MINEO

Contract
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Part 2
Review of potential environmental and social impact of mining

EC DG INFSO-B4

1. INTRODUCTION

Mining has played a significant role in the development of many countries all over the world. The industry has been, and continues to be[1] an important contributor to both national and regional economies and is critical to national defence. Mining, and the industries it supports, is among the basin building blocks of a modern society.

The benefit of mining to those countries has been many, but has come at a cost to the environment. As countries have matured, there has been increasing recognition that **environmental protection is as fundamental to a healthy economy and society as is development**. The challenge is to simultaneously promote both economic growth and environmental protection.

The historic impacts of mining on the environment are significant. While estimates vary, it is generally recognised that in the USA, there are over 200,000 inactive and abandoned mines (IAMs) nation wide. Only a fraction of these are believed to contribute significantly to environmental problems, but the aggregate impact is substantial and in specific cases there are serious localised environmental impacts.

The major environmental issues facing countries were summarised in Agenda 21, the global action plan agreed by countries at the **1992 Earth Summit in Rio**. Priorities for action included protection of inland and marine waters, global atmospheric protection, toxic chemicals and waste. The urgent need for action by governments, international organisations and industry was stressed, with more initiatives called for on cleaner production methods, technology transfer, local capacity building and training. In addition to action at the national level, the increasing number of agreements on international conventions on hazardous waste, climate change and bio-diversity demonstrate the growing commitment to environmental action around the world.

The immediate pollution impacts that affect local communities and ecosystems are usually a first priority for action by mining companies and governments. Company and national environmental plans will indicate what these priorities are and how they should be addressed. Many non-governmental organisations (NGOs) are also active at the local and national level.

This chapter will briefly explain the major environmental issues concerning mining and give an explanation of the best way in which they can be addressed by government and industry.

The major phases in mining which impact the environment are:

- **Exploration** – including surveys, field studies, drilling and exploratory excavations. Some land disturbance and waste already occur at this stage.

- **Project development** – includes roads and buildings, access tunnels, erection of treatment plants, overburden stripping and placing, preparation of disposal areas, construction of

[1] The European mining and extractive industry contributes about 7% of the gross domestic product of the EU from this resource and feeds essential raw materials to all other EU industries at local, regional and EU-wide scales

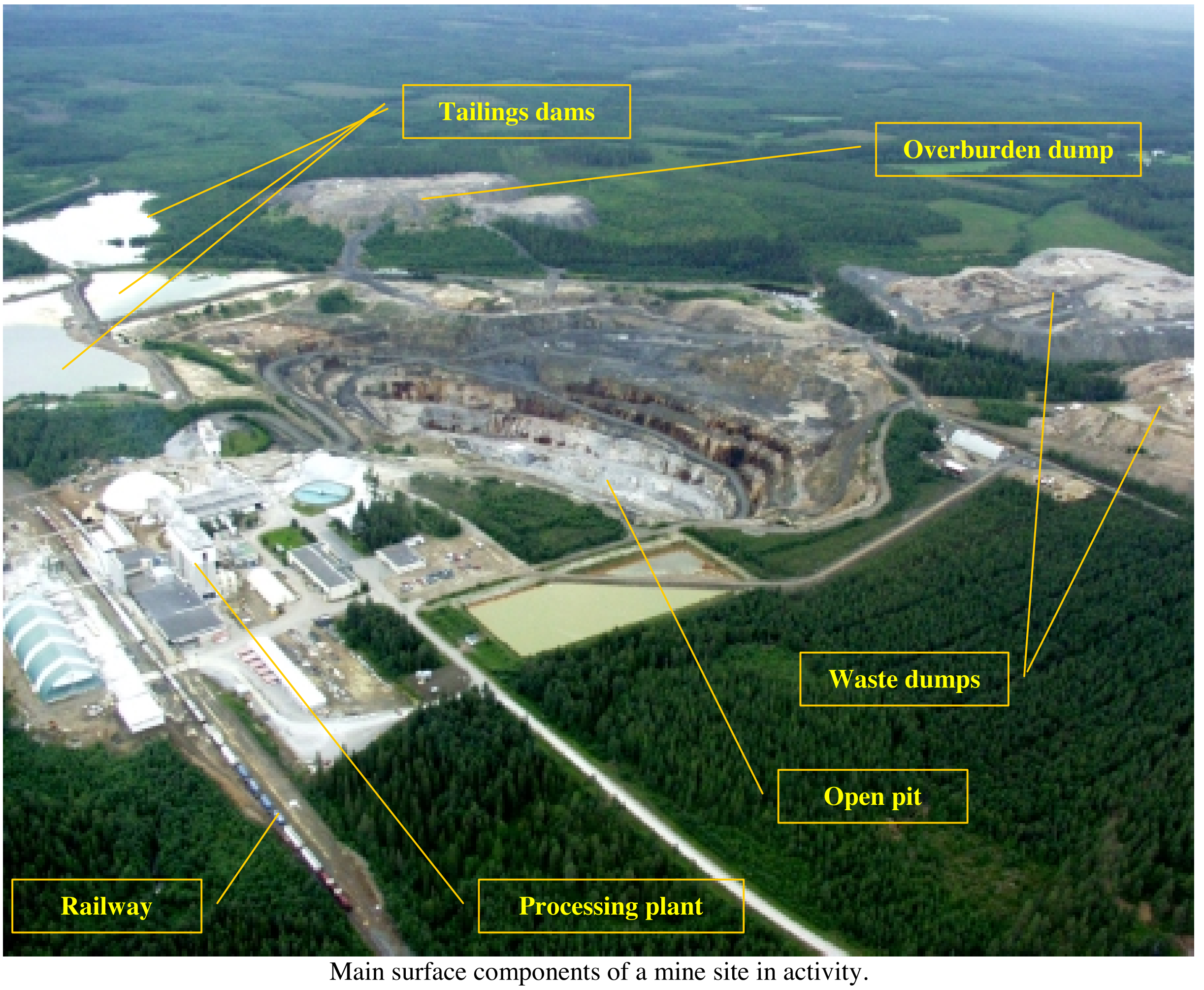
service infrastructure, power lines and generating plants, water supplies and sewerage, laboratories and amenities.

- **Mine operation** – underground or surface mining, hydraulic mining in or near riverbeds. Newer processes may include heap leaching of ore or tailings, and solution mining of buried deposits.

- **Beneficiation** – on-site processing may include comminution to reduce particle size, flotation using selected chemicals, gravity separation or magnetic, electrical or optical sorting, ore leaching with a variety of chemical solutions.

- **Associated transport and storage of ore and concentrates** may be a handling risk and can result in localised site contamination.

- **Mine closure** – rehabilitation is best done progressively rather than at the end of life of the mine. While the closure and rehabilitation is intended to mitigate environmental impact, it is important that it does not itself create secondary effects through excessive fertiliser use, spread of weeds, silting and incompatible landscape features.



Main surface components of a mine site in activity.
Helicopter view of the Lahnaslampi open pit mine – Finland. July 2000

Potential environmental and social impacts of mining activities

MINING ACTIVITIES / POTENTIAL IMPACTS	***Exploration and ore extraction***	Exploration drilling	Resettlement (if necessary)	Extraction and waste rock removal/dispo	Rock blasting and ore removal	Mine dewatering	Placer and dredge mining	Small-scale artisanal mining	***Ore processing and plantsite***	Plant site, materials handling, etc.	Stockpiling	Beneficiation	Phytometallurgical processing	Hydrometallurgical processing	Water usage (all industrial and domestic	Use & storage of process chemicals	Tailings containment/disposal	***Infrastructure, access & energy***	Access roads, rail & transmission lines	Wastewater treatment and disposal	Pipelines for slurries or concentrates	Power sources & transmission lines	Construction camps, town site	***Decomissioning***	Regrading and recontouring	Stabilization of waste dumps and tailings	Mine closure
Air quality																											
Increased ambiant particulates (TSP & PM-10)				●	●					●	●		●				●		●			●	●		●		
Increased ambiant Sulfur dioxide (SO2)													●									●	●				
Increased ambiant Oxides of Nitrogen (Nox)													●									●	●				
Increased ambient heavy metals				●	●					●	●		●				●		●			●	●				
Hydrology, hydrogeology & water quality																											
Altered hydrologic regimes				●		●	●	●		●				●	●		●		●	●		●	●		●		
Altered hydrogeological regimes						●								●	●												
Increased heavy metals, acidity of pollution		●		●		●	●	●		●	●			●		●	●		●	●		●	●		●	●	
Increased turbidity (suspended solids)		●		●			●	●		●	●			●			●		●	●	●	●	●		●	●	
Risk of groundwater contamination		●		●	●	●		●						●		●	●			●						●	
Ecology and biodiversity																											
Loss of natural habitats & biodiversity		●		●			●	●		●							●		●		●	●	●				
Loss of rare and endangered species				●			●	●		●							●		●		●	●	●				
Effects of induced development on ecology		●						●											●				●				
Effects on riverine ecology and fisheries				●		●	●	●			●				●	●	●			●	●		●				
Impacts due to effluents or emissions		●		●			●	●				●	●	●			●			●					●	●	
Social concerns																											
Resettlement issues			●	●	●		●			●							●		●			●	●				
Effects on indigenous peoples		●	●	●	●		●	●		●							●		●			●	●				
Loss of cultural heritage or religious sites		●	●	●			●			●							●		●			●	●				
Loss of livelihood			●														●					●	●				●
Induced development issues		●	●																●			●	●				
Effects on aesthetics and landform				●			●	●		●							●					●	●				
Noise issues				●	●		●			●												●	●				
Occupational & public health concerns																											
Occupational health and safety concerns												●										●	●				
Hazards from process chemicals or explosives					●			●				●				●						●					
Potential increase in disease vectors			●					●															●				
Increased potential for respiratory disorders					●			●				●	●			●						●					
Resource issues																											
Effects of substidence on surface resources						●																					
Agricultural land losses		●	●	●			●			●							●		●			●	●				
Loss of forestry resources				●			●	●		●							●		●			●	●				
Effects on surface water resources				●	●	●	●	●			●	●		●	●		●		●	●		●	●				
Effects on groundwater resources					●	●		●				●		●	●		●			●		●	●				
Disruption to infrastructure				●			●												●		●						
Effects on fisheries				●		●	●	●			●			●	●		●			●		●	●				

after World Bank, Sourcebook update 1998

2. OVERVIEW OF ENVIRONMENTAL IMPACTS IN MINING

Operations and major pollutant sources

At mining sites, the major pollutant sources of concern include waste rock/overburden disposal, tailings, heap leaches/dump leaches, and mine water.

Waste rock/overburden are made of the soil and rock-mining operations move during the process of accessing an ore or mineral body. It also includes rock removed while sinking shafts, and accessing or exploiting the ore body and rock bedded with the ore. The size of the waste rock ranges from small clay particles to boulders. Waste rock can be used as backfill in previously excavated areas or transported off-site and used at construction projects. *However, most of the waste rock generated is disposed of in piles near the mine site.*

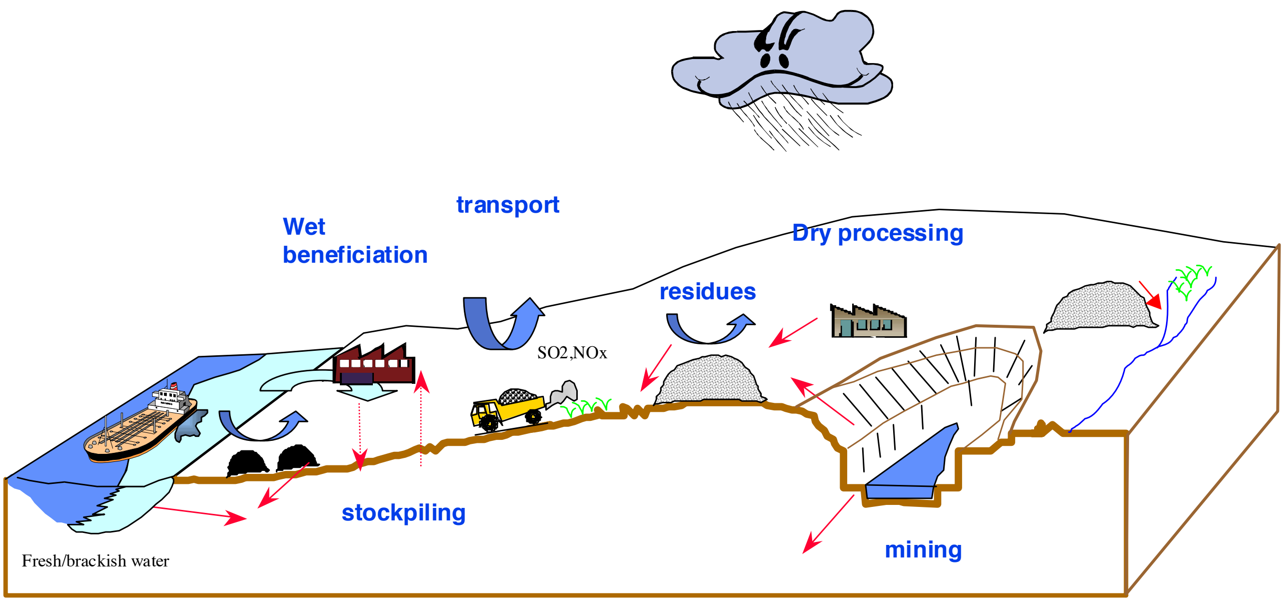
Tailings are the waste solids remaining after beneficiation of ore through a variety of milling processes. After the ore is extracted from the mine, the first step in beneficiation is generally crushing and grinding. The crushed ores are then concentrated to free the valuable mineral and metal particles from the less valuable rock. Beneficiation processes include physical/chemical separation techniques such as gravity concentration, magnetic separation, electrostatic separation, flotation, solvent extraction, electrowinning, leaching, precipitation, and amalgamation. Conventional beneficiation processes generate tailings, which generally leave the mill as a slurry consisting of 40 to 70 percent liquid and 30 to 60 percent solids. Most mine tailings are disposed of in onsite impoundment, such as tailings ponds or tailings dams .

Leaching is another beneficiation process commonly used to recover certain metals, including gold, silver, copper, and uranium, from their ores. In dump leaching, the material to be leached is generally placed (or is already located) directly on the ground and a leaching solution is applied to the material. The type of leaching solution used depends on the characteristics of the ore and the mineral. As the liquid percolates through the ore, it leaches out metals. Leaching may recover economic quantities for years or decades. Dump leach piles can be very large, often covering hundreds of acres. Heap leaching (as distinguished from dump leaching) is used for higher trade (more valuable) ores and is generally smaller than dump leach operations. Almost invariably, there are one or more impermeable liners under the leach material to maximise recovery of the leachate. Heap leaching often takes place over months rather than years. When leaching no longer produces economically attractive quantities of valuable metals, the spent ore is left in place (or nearby) after rinsing or other detoxification.

Long-Term Nature of Mining Impacts

Closure of a mining operation occurs during temporary shutdown of operations or permanent decommissioning of the facilities. During downturns in metals markets and cash flows, temporary shutdowns can reduce the expenditures necessary to maintain environmental controls (roads and diversions erode, siltation ponds and spillways deteriorate even as they are filling and losing treatment capacity). Although reclamation is often thought of as involving only re-grading and re-vegetation, permanent closure now includes such actions as removal/disposal of stored fuels and chemicals, structure tear down, removal of roadways and ditches, sealing of adits, capping of tailings, waste detoxification and final removal of sediment control structures and/or reestablishment of drainage ways. Long-term maintenance is required in many closure situations, such as equipment fuelling and lubrication after normal maintenance facilities have been removed, water diversions, dam stability, water treatment, and treatment sludge management. Without accrued funds or other cash flows to cover these expenses, there can be substantial risk of inadequate attention to proper site closure. Reclamation cost estimates--and bonds--are still sometimes based primarily on re-grading and re-vegetation, and thus can easily underestimate true closure expenses.

Complicating the effective environmental control at mining sites is the **interrelationship** between the extraction, beneficiation, and processing of the ore material and the waste materials generated from each of these operations. Together, mining operations and the pollutant sources of concern can affect surface and ground water quality, create hydrological impacts, decrease air quality, contaminate soils, and diminish ecosystem quality. The major categories of environmental problems encountered from mining are discussed briefly below. The following sections describe surface water quality, ground water quality, hydrological impacts, physical stability, air quality, soils and terrestrial and aquatic habitat/ecosystem quality issues.

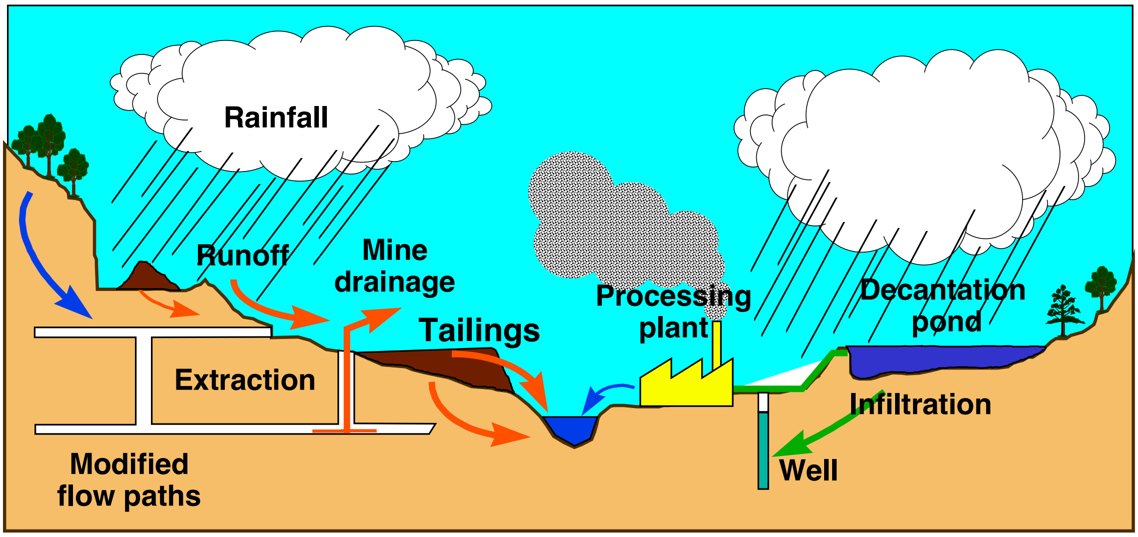


Schematic pattern of interactions between mining activities (surface mining, waste dumping, ore transportation and processing, ore stockpiling..) **and the environment**. The main pathways are represented by red arrows for water (infiltration, runoff, discharge..) and by blue arrows for air (wind erosion, pollutants emission..).

3. IMPACTS ON SURFACE WATER

One of the problems that can be associated with mining operations is the release of pollutants to surface waters. Many activities and sources associated with a mine site can contribute toxic and non-toxic materials to surface waters. Open pits, tailings ponds, ore and sub-ore stockpiles, waste rock dumps, and heap and dump leach piles are all potentially significant sources of toxic pollutants. The mobility of the pollutants from these sources is magnified by exposure to rainfall and snowfall. The eventual discharge of surface runoff, produced from rainfall and snow melt, is one mechanism by which pollutants are released into surface waters. Seepage from impoundment areas and ground water originating from open pits and mine openings is another example by which heavy metals can be mobilised and eventually released to surface waters. Releases of pollutants to surface waters may also occur indirectly via ground water that has a hydrological connection to surface water.

Impacts to surface waters include the build-up of sediments that may be contaminated with heavy metals or other toxic products, short- and long-term reductions in pH levels (particularly for lakes and reservoirs), destruction or degradation of aquatic habitat, and contamination of drinking water supplies and other human health issues.



General sketch model of surface and groundwater contamination by mining operations

Acid Drainage

It is generally acknowledged that a **major environmental problem** facing the mining industry is the formation of acid drainage and the associated mobilisation of contaminants. Commonly called acid mine drainage (AMD) or acid rock drainage (ARD), acid drainage primarily depends on the mineralogy of the rock material and the availability of water and oxygen. Acid drainage is generated at both abandoned and active mine sites. Although testing methods used to predict AMD have improved in recent years, there is often substantial uncertainty, and new mines can develop unpredicted AMD after only a few years of operation.

The potential for a mine or its associated waste to generate acid and release contaminants depends on many site-specific factors. AMD occurs at mine sites when metal sulphide minerals are oxidised. Metal sulphide minerals are common constituents in the host rock associated with metal mining activity. Before mining, oxidation of these minerals and the formation of sulphuric acid is a (slow) function of natural weathering processes. Natural discharge from such deposits poses little threat to aquatic ecosystems except in rare instances.

Mining and beneficiation operations greatly increase the rate of these same chemical reactions by removing sulphide rock material and exposing the material to air and water. Once acid drainage has occurred, controlling the releases is a difficult and costly problem, so prediction is becoming an important tool for regulators and operators.

Materials and waste from metal mining activities that have the potential to generate acid drainage include spent ore from heap and dump leach operations, tailings, waste rock, and overburden material. Equally or more important at some sites are the pit walls at surface mining operations and the underground workings associated with underground mines.

Acid generation is largely the result of oxidation of metallic sulphides. The major metallic sulphide of concern is iron sulphide (FeS) or pyrite. All metal sulphides and reduced mineral species can potentially contribute to acid generation. Metal sulphides besides pyrite that contribute to acid generation include galena (lead sulphide), sphalerite (zinc sulphide) and chalcopyrite (iron copper sulphide). Both water and oxygen are necessary to generate acid drainage.

Other factors affecting acid drainage are the physical characteristics of the material, the placement of the acid-generating and any acid-neutralising materials (whether naturally occurring in the material or supplemental), and the climatological and hydrological regime in the vicinity.

Extraction area

Effects of acid mine drainage on the river sedimentation

Effects of acid mine drainage on surface water

Views Rosa Poieni Copper mine and Kalimani sulphur mine (Romania)

The hydrology of the area surrounding mine workings and waste units is important in the analysis of acid generation potential. Wetting and drying cycles in any of the mine workings or other waste units will affect the character of any produced acid drainage.

Acid generation and drainage affect both surface and ground water. The sources of surface water contamination are leachate from mine openings, seepage and discharges from waste rock or tailings or spent ore, ground water seepage, and surface water runoff from waste rock and tailings piles. It should also be noted that mined materials - waste rock or tailings - used for construction or other purposes (e.g., road beds, rock drains, fill material) or off a mine site can also develop acid drainage.

Cyanide Heap Leaching

For over a century, the mining industry has used cyanide as a pyrite depressant in base metal flotation and in gold extraction. Continued improvements in cyanidation technology have allowed the economic mining of increasingly lower-grade gold ores. Together with continued high gold prices, these improvements have resulted in increasing amounts of cyanide being used in mining. The mining industry now uses much of the sodium cyanide produced in the United States, with more than 100 million pounds used by gold/silver leaching operations in 1990.

The acute toxicity of cyanide, and many major incidents like the cyanide spill that occurred in Baia Mare in Romania in January 2000, have focused attention on the use of cyanide in the mining industry.

When exposure occurs (e.g., via inhalation or ingestion), cyanide interferes with many organisms' oxygen metabolism and can be lethal in a short time.

Overall, cyanide can cause three major types of environmental impacts: First, cyanide-containing ponds and ditches can present an acute hazard to wildlife and birds. Tailings ponds present similar hazards, but less frequently (because of lower cyanide concentrations). Second, spills can result in cyanide reaching surface water or ground water and cause short-term (e.g., fish kills) or long-term (e.g., contamination of drinking water) impacts. Finally, cyanide in active heaps, ponds and in mining waste, primarily spent ore heaps, dumps and tailings impoundment, may be released and present hazards to surface water or ground water. Geochemical changes can also affect the mobility of heavy metals.

Cyanide heap leaching pilot site – Al Hajar, Saudi Arabia

Metals and Dissolved Pollutants

Dissolved pollutants (primarily metals, sulphates, and nitrates) can migrate from mining operations to local ground and surface water. While AMD can enhance contaminant mobility by promoting leaching from exposed wastes and mine structures, releases can also occur under neutral pH conditions. Primary sources of dissolved pollutants from metal mining operations include underground and surface mine workings, overburden and waste rock piles, tailings piles and impoundment, direct discharges from conventional milling/beneficiation operations, leach piles and processing facilities, chemical storage areas (runoff and spills), and reclamation activities. Discharges of process water, mine water, runoff, and seepage are the primary transport mechanisms to surface water and ground water.

One potential source of dissolved pollutants is chemical usage in mining and beneficiation. Common types of reagents include copper, zinc, chromium, cyanide, nitrate and phenolic compounds, and, at copper leaching operations, sulphuric acid. Except for leaching operations and possibly the extensive use of nitrate compounds in blasting and reclamation, the quantities of reagents used are very small compared with the volumes of water generated. As a result, the risks from releases of toxic pollutants from non-leaching-related reagents are generally limited.

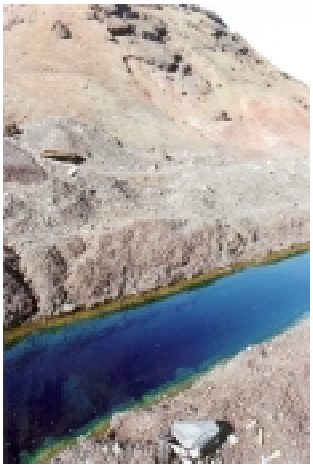
The occurrence of specific pollutants, their release potential, and the associated risks are highly dependent on facility-specific conditions, including: design and operation of extraction and beneficiation operations, waste and materials management practices, extent of treatment/mitigation measures, the environmental setting (including climate, geology, hydrogeology, waste and ore mineralogy and geochemistry, etc.) and nature of and proximity to human and environmental receptors.

Dissolved pollutants discharged to surface waters can partition to sediments. Specifically, some toxic constituents (e.g., lead and mercury) associated with discharges from mining operations are often found at elevated levels in sediments, while undetected in the water column. Sediment contamination may affect human health through consumption of fish that bio-accumulate toxic pollutants. Furthermore, elevated levels of toxic pollutants in sediments can have direct acute and chronic impacts on macro-invertebrates and other aquatic life.

Finally, sediment contamination provides a long-term source of pollutants through potential re-dissolution in the water column.

Hexavalent Chromium dispersed by tailings wash-off - Sukinda mining district - India

Wetland contamination by acid waters (Ph = 4.3)



Water effluents saturated with copper sulphates (1000 mg/l, Ph = 2.5)

Metals dissolved at zinc metallurgical plan at Belovo, Siberia

Erosion and Sedimentation

Because of the large area of land disturbed by mining operations and the large quantities of earthen materials exposed at sites, erosion can be a major concern at hardrock mining sites. Consequently, erosion control must be considered from the beginning of operations through completion of reclamation. Erosion may cause significant loading of sediments (and any entrained chemical pollutants) to nearby waterbodies, especially during severe storm events and high snow melt periods.

Sediment-laden surface runoff typically originates as sheet flow and collects in rills, natural channels or gullies, or artificial conveyances. The ultimate deposition of the sediment may occur in surface waters or it may be deposited within the flood plains of a stream valley. Historically, erosion and sedimentation processes have caused the build-up of thick layers of mineral fines and sediment within regional flood plains and the alteration of aquatic habitat and the loss of storage capacity within surface waters. The main factors influencing erosion includes the volume and velocity of runoff from precipitation events, the rate of precipitation infiltration downward through the soil, the amount of vegetative cover, the slope length or the distance from the point of origin of overland flow to the point where deposition begins, and operational erosion control structures.

Major sources of erosion/sediment loading at mining sites can include open pit areas, heap and dump leaches, waste rock and overburden piles, tailings piles and dams, haul roads and access roads, ore stockpiles, vehicle and equipment maintenance areas, exploration areas, and reclamation areas. A further concern is that exposed materials from mining operations (mine workings, wastes, contaminated soils, etc.) may contribute sediments with chemical pollutants, principally heavy metals. The variability in natural site conditions (e.g., geology, vegetation, topography, climate, and proximity to and characteristics of surface waters), combined with significant differences in the quantities and characteristics of exposed materials at mines, preclude any generalisation of the quantities and characteristics of sediment loading.

The types of impacts associated with erosion and sedimentation are numerous, typically producing both short-term and long-term impacts. In surface waters, elevated concentrations of particulate matter in the water column can produce both chronic and acute toxic effects in fish.

Sediments deposited in layers in flood plains or terrestrial ecosystems can produce many impacts associated with surface waters, ground water, and terrestrial ecosystems. Minerals associated with deposited sediments may depress the pH of surface runoff thereby mobilising heavy metals that can infiltrate into the surrounding subsoil or can be carried away to nearby surface waters. The associated impacts could include substantial pH depression or metals loading to surface waters and/or persistent contamination of ground water sources. Contaminated sediments may also lower the pH of soils to the extent that vegetation and suitable habitat are lost.

Beyond the potential for pollutant impacts on human and aquatic life, there are potential physical impacts associated with the increased runoff velocities and volumes from new land disturbance activities. Increased velocities and volumes can lead to downstream flooding, scouring of stream channels, and structural damage to bridge footings and culvert entries.

In areas where air emissions have deposited acidic particles and the native vegetation has been destroyed, runoff has the potential to increase the rate of erosion and lead to removal of soil from the affected area. This is particularly true where the landscape is characterised by steep and rocky slopes. Once the soils have been removed, it is difficult for the slope to be re-vegetated either naturally or with human assistance.

Upstream erosion of mine-waste rock heaps

Downstream sedimentation in the river course

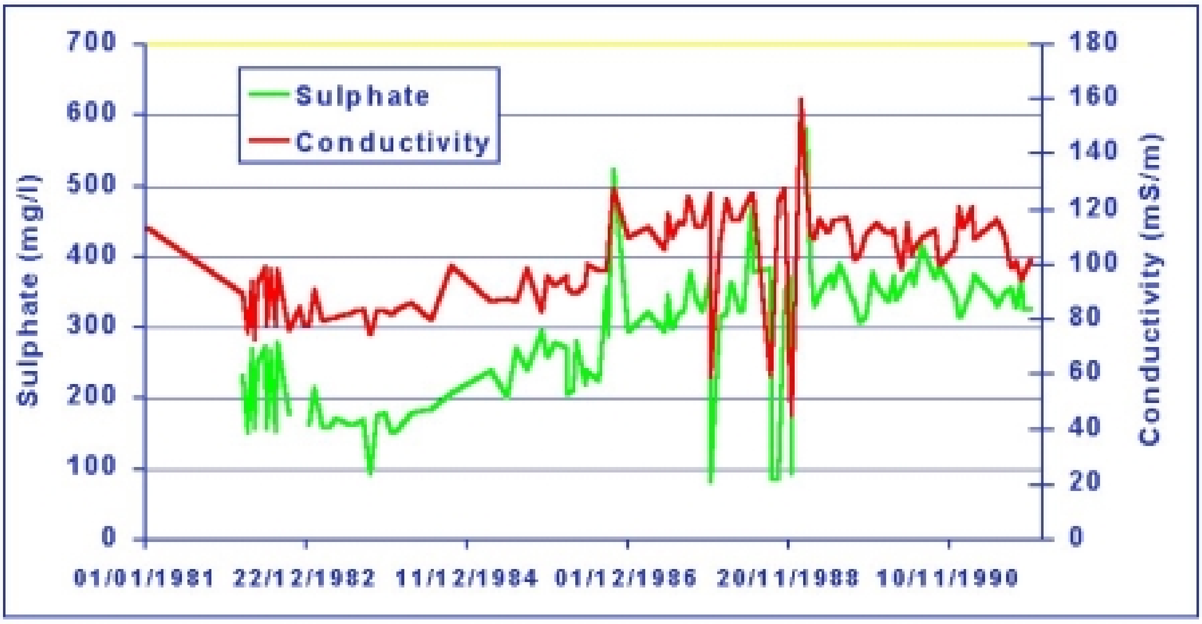
Erosion-sedimentation process in Goa iron ore mining district - India

4. IMPACT ON GROUND WATER QUALITY

Ground water impacts due to mining are not as widespread as surface water impacts because of the much slower velocity of ground water movement, the more limited extent of many affected aquifers, and the lack of available oxygen to continue the oxidation process. Nevertheless, the fact that ground water contamination is extremely difficult to remedy once it occurs makes it a serious concern.

Mining operations can affect ground water quality in several ways. The most obvious occurs in mining below the water table, either in underground workings or open pits. This provides a direct conduit to aquifers. Ground water quality is also affected when waters (natural or process waters or wastewater) infiltrate through surface materials (including overlying waste or other material) into ground water. Contamination can also occur when there is an hydraulic connection between surface and ground water. Any of these can cause elevated pollutant levels in ground water. Further, disturbance in the ground water flow regime may affect the quantities of water available for other local uses. Finally, the ground water may recharge surface water down-gradient of the mine, through contributions to base flow in a stream channel or springs.

The ability of pollutants to dissolve and migrate from materials or workings to ground water varies significantly depending on the constituent of concern, the nature of the material/waste, the design of the management, soil characteristics, and local hydrogeology (including depth, flows, and geochemistry of the underlying aquifers). Risks to human health and the environment from contaminated ground water usage vary with the types of and distance to local users. In addition, impacts on ground water can also indirectly affect surface water quality (through recharge and/or seepage).



Increasing sulphate content and electrical conductivity of groundwater due to mining activities. 10-years time series at Turfontein city water intake – West Rand, South Africa

5. HYDROLOGIC IMPACTS

Mining operations themselves are a critical part of environmental control because they interact with the site hydrology. Mine design not only impacts day-to-day operations, but also closure and post-closure conditions. Mine design, and location, can affect the following site conditions, which in turn can result affect environmental performance.

- Regional surface and ground water movement.
- Ground water inflow into the mine, with subsequent contact with mining related pollutants.
- Surface water inflow and precipitation related recharge.
- Increases in surface and ground water interaction with the mine workings because of subsidence.
- Loss of surface features such as lakes through subsidence.
- Pathways for post closure flow resulting from adits, shafts, and overall mine design.
- Operational and post closure geochemistry and resulting toxics mobility.
- Overall site water and mass balance.

Specifically, mine water, ground water withdrawal, and land subsidence can potentially create environmental problems that cannot be easily corrected.

River silting by mine turbid waters – Mandavi river – Goa district - India

Mine Water

Mine water is produced when the water table is higher than the underground mine workings or the depth of an open pit surface mine. When this occurs, the water must be pumped out of the mine. Alternatively, water may be pumped from wells surrounding the mine to create a cone of depression in the ground water table, thereby reducing infiltration. When the mine is operational, mine water must be continually removed from the mine to facilitate the removal of the ore. However, once mining operations end, the removal and management of mine water often end, resulting in possible accumulation in rock fractures, shafts, tunnels, and open pits and uncontrolled releases to the environment.

Mine-water disposal at Goa mine district - India

Ground Water Drawdown

Ground water drawdown and associated impacts to surface waters and nearby wetlands can be a serious concern in some areas.

Impacts from ground water drawdown may include reduction or elimination of surface water flows; degradation of surface water quality and beneficial uses; degradation of habitat (not only riparian zones, springs, and other wetland habitats, but also upland habitats such as greasewood as ground water levels decline below the deep root zone); reduced or eliminated production in domestic supply wells; and erosion, sedimentation, and other water quality/quantity problems associated with discharge of the pumped ground water back into surface waters downstream from the dewatered area. The impacts could last for many decades. While dewatering is occurring, discharge of the pumped water, after appropriate treatment, can often be used to mitigate adverse effects on surface waters. However, when dewatering ceases, the cones of depression may take many decades to recharge and may continue to reduce surface flows in the Humboldt River and its tributaries. Mitigation measures that rely on the use of pumped water to create wetlands may only last as long as dewatering occurs.

Subsidence

Mining subsidence occurs when overlying strata collapse into mine voids. The potential for subsidence exists for all forms of underground mining. Subsidence may manifest itself as sinkholes or troughs. Sinkholes are usually associated with the collapse of part of a mine void (such as room and pillar mining); the extent of the surface disturbance is usually limited in size. Subsidence of large portions of the underground void forms troughs, typically over areas where most of the resource had been removed.

Subsidence under tailings dam wall due to sinkhole formation induced by mine dewatering. West Rand mining district, South Africa

Surface collapse due to underground mining. Lorraine, France

6. IMPACTS ON PHYSICAL STABILITY

Physical stability of mine is an important long-term environmental concern because of the amounts of materials involved and the consequences of slope failure. Mining operations can result in the formation of slopes composed of earth, rock, tailings, other mine wastes, or combinations of materials. Other than sheer physical impacts, catastrophic slope failure can affect the environment or human health when toxic materials are released from the failure especially if it occurs in an area where such a release results in a direct pathway to receptors[2]. Ensuring physical stability requires adequate pre-mining design of waste management units and may require long-term maintenance.

Tailings dam wall slump risk – West Rand mining district – South Africa)

Pit slope failure in a surface iron mine of the Goa district - India

Slope failure results from exceeding the internal mass strength of the materials composing the slope. This occurs when the slope angle is increased to a point where the internal mass strength can no longer withstand the excess load resulting from over steepening or overloading of the slope. When the driving forces associated with over steepening exceed the internal resisting forces, the slope fails and the materials move to a more stable position.

7. IMPACTS ON AIR QUALITY

The primary air pollutant of concern at mining sites is **particulate matter**. US/EPA has established National Ambient Air Quality Standards for particulate matter with a diameter of less than 10 microns.

A variety of mining operations emit particulate, usually as fugitive dust (as opposed to emissions from stacks), and relatively simple controls are often sufficient:

- Ore crushing and conveyors can be substantial sources of fugitive dust, and control generally involves water sprays or mists in the immediate area of the crusher and along conveyor routes.

[2] In February 1994, the collapse of a tailings dam wall send an avalanche of mud through Merriespruit, a suburb of Virginia in the Free State goldfields (South Africa), killing 17 people and injuring six hundred. 80 million Rands in damage properties was recorded.

- Loading bins for ore, limestone, and other materials also generate dust. Again, water sprays are typically used for control.
- Blasting generates dust that can be, and is sometimes, controlled with water sprays.
- Equipment and vehicle travel on access and haul roads are major sources of fine and coarse dust. Most mines use water trucks to dampen the surface periodically.
- Waste rock dumping can generate dust, but this generally consists of coarse particles that settle out rapidly with no other controls.
- Venting of shafts can emit dusts.
- Wind also entrains dust from dumps and spoil piles, roads, tailings (either dry as disposed or the dry portions of impoundments), and other disturbed areas. Spray from water trucks are often used when the mine is operating. During temporary closures, particularly after the active life, stabilisation and reclamation are aimed in part at reducing fugitive dust emissions. Tailings in particular can be a potent source of fine particulate; temporary or permanent closure great increases the potential for surface tailings to dry out and become sources of dust. Rock and/or topsoil covers, possibly with vegetative covers, can be effective controls.

Dust du to mine-truck traffic

Effects of dust on neighbouring vegetation and housing

Goa mining district - India

8. IMPACTS ON SOILS

Mining operations routinely modify the surrounding landscape by exposing previously undisturbed earthen materials. Erosion of exposed soils, extracted mineral ores, tailings, and fine material in waste rock piles can result in substantial sediment loading to surface waters and drainage ways. In addition, spills and leaks of hazardous materials and the deposition of contaminated windblown dust can lead to soil contamination.

Soil Contamination

Human health and environmental risks from soils generally fall into two categories: (1) contaminated soil resulting from windblown dust, and (2) soils contaminated from chemical spills and residues. Fugitive dust can pose significant environmental problems at some mines. The inherent toxicity of the dust depends upon the proximity of environmental receptors and type of ore being mined. High levels of arsenic, lead, and radionucleides in windblown dust usually pose the greatest risk. Soils contaminated from chemical spills and residues at mine sites may pose a direct contact risk when these materials are misused as fill materials, ornamental landscaping, or soil supplements.

Radioactive crystals of gypsum precipitating in a wetland downstream of a tailings dams – West Rand mining district – South Africa

9. IMPACTS ON TERRESTRIAL AND AQUATIC HABITAT/ECOSYSTEM

By its very nature, mining causes land disturbances. These disturbances can affect aquatic resources, wildlife, vegetation, and wetlands, and can lead to habitat destruction. Surface mining activities directly destroy habitat as a result of removal of overburden to expose ore bodies, deposition of waste and other materials on the ground surface, and the construction of roads, buildings, and other facilities.

Aquatic Life

Mining operations can have two major types of impacts on aquatic resources, including aquatic life. The first type of impact results from the contribution of eroded soil and material to streams and water bodies and from the release of pollutants from ore, waste rock, or other sources. The second results from the direct disruption of ephemeral, intermittent, or perennial streams; wetlands; or other water bodies. Temporary disruptions occur from road construction and similar activities. Permanent impacts are caused by actual mining of the area or by placement of refuse, tailings, or waste rock directly in the drainage way. More often than not, this is in the upper headwaters of intermittent or ephemeral streams. In addition, lowering of area surface water and ground water caused by mine dewatering can affect sensitive environments and associated aquatic life.

Aquatic life is generally defined as fish and benthic macro-invertebrates; however, phytoplankton and other life forms may also be considered, depending on the type of aquatic habitat and the nature of impacts being assessed.

The impacts of mining operations on aquatic resources can be either beneficial or adverse. Potential impacts also vary significantly with the affected species. For example, increases in stream flow may preclude habitation of certain species of macro-invertebrates and/or fish but may also provide new habitat for other species of aquatic life.

Wildlife

Mining operations can have substantial impacts on terrestrial wildlife, ranging from temporary noise disturbances to destruction of food resources and breeding habitat. Unless closure and reclamation return the land essentially to its pre-mining state, certain impacts to some individuals or species will be permanent.

Vegetation

Vegetation consists of natural and managed plant communities. Native uplands consist of forests, shrublands and grasslands; managed uplands include agricultural lands, primarily croplands and pastures.

10. VISUAL IMPACTS AND LANDSCAPE DEGRADATION

Among the potential negative impacts of mining, the visual impact of surface mining (mainly quarrying and waste rock dumping) deserves special attention. Here, we need to consider sites the total surface of which normally range from 10 to 250 hectares, areas which are distinctly visible.
In certain cases, the effect on the landscape can be significant and unpleasant to the eye. Generally speaking, the significance of the change is linked to the topography of the area and to the type of landscape and vegetation.
In any case visual impact is not easily discussed in absolute terms. Whether or not an open-pit is unpleasant to the eye, beside the subjective dimension of the question, is very much a matter of integration into the surrounding environment. Physical sceening, screen planting, landscaping and the use of existing features contribute to local surroundings.
Clearly, it is difficult to measure visual impacts quantitatively through standards and regulations. It is generally agreed, that the value placed on a certain type of landscape is a subjective issue and in some cases, for example, authorities have refused permits for landscape reasons, when in fact, there is no opposition from local residents.

Waste rock dumping – Goa district - India

Erzberg mine area - Austria

11. SOCIAL AND CULTURAL IMPACTS

The introduction of new economic developments such as mining can result in **major changes** in the human environment at a project site, especially if there are small, traditional communities in the vicinity that have scarcely been exposed to modern modes of living. In other instances, the presence of new activities can result in beneficial effects.

A substantial portion of today's mining industries are located in remote areas that are mostly inhabited by indigenous people. As these people commonly live in small, simple communities that previously had little exposure to society at large, there is a real need to establish guidelines for dealing with resulting socio-cultural impacts.

Change, whether social or cultural, is neither negative nor positive in itself. Change can be undesirable when it leads to social conflicts, conflicts between basin sets of values and economic setbacks.

As such mining operations share many common features with other economic enterprises regarding their potential impacts. However, there are two major conditions that place mining in a unique position compared with other ventures.
1)- the mining site is located where the mineral deposits are discovered, and not usually in close proximity to service centres, power supply and labour force. This requires that the latter need to be brought to the mining site and extensive transportation arteries need to be constructed.
2)- the amount of ore that is available at a particular site is always limited. Thus, the mining activities at the site are terminal, although the life-span of a mine might not be known in advance. Whilst it is possible to return the land directly affected by mining , almost back to its original state after the mining operations have ceased, this may not the case for the human population. Exposure to a radically new environment may leave lasting imprints in the minds

of people, whether it is changed values and social standards, changed expectations of social rights and obligations, or changed skills.

The following guidelines on socio-cultural issues are divided into three parts, based on the origins of social impacts:

- social impacts as the result of changes in the physical environment (clearing lands, depositing minerals, changes in water conditions, construction of mining site, roads and power supply infrastructure);
- impacts due to the presence of a mining camp/town in close proximity to a surrounding population;
- impacts on the labour-force connected with the mining operations.

Within the literature, there are many similarities in the impact of mining on local communities. An element which is introduced to a community in conjunction with mining and which has highly detrimental effects on the local community (for instance the construction of a road into the area of a previously isolated population) may in another setting have favourable results. It is therefore difficult to establish standards on socio-cultural issues for mining operations.

Traditional housing threatened by mine dumps – Sukinda mining area, India

Paddy (rice) fields cultivated at proximity of mine dumps – Goa mining district, India

Changes in the Physical Environment and Indirect Social Impacts

Shocks and vibrations as a result of blasting in connection with mining can lead to noise, dust and collapse of structures in surrounding inhabited areas. The animal life, on which the local population may depend, might also be disturbed.
The building of roads in hilly regions will often lead to destabilisation of slopes which induces soil erosion and siltation in streams. This may result in flooding by streams and rivers.

Removal of overburden, disposal of minerals, construction of mining town/camp sites, roads and power lines, possibly the use of wood and water from the surroundings and the emptying of water from mines may lead to conflicts of interest with traditional land owners.

The vital resources of the local population may become depleted (agricultural land, wild plants, game, water, fish). It must be emphasised that although subsistence economies might be based on one major activity (cultivation of certain staple crops, husbandry of certain animals, etc.), minor economic activities (hunting, gathering of wild plants for sale or own consumption) may also be crucial for the survival of their society.

Degradation of pastoral activity by mining activities. Meadows and pasture threatened by extension of mine dumps. Goa mining district, India

The decreasing vital resources may lead to lower health and nutritional conditions, and consequently to a lower working and learning capacity.

Sapphire discovery in Ilakaka (Madagascar), a modern gold rush
(translated from http://www.multimania.com/pairain/saphir.htm)

In October 1998, a zebu guardian fond a "blue stone". Coming from all parts of the country, sapphire prospectors rushed with their pans and buckets and invaded the area. Ten months later, a town of 100,000 inhabitants, Ilakaka, raised from the bush, 80 Km from Sakaraha and 210 Km from Tuléar, close to the Isalo natural park that is visited by some 20,000 tourists a year.

The stake explains the fever. In few hours, a lucky miner can get equivalent of two year wage (a 3 grams high quality stone can be negotiated some 1000 €!). Exceptional quality stones can be found and the site is known as the best in the world. Buyers are coming from entire world to buy the gems: 200 of them, Thais, Africans, Americans, Swiss, etc, are installed behind their wooden shelters and send them to their company headquarters for heating.

Miners are generally unemployed people or come from other mining areas. They often work in team of three: one digs, one transports the extracted material, and the last washes the material in the river.

They exploit some 25 sq.m. to 7 m deep. They dig tunnels that often collapse on miners.

Miners can dig during months without finding any gems. The luckiest one can buy 3 or 4 zebus after few times.

Ilakaka, the town raised from nowhere, organises itself. Everything can be found, but there is neither water supply, nor electricity and there is no hygiene. Traffic, alcohol, prostitution, robbery are common. Price inflation accompanies the rush. The entire surrounding region is destabilised and the emerging tourism industry starts suffering. Impacts on flora and fauna, landscape degradation are among the envisaged consequences.

The government of the Republic of Madagascar has taken different measures to stop the illicit exportation of the gems, without success. In August 2000, he stops sapphire exportation for a while and has send troupes in Ilakaka.

Direct Social Consequences of the Presence of a Mine

The presence of a mine and an attached service centre or even a town in the vicinity of a local population will undoubtedly have some social impacts. The extent of impact, however, can differ enormously depending on the characteristics of the mine (the use for skilled versus unskilled labour, whether the labour is stabilised, unstablised or local, etc.) and on the surrounding population (its acquaintance with money economy and wage-work, its previous contact and connection with the outside world including the state bureaucracy).

The mine might offer attractive possibilities for wage work for certain segments of the local population (young men, people with education or certain skills). This might put them in a position to obtain badly needed cash for their families, and therefore also enable them to purchase certain consumer goods.

But employment with the mine may conflict with traditional obligations in the local communities, for example co-operation among neighbours in land cultivation. There may not be sufficient hands to do such crucial work, to the detriment of the quality of the agricultural output.

The building of roads into a mining area may also have both positive and negative effects on the surrounding population. Goods and services can be more easily transported into the area, although this does not guarantee that they will be accessible to the local community. These people may on the other hand be able to market their goods outside their own community. But that can lead to crucial resources being exported from the area and therefore not accessible to local people with less purchasing power.

11. CONCLUSION

This review highlighted that impacts of mining on the environment are very diverse in nature, extension and effects. If several of them are clearly visible and easy to identify, the rest is more insidious and needs sophisticated and often expensive methods for identification and monitoring.

Differing in that from other industrial activities, extraction and exploitation is located where the resource exists, and as such cannot avoid any harmful effect which has to be minimised as much as possible, within an acceptable economic frame. The role of Environmental Impact Assessments and Environmental Management Systems is fundamental with this respect.

Airborne and spaceborne remote-sensing data can play a significant role in environmental management and monitoring. Representative examples are given and described in Part 3 of the User Need Document. This is particularly true for the monitoring of "visual" impacts, like landscape degradation and more generally all physical transformation of the surrounding areas, which can be easily identified, mapped and monitored from panchromatic or multispectral aerial photographs and/or satellite images.

Thanks to the latest developments in spectroscopic instruments (high spectral resolution along with high signal to noise ratio), hyperspectral sensors are now able to generate exceptionally high-quality digital hyperspectral information far beyond the capabilities of current multispectral remote sensing data. Indeed, hyperspectral sensors are characterised by their high spectral resolution across a wide range of the electromagnetic spectrum, enabling the identification of the chemical composition of the imaged target (rock, soils, or vegetation). This type of sensors enables access to identification, mapping and monitoring of surface contamination related to polluting activities and opens wide perspectives in the use of Earth Observation data in the monitoring of environmental impacts related to mining and extractive industry.

ANNEX – Coal mining and environmental concern in Germany