inhalation of crystalline silica or sand dust) and silico-tuberculosis. The tendency of children working in mining encourages absence in school and increases the school dropout rate. In addition, accidents, theft, changes in indigenous lifestyle, and competition among local residents for natural resources may increase in mining areas.

In PNG, the mine operators discharge a significant amount of tailings and overburden (about 80 million tons) etc. into the river system each year, this discharge is causing widespread and diverse harm to the 50,000 people who live in the 120 villages downstream of the mine. The dumping resulted in the river bed to rise to 10m disrupting indigenous transportation routes. Further flooding and contaminated mud on the flood plain have affected plantations of taro, bananas and sago palm (staples local diet) (1300 square kilometres were damaged) [45,46].

Mining has resulted in thousands of deaths and injuries all over the world. Some of the most common causes are mine collapse, coal dust explosions, methane gas, rock falls, carbon monoxide poisoning. Over the years, mining safety standards have been improved.

Table 10: Some examples of mining disasters in Australia and examples of world's top mining disasters [47, 48].

Country	Date	Location	Causes	No of fatalities
Australia	2006 (25 April)	Beaconsfield mine, Tasmania	Mine collapse	One killed and the remaining two were found alive after five days.
Australia	2000 (26 June)	Bronzewing Gold Mine in Western Australia	18,000 cubic meters of sand-slurry, sludge, mud and rock broke through a storage wall	3 men killed
Australia	1999	Northparkes mine, NSW		Four miners killed
Australia	1994 (January)	Moura, Queensland	An explosion	2 men killed (January), 11 men killed (September)
Australia	1986 (July)	Moura, Queensland	An explosion	12 coal miners lost their lives
Australia	1975 (September)	Kianga Mine, Moura, Queensland	underground explosion	13 men killed
Australia	1972 (31 July)	Box Flat Mine in Swanbank, South East Queensland,	underground gas explosion	17 miners were lost after an underground gas explosion
Australia	1965 (9 November)			
Australia	1945 (20 April)	Balmain Colliery, NSW	An explosion	3 killed and 2 injured
Australia	1932	Balmain Colliery, NSW	During sinking of bore, ignition of gas	2 men killed

Australia	1921 (19 September)	Mount Mulligan mine, Queensland	An explosion due to use of naked flame for lighting)	Killed 75 workers.
Australia	1912 (12 October)	North Mount Lyell	Fire	Killed 42 miners
Australia	1902 (31 July)	The Mount Kembla (coal mine)	An explosion	Killed 96 miners, including two engaged in rescue work; worst mining disaster in Australian history
Australia	1900 (17 March)	Balmain Colliery, Birchgrove, New South Wales (coal, gas mines)	During lowering down the birthday shaft	6 miners were killed
Australia	1887 (23 March)	Bulli in New South Wales	an explosion at the mine	81 people killed
Australia	1882 (12 December)	New Australian gold mine, Creswick, Victoria	trapped underground by flood waters	24 miners killed
World's Top Mining Disasters				
Country	**Date**	**Location**	**Causes**	**No of fatalities**
China	1942 (26 April)	Honkeiko (Benxihu) Colliery	-	1,594 miners died
France	1906 (10 March)	Courrieres (pit disaster)	Coal dust explosion	1,100 miners died
India	1975 (27 December)	Chasnala (coal mine)	Explosion resulting 7,000,000 gallons of water per minute to flood the mine	372 miners killed
India	1965 (28 May)	Dhanbad (coal mine)	Explosion followed by fire	375 miner killed
Japan	1963 (December)	Mitsibuishi Hojyo Coal mine, Kyushu	Explosion of coal mine	687 miner killed, worst mining disaster in Japans history
South Africa	1960 (1 January)	Coalbrook	Rock fall	437 miner killed, deadliest mining accident in South Africa
UK	1913 (14 October)	Senghenydd, Welsh mining, Wales (coal)	Methane gas explosion	438 men and boys killed
UK	1866 (12 December)	Barnsley, England	Explosion	361 miner killed
USA	6 December 1907	The Monongah Mining Disaster, West Virginia	Underground explosion	Worst mining accident of American history; 362 workers were killed
Zimbabwe (Rhodesia)	6 June 1972	Wankie coal mine disaster	Methane explosion	One of the worst mining disasters with 426 fatalities.

6. Reducing mining Impacts [1,3]

6.1: Environmental management plan [3]

Environmental management plan such as environmental impact assessment, environmental monitoring (during operation and after closure) and adaptation of best practices should be an integral part of managing mine related environmental issues. Furthermore, a number of management strategies can be taken at mine sites to contain all contaminated water to protect aquatic environments and to reduce the water volume requiring treatment. Since every mine produces its very own unique waste, therefore, waste generated at each mine requires its very own characterisation, prediction, monitoring, treatment, and secure disposal. Various techniques can reduce mine water volumes: (a) interception and diversion of surface waters through construction of upstream dams; (b) diversion of run-off from undisturbed catchments; (c) maximization of recycling or reuse of water; (d) segregation of water types of different quality; (e) controlled release into nearby waters; (f) sprinkling of water over dedicated parts of the mine site area; (g) use of evaporative ponds. These water management strategies will reduce the potential AMD water volume [3].

Since sulfide oxidation can lead to the generation of AMD and to prevent this process of AMD generation, few established technologies (barriers such as wet and dry covers) are being practiced which are aimed to control or exclude one or more factors that cause sulfide oxidation. For example, reducing oxygen availability is the most effective control on the oxidation rate, which can be achieved using wet or dry covers. In the wet covers, oxygen diffuses very slowly and has limited solubility in water. In contrast, a dry cover with low oxygen permeability restricts water and oxygen movement into and through the waste. In wet cover techniques, sulfidic wastes are submerged to establish an anoxic environment to slowdown the rate of sulfide oxidation, whereas in dry covers technique, solid materials are placed (e.g. clay subsoils, soils, organic wastes, and neutralising materials such as limestone (calcium carbonate), lime (calcium-containing inorganic materials), dolomite (carbonate mineral composed of calcium magnesium carbonate $CaMg(CO_3)_2$), kiln dust (burning, or drying substances) are used to inhibit the growth of acidophilic iron oxidizing bacteria.

The other techniques:

- *Organic wastes* where alkaline organic waste such as sewage sludge, wood chips, sawdust, manure, peat, pulp and paper mill residues, and municipal solid wastes compost are used to inhibit pyrite oxidation (iron sulfide) via inhibition of the proliferation of sulfur and iron oxidizing bacteria, promoting the reduction of dissolved sulfate and metals and the formation of solid
- *Bacterial inhibition*: in this technique, antibacterial agents such as anionic surfactants, cleaning detergents, organic acids, and food preservatives are used to inhibit the growth of bacteria. In the presence of such compounds, hydrogen ions in the acidic environment move freely into or through bacteria cell membranes, causing their deterioration.

Though remediation technologies can be used to control sulfide oxidation, however, prevention or minimisation of sulfide oxidation at the mine source is better than the treatment of AMD waters. Preventative measures applied to control sulfide oxidation will also help to control the volume of AMD waters. Collection and treatment of AMD can be achieved using established and sophisticated treatment systems including evaporation, neutralisation, wetlands, and controlled release and

dilution by natural waters. Better technologically advanced processes can also be used (e.g. osmosis, electrodialysis, ion exchange, electrolysis, biosorption, bioreactor tanks, limestone reactors) to reduce AMD volume or to raise pH or to lower dissolved metal and sulfate concentrations or to lower the bioavailability of metals in solution or to oxidise or reduce the solution; or to collect, dispose or isolate the mine water or any metal-rich sludge generated [3].

6.2: Legislation [1]

There are some major laws and regulations relevant to mining industry [1].

- US Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)- (Known as **Super fund**)- requiring companies to report releases of hazardous substances to the environment and requires clean-up of hazardous sites (currently being used by the US EPA to clean up mineral contamination at numerous locations)
- US Federal Water Pollution Act (known as the Clean Water Act) requires mining operations to meet standards for surface water quality and for controlling discharges to surface water
- EU Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006: this directive is to prevent or minimise any adverse effects on the environment and the health risks resulting from the management of waste from the extractive industries, such as tailings and displaced material. This directive applies to waste resulting from the extraction, treatment and storage of mineral resources, and the working of quarries (mines).

6.3: Monitoring [3].

- Adequate monitoring to measure concentrations of trace elements in soil, surface water, groundwater, air and sediments and at various levels of biological organisation (plants and biota).
- Investigations of the environmental impacts of mine wastes require an assessment of the concentration of elements in soils, sediments, plants and biota in background and contaminated sample populations.
- Monitoring techniques can be designed to monitor or identify the early presence of or the changes to any products of the acid producing sulfidic wastes. Sulfidic wastes can be identified by obtaining waste temperature measurements, oxygen pore gas concentration profiles, and leachate (mine water) analyses for dissolved contaminant concentrations and loads. Rapid increases in temperature profiles of waste dumps indicate the exothermic oxidation of sulfides, whereas the depletion of oxygen concentration within gas pores is also indicative of sulfide oxidation.

7. Conclusion [1]

Mining is both beneficial (e.g. economic prosperity of a nation, employment) as well as harmful to environment (e.g. water and food contamination by harmful metalloids, metals and processed chemicals; decline or loss of biodiversity due to toxicity of metals) and human health (e.g. cancer from exposure to As, Cd, U; lung diseases from exposure of coal dust). Monitoring and assessing the risk posed from chemicals released from mining activities (metalloids, metals and processed chemicals) via air, soil, water routes to the environment and public health should be given a priority. Mining can result in deaths and injuries from mine collapse, coal dust explosions, and exposure to methane gas, rock falls, and carbon monoxide poisoning, therefore, mining safety standards need to be improved in particular in third world countries. Initiatives should be developed to reduce the amount of hazardous material released into the environment. Clean-up and remediation measures are crucial since abandoned mines will continue to have an impact on both health and environment unless mine closure practices are strictly preformed. It is vital to conduct regular monitoring and surveillance/investigation activities of the environment and community's health. There is a further need for a deeper and long-term evaluation of the mining impacts on workers and communities' health. All these measures will help to protect the health and safety of people working in, living near, and those otherwise impacted by historic, current, and proposed mines.

8. References

1. Coelho, P.C.S., Teixeira, J.P.F and Gonçalves, O.N.B.S.M (2011) Mining activities: Health impacts. In: Nriagu JO (ed.) *Encyclopedia of Environmental Health.* 3: 788–802 Burlington: Elsevier.
2. Cordy, P., Veiga, M. M., Salih, I., Al-Saadi, S., Console, S., Garcia, O. (2011). Mercury contamination from artisanal gold mining in Antioquia, Colombia: The world's highest per capita mercury pollution. *Science of the Total Environment.* 410-411: 154–160
3. Lottermoser, B. G. (2010).Mine waste- Characterization, treatment and environmental impacts. Third edition. Springer Verlag Berlin Heidelberg. .ISBN 978-3-642-12418-1.
4. http://www.mapsofworld.com/world-mineral-map.htm World mineral map.
5. http://en.wikipedia.org/wiki/File:2005copper_(mined).PNG Copper output in 2005
6. http://en.wikipedia.org/wiki/File:2005cadmium.PNG Cadmium output in 2005.
7. http://en.wikipedia.org/wiki/File:Gold_(mined)2.png Global gold output in 2005.
8. http://en.wikipedia.org/wiki/Nickel.Nickel output in 2005.
9. http://watd.wuthering-heights.co.uk/nuclear/uraniumreserves.htm Uranium: How Much and Where.
10. http://www.bgs.ac.uk/arsenic/ Arsenic contamination of groundwater.
11. Pegg, S. (2006). Mining and poverty reduction: Transforming rhetoric into reality. *Journal of Cleaner Production.* 14: 376-387.
12. Hilson, G. and Paradie, S. (2006). Mercury: An agent of poverty in Ghanas small scale gold-mining sector? *Resource's Policy*. 31: 106-116.
13. Kitula, A.G.N. (2006). The environmental and socio-economic impacts of mining on local livelihoods in Tanzania: A case study of Geita District. *Journal of Cleaner Production*. 14: 405-414.
14. Graham A. Davis, G.A. and Cordano, A.L V. (2012). The fate of the poor in growing mineral and energy economies. *Resources Policy*. http://dx.doi.org/10.1016/j.resourpol.2012.10.002.
15. http://en.wikipedia.org/wiki/Mining_in_Australia Mining in Australia.
16. http://en.wikipedia.org/wiki/Economy_of_Australia Economy of Australia.
17. http://www.mbendi.com/indy/ming/p0005.htm World mining-Overview
18. https://www1.eere.energy.gov/industry/mining/pdfs/overview.pdf Mining overview: Mining backbone of the US Economy.US Department of Energy.
19. http://www.mbendi.com/indy/ming/p0005.htm#CountryProfiles World mining-Overview.
20. Akcil, A. and Koldas, S. (2006). Acid mine drainage (AMD): causes, treatment and case studies. *Journal of Cleaner Production*. 14: 1139-1145.

21. www.lhup.edu/.../Coal%20Mining%20Options%20in%20Bang... Open pit Coal mining option in Bangladesh- Lock Haven University
22. http://en.wikipedia.org/wiki/Acid_mine_drainage Acid mine drainage.
23. Nordstrom, D.K., Alpers, C, N., Ptacek, C. J., and Blowes, D. J. (2000). "Negative pH and Extremely Acidic Mine Waters from Iron Mountain, California". *Environmental Science & Technology* 34 (2): 254–258.
24. http://en.wikipedia.org/wiki/File:Northland_waste_water.jpg Acidic lake waste water at Northland Mine in Temagami, Ontario, Canada
25. http://en.wikipedia.org/wiki/File:Iron_hydroxide_precipitate_in_stream.jpg Iron hydroxide precipitate (orange) in a Missouri stream receiving acid drainage from surface coal mining.
26. Kibria, G., A. K. Yousuf Haroon, D. Nugegoda and G. Rose. (2010). *Climate change and chemicals: Environmental and biological aspects.* New India Publishing Agency, New Delhi, India, 460 pp. ISBN: 9789-38-0235-301. http://researchbank.rmit.edu.au/view/rmit:12529
27.WHO (1996). Guidelines for drinking-water quality, 2nd ed. Vol. 2 Health criteria and other supporting information, p. 940-949; and WHO, 1998. Addendum to Vol. 2. p. 281-283. Geneva, World Health Organization. Summary tables. http://www.who.int/water_sanitation_health/GDWQ/Summary_tables/Sumtab.htm
Annex 3. Drinking-water quality guidelines for parameters of concern in agricultural drainage water http://www.fao.org/docrep/005/y4263e/y4263e0g.htm
28. Marcotullio P.J. (2007) Urban water-related environmental transitions in Southeast Asia. *Sustainability Science.* 2:27–54.
29. IARC (2006). International Agency for Research on Cancer (IARC). IARC monographs on the evaluation of carcinogenic risks to humans. http://monographs.iarc.fr/ENG/Classification/index.php
30. ANZECC and ARMCANZ (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand) (2000) National water quality management strategy, Australian and New Zealand guidelines for fresh and marine water quality. ANZECC & ARMCANZ, Canberra, Australia.
31. http://en.wikipedia.org/wiki/Cadmium Cadmium
32. Kibria, G. (2012). Environmental/Ecological Risk Assessment (ERA) Model for Assessing Risks in Irrigation Areas (Rivers, Creeks, Channels, drains) of toxicants (Pesticides, Herbicides and Trace Metals) to Various Receptors. National and international research collaboration (2001-2012) between the Goulburn Murray Rural Water Corporation, Tatura, Victoria, Australia (G-MW), and federal, state and regional government departments and the Universities. 42 p. http://www.g-mwater.com.au/downloads/R_D/my_version.pdf
33. http://en.wikipedia.org/wiki/Copper Copper
34. http://en.wikipedia.org/wiki/Mercury_(element) Mercury
35. http://en.wikipedia.org/wiki/Gold Gold
36. http://en.wikipedia.org/wiki/Uranium Uranium
37. Kibria, G. (2011). *Nuclear Power Plant Accidents and Its Effects.*
http://www.sydneybashi-bangla.com/Articles/GolamKibria_Nuclear%20Power%20Plant%20Accidents_Its%20Effects_Golam%20Kibria_10%20.pdf
38. http://en.wikipedia.org/wiki/Tailings Tailings
39.http://en.wikipedia.org/wiki/Cyanide Cyanide
40.http://www.fof.org.au/uploads/media/MJA_Coal.pdf The mining and burning of coal: effects on health and the environment
41.http://en.wikipedia.org/wiki/Coal_mining Coal mining
42.http://en.wikipedia.org/wiki/Coalbed_methane Methane
43.http://globalvoicesonline.org/2012/11/25/protests-in-phulbari-against-open-pit-coal-mining-project/Bangladesh Protests Against Open Pit Coal Mining in Phulbari
44. http://en.wikipedia.org/wiki/McArthur_River_zinc_mine McArthur River Zinc mine
45.Hettler, J.; Irion, G., Lehmann, B. (1997). "Environmental impact of mining waste disposal on a tropical lowland river system: a case study on the Ok Tedi Mine, Papua New Guinea". *Mineralium Deposita*.
46.http://en.wikipedia.org/wiki/Ok_Tedi_environmental_disaster Ok Tedi environmental disaster
47.http://en.wikipedia.org/wiki/Mining_in_Australia
48.http://structure-structural-software.blogspot.com.au/2010/11/top-10-mining-disasters-around-world.html
49. Kibria, G., Haroon, A. K.Y. and Nugegoda, D. (2013). *Climate change and Agricultural food production: Impacts, vulnerabilities and remedies*. New India Publishing Agency. New Delhi. 300 p. ISBN: 9789381450512
http://www.bookfactoryindia.com/index.php?p=sr&Uc=9789381450512

Notice: *The article is based on various sources and was compiled by Golam Kibria, Ph.D in March 2013 for http://www.sydneybashi-bangla.com (35) for community benefits. Views expressed in this article are those of the author and are not to be taken to be the views of any others including third parties. The information in this article may be assistance to you but the author donot guarantee that it is without flaw of any kind and therefore disclose any liability for any error, loss or other consequences which may arise from relying on any information in this article. All figures/diagrams/tables included in the article were acknowledged in the reference section as well as at the bottom of each figure/diagram/table and were used in good faith and intention of promoting science in particular in the third world countries such as the Asia-Pacific and Africa regions where information are not readily available or lacking and as part of knowledge sharing and awareness on environmental and sustainability issues. The author did not receive any financial benefits or payment or royalty for this article. This is a voluntary work to benefit the wider communities.*