

## **7 Chemicals from industrial activities**

### **7.1 Introduction**

In a catchment area, industries, particularly those involved in extraction, manufacturing and processing, may be important in the assessment of chemical risks of drinking-water because they can be the source of significant contamination.

Mineral production is an important component of the economy for many countries, and in some cases it can be the major source of international revenue. However, mining and mineral production operations that are not well managed can contaminate groundwater and surface water, and can adversely affect the health of nearby communities that rely on this source for drinking-water or agriculture.

Extractive industries include mining of mineral deposits (principally metal-bearing ores and coal deposits), oil and natural gas production, and quarrying for building and road-making materials. Poorly operated or abandoned mine sites are often significant sources of water contamination; contaminants of particular health concern from these sources include heavy metals, and mineral-processing chemicals, such as cyanide.

Water pumped from abandoned mine shafts and open-cut pits is often used for water supply, and is generally safe and reliable. However, these water sources may sometimes be contaminated by mineral processing chemicals, acid mine drainage (AMD) and waste disposal. These risks must be considered and assessed to determine whether such water sources are safe to be used for drinking-water supply.

Manufacturing and processing industries are also a potential source of chemicals in drinking-water. Assessment of the types and amounts of chemicals in the effluent discharged from industrial sources should be used to make judgements on the possible chemicals that could be present in receiving water used as a drinking-water source.

It is sometimes difficult to identify all industrial sources in a catchment area because there may be many small-scale industrial sources. In such a case, it is best to focus initially on the major industrial areas according to effluent quantity and type. The types of manufacturing and processing industries important for drinking-water contamination include chemical, metal, textile dyeing, tannery, paper and pulp, electroplating and printed circuit board manufacturing. It is therefore desirable that these industrial sources be identified in the target area.

### **7.2 Data sources**

Information about the distribution and nature of extractive industries can often be obtained from government agencies (principally mines departments or geological surveys), geology departments in universities, and specialist research institutes associated with the mining industry.

Information about the location and nature of manufacturing and processing industries can usually be obtained from environmental protection agencies, departments of trade and industry associations (chamber of commerce, etc). Information may also be available from government departments or agencies that deal with natural resource management or environmental protection issues.

Where contaminated sites exist, information about historical industrial activities can often be obtained from environmental protection agencies. Such disused sites may continue to pollute drinking-water sources for many years or decades after the industry has closed down if residual soil contamination at the site has not been cleaned up.

Appendices 1 and 2 present information on industrial chemicals listed by industry and by chemical, respectively, and are both useful in identifying chemicals likely to be discharged from industrial sources. Appendix 2 should be used as a guide to identifying the interrelation between industrial activities and chemicals potentially discharged through effluents. This appendix uses a classification based on the United Nations Standard Industrial Classification (Economopoulos, 1993). The information given in appendices 1 and 2 is extensive, but is not exhaustive and does not cover every possibility that may be encountered.

## 7.3 Extractive industries

### 7.3.1 Extractive industry activities

Typically, mining operation include a number of phases that can have different impacts on water quality; these are listed below.

- **Exploration.** Exploration for mineral and petroleum resources involves field surveys, drilling programmes and exploratory excavations. Some water contamination can be produced at this stage from land clearing; for example, if clearing exposes a layer with high content of heavy metals, leading to contamination of stormwater by the heavy metals and by waste disposal from exploration camps. Unfilled exploration boreholes can allow contaminants from the surface to be washed into groundwater without being attenuated in the soil profile.
- **Project development.** The development of a mining site and supporting infrastructure causes extensive land clearance. Also, groundwater and surface water contamination can be caused by spills and leaks from fuel storage tanks, and from waste disposal.
- **Mine operation.** The type of operations can include pumping from boreholes (oil and natural gas, solution mining), heap leaching of rock piles, underground mining, open cuts and surface dredging. Oxidation and leaching of minerals from mining spoil and other waste products can contaminate groundwater and surface water.
- **Beneficiation.** Processing of minerals using a variety of mechanical and chemical treatment processes can be the most significant source of water contamination at a mine site. The major sources of contamination from mineral processing are leaks from storage ponds holding processing liquors, and leakage from tailings dams used to separate and recover processing liquids from fine solid wastes.

- **Mine closure.** Closure and rehabilitation of a mine site to mitigate environmental impacts (e.g. stabilisation and revegetation of waste rock and tailings) can contaminate groundwater if not well managed. Sources of contamination include continued seepage from waste rock and tailings if these are not well stabilised; salinisation of groundwater by evaporation from abandoned open pits and the excessive use of fertilizers in rehabilitation programmes.

### 7.3.2 Effects of mining on water quality

The type of water contamination produced by a mining operation depends to a large extent on the nature of the mineralization and on the processing chemicals used to extract or concentrate minerals from the host rock.

The water contaminants of most concern are summarized in the Table 7.1.

**Table 7.1 Chemical contaminants of mine wastewaters**

Type of mine	Wastewater generated	Characteristics of wastewater	Chemicals possibly contained
Open-cut and underground mining of base metal sulfide deposits, precious metal deposits or uranium deposits with sulfide minerals, sulfide-rich heavy mineral sands, coal deposits	Acid mine drainage from waste rock heaps and ammonium nitrate-fuel oil explosive used for rock blasting	Low pH (< 4.5, possibly as low as 2) of water in springs, seeps, open cuts and streams draining from the mine site. Extensive vegetation death, yellow or white salt crusts on the soil surface, pale blue cloudy appearance of surface water	Arsenic, antimony, barium, cadmium, chromium, cobalt, fluoride, lead, mercury, molybdenum, nickel, nitrate, selenium, sulfate, uranium (radon may be of concern where there are high uranium concentrations)
Base metal and precious metal deposits	Flotation agents used to concentrate minerals from ore; the main sources of contamination are seepage from processing mills and tailings dams		Depends on the type of mineralization —contaminants from flotation agents of health concern include chromium, cresols, cyanide compounds, phenols and xanthates
Gold deposits	Chemicals used to extract gold from ore (cyanide and mercury), particularly from tailings dams	High pH of water (up to pH 10) when cyanide is used	Arsenic, free cyanide, weak acid dissociable cyanide, mercury
Uranium deposits	Acid leaching (especially sulfuric acid) used to extract uranium from ore	Low pH of water, high sulfate concentrations in water	Arsenic, antimony, barium, cadmium, chromium, cobalt, fluoride, lead, mercury, molybdenum, nickel, radon, selenium, sulfate, uranium
Petroleum and natural gas	Disposal of brines associated with petroleum hydrocarbons	High salinity of water, high concentrations of hydrogen sulfide, methane or detectable hydrocarbon odours in water	Boron, fluoride, hydrocarbons, uranium

AMD is probably the most severe environmental problem that occurs on mine sites. It happens where mineral and coal deposits contain sulfide minerals, particularly pyrite ( $\text{FeS}_2$ ). When waste rock containing sulfides is exposed to air, these minerals are oxidized, releasing sulfuric acid. The process is accelerated by bacteria such as *Thiobacillus ferrooxidans* that obtain energy from the oxidation reaction for their growth. The release of acid can cause the pH of surface water and groundwater to become very low (as low as 2). Under these very acidic conditions, metal concentrations in water can become very high due to the dissolution of elements from waste rock. Acidic water at mine sites often kills vegetation, and may cause fish deaths in rivers. Apart from low pH, visual indicators of AMD at mine sites include the following:

- large areas where vegetation has died due to acidic runoff and shallow acidic groundwater;
- the presence of abundant yellow or white salt crusts on waste rock and at the surface of the soil. The crusts comprise alum-like sulfate minerals containing variable amounts of sodium, potassium, iron and aluminium, such as the mineral jarosite. They are often very soluble in water, releasing acid and precipitating ferric hydroxides;
- surface water bodies on the mine sites often appear to have a milky blue-white cloudy appearance due to the presence of flocs of aluminium hydroxide. If the water is extremely acidic ( $< \text{pH } 3$ ), it may appear to be crystal clear due to the precipitation of the flocs.

Of the chemicals used to process ores, cyanide may be the most problematic due to its toxicity and the complexity of its chemical behaviour in groundwater. Cyanide degrades rapidly into nontoxic chemical compounds when exposed to air and sunlight, but in groundwater it may persist for long periods with little or no degradation. Cyanide (usually in the form of potassium or sodium cyanide) is used to extract gold from its ore, but in the subsurface it can react with minerals in soil and rock to form a wide range of metal cyanide complexes, many of which are very toxic.

Abandoned pits and mine shafts are commonly used for water supply after mine closure. Depending on the type of mining activity, water from these sources could pose a risk to human health from high dissolved metal or cyanide concentrations.

### 7.3.3 Risk factor checklist

Box 7.1 summarizes the main risk factors associated with chemicals derived from extractive industries.

#### **Box 7.1 Risk factors — extractive industries**

##### **Site suitability**

Industries are located within close proximity of:

- a potable water source
- a waterway.

Water from abandoned mine shafts and pits is being used as a source of drinking-water.

**Effluent discharge**

Discharges to receiving water or onto the ground:

- are unlicensed and unregulated
- take place without reference to effluent acceptance criteria.

There are no effluent treatment facilities.

Runoff water from the site is treated before discharge.

The effluent quality is monitored on chemical parameters relevant to mining activities at the site.

The effluent is discharged onto the ground.

The effluent has a particular appearance or odour.

**Industrial operation**

Chemicals, including floating agents, are used for operation and maintenance.

Acid leaching of ore is carried out.

Solid wastes are disposed of at the site.

**Operation and maintenance of an on-site treatment facility**

Effluent treatment facilities are operated without emergency storage facilities to cope with system breakdown.

## **7.4 Manufacturing and processing industries**

### **7.4.1 Initial indicators**

Industrial pollution might be suspected if a water source exhibits any of the following physical properties:

- strong chemical odours (often similar to phenolic disinfectant), like petrol, or sharp and acrid (irritate the back of the nose or throat);
- colours unexplained by iron or manganese tests;
- reports of bitter or metallic tastes not explained by iron or manganese tests;
- persistent foaming on the water surface;
- a multicoloured, iridescent sheen on the water surface that does not break up when prodded with a stick;
- any other unusual appearance.

### **7.4.2 Developing an inventory**

A variety of chemicals used or produced in industrial processes are harmful to human health if released into drinking-water sources. Chemicals likely to be in a particular watershed may be selected by developing inventories of the industrial processes undertaken in the catchment. An inventory for each industrial source should include the following information:

- type of industry;
- year of the start of operation and historical development;
- occupied land area and number of employees;
- amount and nature of raw materials, final products and by-products;
- industrial processes employed;
- amount of water used;
- amount and nature of wastewater generated;
- details of water receiving the effluent;
- amount and nature of solid wastes;
- solid waste disposal.

### **7.4.3 Assessing the impact**

When assessing the impact of industrial discharges on receiving waters, the most critical characteristics are:

- the types of chemicals discharged — this depends on the type of industries and processes used;
- the amount and concentration of chemicals in the effluent — these vary over time depending on the operation mode of both manufacturing and wastewater treatment processes employed (e.g. hourly, daily, weekly, monthly and seasonal variations).

Solid wastes and/or gaseous emission generated from industrial sources also contribute to the amount and concentration of chemicals in the effluent if they are treated with water or they have any contact with water.

### **7.4.4 Site inspection**

Section 7.2 (above) discusses data sources for information on types of chemicals used and the amount discharged to the environment. Additional information can be obtained through a site inspection, which is a very useful and effective tool for augmenting and strengthening the information gained from compiling a source inventory. A site inspection may also be an effective alternative strategy for monitoring discharges from industrial sources.

Collecting site information is very important because chemicals could be used and discharged from industrial sources other than those specified in appendices 1 and 2. For example, a battery manufacturing industry could be the source of metals such as mercury, cadmium, lead, nickel, manganese, iron, copper and lithium. Certain chemicals listed in the appendices are widely used in industries; for example, degreasing agents (organic solvents) such as dichloromethane, 1,1-dichloroethane, 1,2-dichloroethane, 1,1,1-trichloroethane, 1,2-dichloroethene, trichloroethene and tetrachloroethene. Moreover, effluents from recycling industries contain a variety of chemicals depending on the type of raw and final products.

Important issues to be noted in a site inspection in the context of water safety are:

- amount of chemicals used and their fates in industrial processes;
- water use and its quantity;
- sanitary conditions of the facility, especially conditions of the floor;
- wastewater treatment processes, and their effectiveness.

Industrial sources may represent a potential risk from chemical spills. On-site wastewater treatment facilities should be checked for:

- capacity;
- treatment processes employed;
- chemicals used;
- amount and nature of sludge generated;
- effluent monitoring practice and results;
- operation records;
- personnel engaged in the operation of the facilities.

If gaseous emissions are treated with water, the disposal of the wastewater generated, together with its quantity and quality, should be considered. Solid wastes or sludge containing chemicals deposited onto land may contaminate groundwater (through seepage) and receiving water (through surface water runoff via rainfall). If solid wastes or sludge are disposed at points remote from the source, their sites should also be assessed. More details on solid wastes are given in Section 6.4.

#### **7.4.5 Risk factor checklist**

Box 7.2 summarizes the main chemical risks associated with manufacturing and processing industries.

##### **Box 7.2 Risk factors — manufacturing and processing industries**

###### **Site suitability**

Industries are located close to:

- a potable water source
- a waterway.

###### **Effluent discharge**

Discharges to receiving water or onto the ground:

- are unlicensed and unregulated
- take place without reference to effluent acceptance criteria.

There are no effluent treatment facilities.

The effluent quality is monitored.

The effluent is discharged onto the ground.

The effluent has a particular appearance or odour.

#### **Industrial operation**

Chemicals are used for operation and maintenance.

Water is used for the purpose other than indirect cooling.

Solid wastes are disposed of at the site.

The exhausted gas is washed with water before emission.

#### **Operation and maintenance of an on-site treatment facility**

Effluent treatment facilities are operated without emergency storage facilities to cope with system breakdown.

### **7.4.6 Pathway considerations**

Section 2.3 (see Chapter 2) sets out the general principles of concentration changes as a chemical travels from source to consumer. It may be useful to refer to Section 2.3 before deciding, on the basis of pathway considerations, which chemicals are likely to reach the consumer.

Depending on their persistence, chemicals discharged through the effluent from industrial sources to a surface water body may reach an intake of a drinking-water supply. The chemicals accumulate in the bottom sediment of a water body, and may be flushed out in the event of high water flow. Industrial effluents that are discharged into the ground can also contaminate a groundwater source used as a drinking-water supply.

The presence of industrial chemicals in a water source does not necessarily indicate that they will be present in treated drinking-water. The extent to which chemicals will be removed before the water reaches the consumer will depend on the nature of the contamination and the type of treatment processes used. However, many industrial chemicals are toxic at relatively low concentrations, and water polluted by industrial activities often contains a number of different toxic chemicals. It is therefore important to identify and assess the risk posed by all the potential chemicals in a polluted water source.

### **7.5 Reference**

Economopoulos AP (1993). *Environmental technology series: Assessment of sources of air, water, and land pollution: A guide to rapid source inventory techniques and their use in formulating environmental control strategies, Part one: Rapid inventory techniques in environmental pollution*, World Health Organization, Geneva.