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Mining wastewater management and its effects on groundwater and ecosystems

A. Celebi and S. Özdemir

ABSTRACT

Large-scale mining activities have a huge impact on the environment. Determination of the size of the effect and monitoring it is vital. In this study, risk assessment studies in mining areas and the effect of mining on groundwater and ecosystems were investigated. Best management practices and risk assessment steps were determined, especially in areas with huge amounts of mining wastewater. The pollution of groundwater and its reaching humans is a risk of major importance. Our study showed, using many cases with different parameters and countries, that the management of mining wastewater is vital. Environmental impact assessments and monitoring studies must be carried out before operation and at the closure of the mine. Policies must be in place and ready to apply. Factors of climate, geology, ecology and human health must be considered over a long period. Currently, only the developed countries are applying policies and paying attention to the risk. International assessments and health risk assessments should be carried out according to international standards.

Key words | groundwater, management, mining, pollution, risk assessment

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INTRODUCTION

Mining operations and the pollutant sources of concern can affect surface and groundwater quality in terms of many parameters; in particular, they can create hydrological impacts, decrease air quality, contaminate soils, and diminish ecosystem quality. The major categories of environmental problems arising from mining are water pollution and the risk of it reaching humans (EPA 1997).

The mining industry is one of the major emerging sectors in the world. For instance, in Turkey, overall 2011 gold production was expected to reach 25 mt/y, compared to 17 mt/y in 2010. In the long term, analysts expect it to stabilize at around 60 mt/y. However, preparing mining waste policy and applying it is quite new in Turkey (GBR 2012).

Tailings are fine-grained waste material from the mining industry. Since the extracted metal represents only a small percentage of the whole ore mass, the vast majority of the material mined ends up as fine slurry. The tailings contain all other constituents of the ore apart from the extracted metal, among them heavy metals and other toxic substances. Moreover, the tailings contain chemicals added during the milling process (Ganesh 2006). The quality of the drainage is controlled by a series of mineralogical and geochemical reactions in the waste area, and the outcome of these reactions is reflected in the seepage waters surfacing through tailings dams (Blowes *et al.* 2003; Lottermoser 2007; Heikkinen 2009). The seepage quality further changes due to precipitation and dilution during transport to the receiving water body (Chapman *et al.* 1983; Räisänen *et al.* 2005). Seepage to groundwater during the mining operation and even after the closure is typically a vast environmental risk factor.

Abandoned mine sites also generate chronic environmental hazards. Contaminated runoff from abandoned mines impacts on land, groundwater, streams, rivers, and lakes. The principal environmental pollutants from abandoned mines are arsenic, lead, and other heavy metals associated with acid rock drainage. The degree of potential contamination depends on many factors, such as the commodity being mined (gold, copper, chromium, etc.), mining methods, ore processing methods and disposal methods. Other contaminants can include chemicals used to process ore and fuel, lubricants, and solvents used to operate and maintain equipment (The Sierra Fund 2008).

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The main purpose of the present study is to show best mining management practice and how to measure potential risks in the mining areas to water and also the risk of water-related pollution to humans and the ecosystem.

ENVIRONMENTAL RISK ASSESSMENT STUDIES IN MINING WASTEWATER MANAGEMENT

The large-scale industrial activity that takes place in the natural environment is potentially disturbing large amounts of material over large tracts of land. At mining sites, the major pollutant sources of concern include waste rock/overburden disposal, tailings, heap leaches/dump leaches and mine wastewater. Tailings are the waste solids remaining after the beneficiation of ore through a variety of milling processes. Leaching is another beneficiation process commonly used to recover certain metals, including gold, silver, copper, and uranium from their ores. The long-term nature of mining impacts requires that predictive tools, design performance, monitoring, and financial assurance be effective for many decades. For instance, negative changes in geochemistry over time may occur when a material's environment changes. Financial assurance helps to ensure that resources will be available to address long-term mine water and site management (EPA 1997).

All projects carry a certain level of risk and how this is dealt with affects a project's success (Gardiner 2005). The classification of risks creates a common framework for grouping risks, although different cultures could classify the same risk differently (Wyk *et al*. 2008). Edwards & Bowen (2005) suggest two primary categories for classifying risks:

- *Natural risk*: those from systems 'beyond human agency', which includes risks from weather, geological, biological and extraterrestrial systems.
- *Human risk*: risks from social, political, cultural, health, legal, economic, financial, technical and managerial systems.

Large construction projects and mining projects may share risks with similar characteristics because both are uncertain, complicated and costly. Therefore, research on construction risks in several countries was conducted. The risk descriptions are listed in Table 1 in the left column; risk rankings based on their impact on project failure according to the literature are adjacent to each risk. Finally, those countries where the risks are considered to be significant during project implementation are noted in the second row of the table. The countries in the table are all from various economies in Asia and Australia.

Environmental risk assessment (ERA) studies originate from and are based upon risk assessment studies. Figure 1

Table 1 | List of construction project risks in various countries (adapted from Chinbat 2011)

Risk description	Vietnam*	Kuwait*	China*	Palestine*	UAE*	Australia*	Hong Kong*
Owners' financial difficulties	1	1	2	8	14		
Inadequate experience	2				23		
Shortage in manpower supply and availability		3			7	2	3
Shortage of skills/techniques	14					3	5
Labor strikes and disputes			45		34		
Low productivity of labor and equipment	16	6	12		20		6
Human/organizational resistance		26	41			6	
Accidents during construction		23	20	3	33		
Shortage in material supply and availability				12	10		
Shortage in equipment availability				16	18		
Regulatory risks		19					
Changes in laws and regulations		22	25	28	35		
Corruption and bribes			23		37		
Inclement weather	12	23	26	33	40		2
Environmental factors		24		24			

*Number of cases occuring in the country.

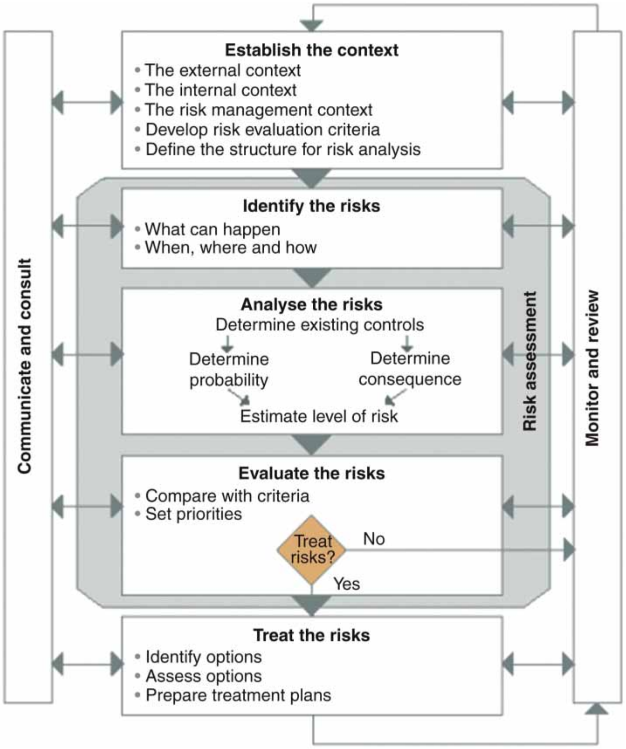

Figure 1 | Risk management process (Standard Australia 2009).

shows a good example of environmental risk management standards, along with the procedure's steps.

With respect to the overall framework in risk management (Figure 1), steps 1 to 3 represent the stage before risk assessment, which is the 'establish the context' phase; step 2 represents the 'risk assessment' phase (identify risks, analyse risks, evaluate risks); and step 3 (after risk assessment) represents the treat the risks phase.

1. *Establish the context:* All external and internal, risk management contexts, along with clear evaluation criteria and descriptions must be prepared before the risk assessment step.
2. *Risk assessment:* Identifying risks involves the use of risk assessment 'tools' appropriate for identifying potential loss scenarios associated with the project. These tools consist of the following:

- Introduction – Before the potential issues are brainstormed, it is important that the whole team has a good understanding of the project, which should be confirmed by the facilitator.
- Brainstorming – Used to draw out the main issues using the understanding, relevant experience and knowledge of the team. This session also uses prompt words to build on the experience base of the team and to identify any potential environmental issues and potential loss scenarios.
- Modified hazard and operability analysis – This involves the review of key words drawn from the project and aerial photographs and environmental issues at each location during each phase of the operation.

A good example of an ERA study was conducted in Australia. In the study, environmental risk priorities were determined, and the number of votes assigned to each priority study area is shown graphically in Figure 2 (Stratford Coal 2012).

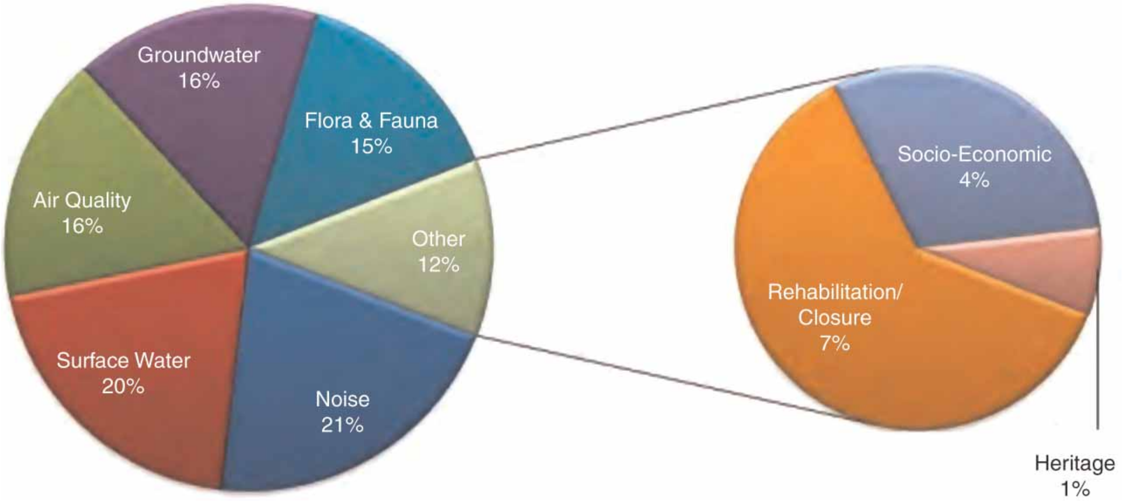

Figure 2 | Proportional priorities by a study area (Yancoal Australia).

Analyse risk: Potential loss scenarios are numbered for risk by the ERA team. A tabular analysis is used for this risk ranking process, based on the probability and consequence of a loss scenario occurring as decided by the ERA team. The following definition of risk is used:

- the combination of the probability of an unwanted event occurring; and
- the maximum reasonable consequences should the event occur (Stratford Coal 2012).

Evaluate the risk: Risk is assessed according to clear criteria, and risk values are obtained.

3. *Treat the risk:* Risk assessment results indicate whether a process needs treatment or not and plans must be prepared accordingly.

GROUNDWATER POLLUTION RISK IN MINING AREAS

Groundwater contamination is extremely difficult to remedy compared with that of surface water, when it occurs it becomes a serious concern. Mining operations may affect groundwater quality in several ways. The most obvious occurs in mining below the water table, either in underground workings or in open pits. This provides a direct conduit to aquifers. Groundwater quality is also affected when water (natural or processed water or wastewater) infiltrates through surface materials (including overlying wastes or other material) into groundwater. Contamination may also occur when there is a hydraulic connection between surface and groundwater. Any of these could cause elevated pollutant levels and contamination in groundwater. Furthermore, disturbance in the groundwater flow regime can affect the quantities of water available for other local uses. Eventually, the groundwater may recharge surface water down the gradient of the mine, through contributions to base flow in a stream channel or springs (Figures 3 and 4).

The ability of pollutants to dissolve and migrate from materials to groundwater 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 the geochemistry of underlying aquifers). Risks to human health and the environment from contaminated groundwater usage vary with the types and distance to local people. In addition, impacts on groundwater may indirectly affect surface water quality (through recharge and/or seepage) (EPA 1997), meaning that sustainable groundwater management is vital. The Dutch Intervention Value for groundwater is based on the serious risk level for humans and the ecosystem, including direct consumption of groundwater as drinking water. The value is a trigger for further investigation and a decision about the urgency of the remediation of historical groundwater contamination (Lijzen *et al.* 2014).

Figure 3 | Examples of seepage water sampling points at showing the upper seepage area at the toe of the upper section of the dam (Heikkinen 2009).

Figure 4 | Streambed of the natural influx groundwater about 4 km downstream from mining area (Huang *et al.* 2010).

Recent studies have revealed mining area groundwater contamination. For example, research has been used to characterize pollutant sources and to quantify the resulting current and future effects on both groundwater and river water quality in a study in Germany. The reactive transport simulations illustrate the long-term fate of sulfate from the mining dumps into groundwater and from groundwater into surface water. The simulations indicated that groundwater borne diffuse input of sulfate into the rivers is 2,200 t/year and could increase to 11,000 t/year in the next 40 years. The results for the river compare well with the observed increase of sulfate concentrations before and after passing the mining area (Graupner *et al.* 2014). Arsenic is a common constituent in groundwater that affects human health adversely at levels as low as 10 lg/L (WHO 1993; Bhattacharya *et al.* 2002). In a mine area of western Turkey, arsenic showed high spatial variation ranging from 33 to 911 lg/L in the groundwater samples. Arsenic values increased close to the mines, reaching 305 lg/L and decreased to the south of the study area (Gemici *et al.* 2008). A wide variety of adverse health effects, including skin and internal cancers and cardiovascular and neurological effects, have been attributed to chronic exposure, primarily from drinking water (NRC 1999) (Figure 4).

DIMENSION OF ECOLOGICAL RISK FOR MINING ACTIVITIES

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

Aquatic life: Two major types of impact on aquatic resources occur in mining operations. The first type of impact results from the contribution of eroded soil and material to 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 perennial streams, wetlands or other water bodies. 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 way of drainage. In addition, lowering of area surface water and groundwater caused by mine dewatering could affect sensitive environments and associated aquatic life. The impacts of mining operations on aquatic resources can also be beneficial. Potential impacts also vary significantly with the affected biota. For example, increases in stream flow may preclude the habitation of certain species of fauna and/or flora but may also provide new habitat for other species of aquatic life.

The impacts of mines on aquatic resources have been well documented. The Mineral Creek fisheries and habitat survey conducted by the Arizona Game and Fish Department and the US Fish and Wildlife Service showed that significant damage was caused by active mining activity on the shores of Mineral Creek. The upstream control station showed an overhead cover (undercut bank, vegetation, etc.) of 50 to 75%. The dominant substrate was small gravel and in-stream cover consisted of aquatic vegetation. Five species of fish were observed for a total of 309 individual fish. The downstream station showed an overhead cover of less than 25%. The dominant substrate was small boulders and in-stream cover consisted of only interstitial spaces and very little aquatic vegetation. No species of fish and very few aquatic insects were observed or captured. This Mineral Creek survey proves a significant degradation of habitat below the mine. In another study and area, which received a massive discharge of tailings and pregnant leach solution from an active copper mine, was also surveyed (EPA 1994, 1997). The tailings had a smothering, scouring effect on the stream (Kauppila *et al.* 2011).

Wildlife and vegetation: 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. Biological diversity is often viewed as a way to measure the health of an ecosystem. Noise during the construction phase or during operations, for example, can displace local wildlife populations from otherwise undisturbed areas surrounding the site. Some individuals or species may rapidly acclimate to such disturbances and return while others may return during less disruptive operational activities. Still other individuals may be displaced for the life of the project. Other wildlife impacts include habitat loss, degradation or alteration. Wildlife may be displaced into poorer quality habitat and therefore may experience a decrease in productivity or other adverse impacts. Habitat loss may be temporary (e.g., construction-related impacts), long term (e.g., over the life of a mine), or essentially permanent. Vegetation is significantly related to the diversity of wildlife. All vegetation is removed before and during mine development and operation in the area. Vegetation that is immediately adjacent could be affected by roads, water diversions or other developments. Vegetation that

Figure 5 | The view of a borate mine (a) and the waste pool (b) (Gemici *et al.* 2008).

is further away from activities may be affected by sediment carried by overland flow and by fugitive dust (EPA 1997).

West African rainforest birds were observed being strongly affected by adjacent mining whether the mining was immediately adjacent or >500 m away, irrespective of the distance to forest edge in Ghana. Even with no additional forest loss, increased surface mining is likely to result in declines of forest birds (Deikumah *et al.* 2014). The negative effects of mining are also visible. A good example of visible effects on the environment are shown in Figure 5 (Gemici *et al.* 2008).

CONCLUSION

Environmental disasters from mining areas are certainly preventable, barring unpredictable scenarios. Today's technologies are available to ensure the safe containment of hazardous material. Detailed ERA studies should be carried out for all sizes of mining activity. Risk assessment should be both qualitative and quantitative, as well as taking into account all parameters over a long period. In particular, groundwater pollution should be carefully monitored and it should not be used as drinking water by local people. Effects on ecosystems and natural life can be very negative, and even irreversible. Cost is the main parameter for designers, but comparatively small investments today can prevent future liabilities and environmental losses. Further research on groundwater contamination and ERA is crucial in moving forward to the sustainable management of mining sites.

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