CHAPTER 5

Impact of mining on the environment – waste-wise

5.1 INTRODUCTION

Almost all the mining involves the penetration of the lithosphere through quarries, opencast mines and the underground mines. Hydrosphere comes into the picture in the process of working the river placers and extracting minerals (usually heavy minerals, but in the case of Namibia, diamonds) from the seabed. Mining and extraction of minerals have impacts on rocks, soils, water, air and the biota.

Three types of changes may be expected as a consequence of mining: (1) Change in the natural topography, and the consequent disturbance in the suitability of land for various uses, such as, agriculture and forestry, (2) Change in the hydrogeological condition, affecting groundwater and surface water, and (3) Change in the geotechnical conditions resulting in the deformation of the natural conditions of the rock mass, including dislocations the surface (Vartanyan, 1989, p. 39).

The impact of mining in a given district is determined by the geological characteristics of the rocks, such as, age, lithology, structure and tectonics, geomorphic setting, weathering, etc. Most of the Archaean belts have undergone polyphase metamorphism and deformation. On the other hand, some of the younger formations may be flat-lying and unmetamorphosed. Igneous and metamorphic rocks are generally much harder than the sedimentary rocks. In the tropical countries, weathering can go very deep.

Surface mining usually involves the removal of the soil cover and the detritus through the use of scrapers, bulldozers or digging machines, followed by the drilling and blasting of the rock below it. The mined material is crushed, stored, dressed and concentrated in various ways. These operations have the effect of changing the stress balance in the rock, hydrostatic pressure in the pores and aquifers, and releasing dust and gas into the atmosphere. The resulting vibrations, landslides, and contamination of soil, water and air may adversely affect people, animals, vegetation and engineering structures.

The response of the rocks to drilling and blasting depends upon the geotechnical properties of the rocks (Johansson, 1986; Zhu, 1986; Nilsen, 1986; Lappalainen, 1986,

quoted by Vartanyan, 1989). For instance, the strength index in uniaxial compression of some granites have been found to vary from 38 to 275 Mpa depending upon the modal composition and stress orientation of a granite. The uniaxial compression strength of a sandstone may vary from 58.3 Mpa in dry state to 29.1 Mpa when wet; shearing strength perpendicular to the bedding is 4.1 Mpa and parallel to it, 2 Mpa, and so on.

The stability of rock masses is determined by the presence of fractures, folds and faults. Intrusive rocks generally have three main conjugate system of joints, which intersect each other, leading to cubical joints. Folding determines the kind of jointing in gneisses and shales. Some rocks have cavities in the fractures, which are often filled with clays that swell when moistened. The swelling could be as high as 80%. This results in strong pressure leading to rock displacement. In the solid rock, permeability is generally low.

Rock stress changes as mining progresses. Hence, it is essential to monitor the stress. Vertical stress is about one-third to one-half of the main horizontal stress. Some studies show that the horizontal stress in the bedrock could increase from 5 Mpa at the surface to about 50 Mpa at a depth of 700 m.

5.2 IMPACT OF MINING ON THE GEOENVIRONMENT

5.2.1 *Impact of mining on the lithosphere*

Mining involves the extraction of large quantities of rocks, liquids and gases from the depths of the earth, and therefore causes damage not only on the surface but also to depths of hundreds and thousands of metres.

In the case of surface mining, the extent of geomorphic change is conditioned by the thickness of the overburden covering the deposit, the quantity of barren rock that needs to be excavated per unit of the extracted mineral and the area of the mine. Underground mining may lead to surface subsidence with consequent disturbance to surface runoff, formation of water-filled depressions, and flooding in the coastal areas or near lakes.

When the horizontal layer deposits are mined, waste banks are left behind in the worked out area as the mining front advances. This leads to the formation of alternating ridges and depressions of the waste rock. In the case of steeply-dipping lodes, big cone-shaped excavation pits form.

Wind-blown dust, spontaneous combustion and contamination of precipitation are some of the adverse consequences of the waste dumps. Also, the waste dumps use and degrade land that could be used for farming or forestry. For instance, in the former East Germany, the mining of brown coal decreased the farm land by 320 km^2, and forest land by 90 km^2 (these degraded lands have subsequently been ameliorated).

Mining under water generally involves dredging of loose sediments under water. If the sediments involved are alluvial sediments, then the river beds, flood plains and river terraces will be affected. Dredging may leave behind waste dumps and small valleys. The mining of the estuaries and intertidal zones (usually for heavy minerals) disturbs the balance between the land and sea, and may trigger beach erosion.

Cavities are formed underground when geotechnical methods of mining (such as, leaching, dissolution, fusion) are used. This leads to increase in porosity and decrease in the strength of the rocks. The area becomes prone to collapse of roofs and subsurface subsidence. Instances are known of collapse of rock-salt mines when water entered the abandoned mine and dissolved the salt pillars left there for roof support. Underground gasification of coal in the Angren coal basin in the former Soviet Union (involving a coal seam 5–15 m thick at a depth of 100–130 m, in an area of about 1 km^2) gave rise to one of the biggest landslides in the world, with a volume of 0.8 km^3 spread over an area of 8 km^2 (Vartanyan, 1989, p. 42).

Landslides and rock and mud flows are common in the mining areas, especially when the wastes are dumped on the hillsides. For instance, the volume of the mud-flow arising from the Yimen copper mine in China, was of the order of 200,000 m^3. Another mudflow of the volume of 100,000 m^3 from a mine in Yunnan, China, destroyed 6.2 km^2 of the fertile land on the plain. The mining of limestone and dolomite over a length of 40 km in Mussorie Hills in U.P., India, had disastrous environmental consequences. The mine owners picked up only the very high-grade material (+50 mm size stones which are in demand for the sugar industry) and more than 30% of the ore (−50 mm size material) was cast off to slide down the 30–50° slope. When heavy rains saturate the loose material, the debris flow cascades into the valley, clogs the river channels and gets spread over agricultural fields. The vibrations caused by the blasting operations destabilized the hill slopes, by opening out joints, fractures, fissures and cracks. This triggered mass movements, and reduced the discharge of springs (e.g. *Shahastradhara*, which means thousand discharges) which feed the streams. Consequently, many streams dried up (quoted from K.S. Valdiya, in *Environmental Geology*, 1987).

5.2.2 *Impact of mining on the hydrosphere*

Mining profoundly affects the hydrosphere in the following ways: (1) Groundwater table is lowered for mining to take place, (2) Mine water is discharged into the river systems, (3) Seepage from the settling tanks and evaporators adversely affect the quality of groundwater, and (4) Water is pumped into the ground for the extraction of a mineral (say, salt).

Figure 5.1 (source: Vartanyan, 1989, p. 43) illustrates how the water drawdown in the course of the mining affects the hydrological processes. It shows how with the increase in the volume of mining activities and water pumping, a cone of depression comes into existence rapidly, the transient ground flow is reduced, and the mineralization of mine water and river water increases, with time.

As a consequence of the surface mining, all the aquifers above a mineral deposit may be drained. In the case of the aquifers below a mineral deposit, water pressure

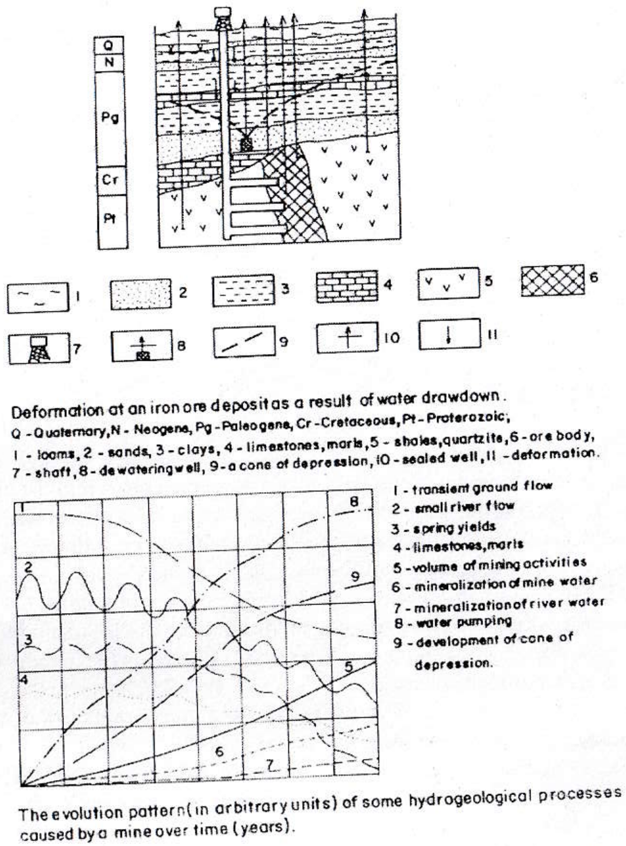

Figure 5.1 Diagram illustrating how the water drawdown in the course of mining affects the hydrological processes (source: Vartanyan, 1989, p. 43).

will be reduced, resulting in the formation of cones of depression. Also, surface mining involves the placement of large waste water ponds, seepage from which can pollute both surface water and groundwater.

Underground mining results in the dewatering of rock and reduction in the hydraulic head. The consequences of removal of large quantities of groundwater are the compaction of sand and clay, development of major jointing, surface subsidence and damage to mine shafts and other installations. For instance, coal mining in the Upper Silesian basin of Poland at a depth of 400 m, adversely affected the hydrological regime in an area of 1200 km^2. Coal mining in the Guishou province of China has caused the subsidence of 0.1–0.3 m over an area of 93,000 km^2. Gold mining at a depth of 3000 m in the Western Rand area of the Republic of South Africa, has resulted in the formation of karstic sinkholes with depths of about 60 m and diameter of 90 m. In one district in the karstic region in the Urals in the former Soviet Union, the mine drainage increased the groundwater discharge from 3000 to 20,000 m^3/h.

The depression of groundwater levels and piezometric cones may sometimes lead to complete dewatering of the aquifers in the mining area. The size of the cones of depression depends upon the geological structure of the area and the type of mining. It may vary in radius from a few hundred metres to tens of kilometers. In districts where there is extensive mining, the cones may link up and cover the whole region. As a consequence of mining, huge cones of depression with a radius of 10–15 km have formed. Computer simulation has indicated that by the beginning of the twentyfirst century, the groundwater level in the European part of Russia may get lowered by hundreds of metres, and piezometric cones of more than 200 km may develop.

As is well known, groundwater resources are depleted within the limits of the cones of depression. The water wells may go dry, and serious shortages of water may occur. Surface water resources may also be affected. The direction of movement of groundwater may change, and the springs feeding the streams may dry up. Swamps fed by groundwater seepages and fertile paddy soils (like gleysols and fluvisols) in the low-lying areas may be drained, thus affecting the productivity of land and the ecosystems. Small rivers and streams are particularly susceptible to the adverse consequences arising from mining, such as the inflow of highly mineralized waters and the reduction in the runoff.

When water under pressure is used for mining, the hydrological consequences are exactly the reverse of normal mining – the groundwater level may rise, artificial springs may come into existence, and the groundwater recharge and rise in the water level may occur in the vicinity of settling, tailing and clear water ponds, etc.

Mining has a profound effect on the geochemistry of both surface waters and groundwaters. The chemical composition of mine waters may range from freshwater to brine, depending upon the chemical composition of the pore water in the drained layers, and the content of the soluble salts in the formations. The water–rock interaction, particularly in the oxidation zone created by the mine workings, renders the waters highly acidic and capable of taking into solution a variety of toxic and heavy metals, such as, lead and cadmium. Where the mine water is discharged into streams, seepage invariably occurs, contaminating the groundwater. The stream water and the groundwater thus polluted become unfit for human consumption or even for irrigation, unless and until it is cleaned.

A case history of coal mining from Guandong and Guizhon areas in China, illustrates how serious the hydrogeochemical consequences could turn out to be. The coal seams have a high sulphur content, and as expected, the mine waters have a highly acid pH, as low as 2 to 3. The mine waters from Guizhon contained ten times

the allowable concentration of contaminants. When the mine water was discharged into the streams, there was a marked decline in the catch of the fish and shrimp. When the water was used for irrigation, the yield of farm crops declined. It has been estimated that the polluted waters contaminated an area of 47,000 ha of rice paddies (Mengxiong & Alsong, 1989).

5.2.3 *Impact of mining on the atmosphere*

Dusts and gases are emitted in the course of working of the mineral deposits, or from dumps of coal and ore, waste tips, tailings, etc.

In the opencast mines, dust may be released in the course of blasting. Escaping gases from rock and mineral masses, exhausts from the internal combustion engines in the mining machinery, gases released from the waste tips, etc. contribute to the gaseous emissions from the opencast mining. In the case of underground mining, air released from the underground workings, and rock masses, pollute the atmosphere.

Methane, carbon monoxide, nitrogen oxide, and sulphur compounds may be released to the atmosphere in the process of mining. For instance, huge quantities of methane are released during coal mining in the Donetsk Coal Basin in the former Soviet Union (2.5 billion m^3 of gases, of which methane constitutes 32%). The extracted gas is used as boiler fuel.

Burning waste tips discharge noxious gases into the atmosphere. A medium-sized burning waste tip, can emit annually: 620–1280 t of SO_2, 11–30 t of NO_2, 330–500 t of CO, and 230–290 t of H_2S. There were instances where a burning waste tip polluted the air for about 2 km around. As coal contains sulphur in the organic form of pyrite (FeS_2), the burning waste tips of coal mines discharge large quantities of SO_2 and H_2S. It has been estimated that a total of 175 million tonnes (Mt) of gases are discharged from all the waste tips of the coal mines in the world. This amount includes 23 Mt of CO, 2 Mt of SO_2, 0.9 Mt of H_2S and 0.3 Mt of NO_2.

Blasting operations in quarrying and opencast mining pollute the atmosphere through dust and gases. For instance, if 200–300 t of explosives is used for blasting in a particular operation, the volume of the dust generated may be of the order of 20–25 million m^3. Blasting operations also discharge nitrogen compounds, such as NH_3 and NO_2, into the atmosphere. One tonne of explosives produce 40–50 m^3 nitrogen oxides.

The discharge of dusts and gases into the atmosphere is bound to have health effects. It has been reported that in the highly industrialized Ruhr District of Germany, the incidence of respiratory diseases is 60% above the national average.

High intensity noises, which are generated during blasting and the operation of the mining machinery, are hazardous to human health.

It is now a common practice in most of the mining areas in the Industrialized countries to monitor the air continuously, for (1) the discharge, content and precipitation of dust and the concentration of heavy elements like cadmium, lead, etc. in air (pg/m^3), and (2) the concentration of gases such as, SO_2, CO_2, H_2S, NO_x, NH_3

etc. in the air. When the ambient levels rise beyond the prescribed loads, corrective action is taken promptly to bring down the concentrations to the acceptable levels.

To prevent loss and minimize pollution in the course of long rail transportation from the mine to the smelter, ore concentrates (e.g. Pb–Zn) are packed in heavy duty polythene bags. When the concentrates are transported by open trucks for short distances (say, less than 50 km), a minimum moisture content of 8% is maintained.

5.2.4 *Impact of mining on the biosphere*

Mining activity adversely affects the biosphere through the loss of the farming land, and through the degradation of the ecological systems. Microclimate in the mining area is also affected. Land subsidence in the areas of underground mines, and the creation of waste tips lead to the destruction of the vegetation, and the death of animals and birds. It should not be forgotten that man is a part of the biosphere, and he cannot avoid being adversely affected when the vegetation and the animals are degraded.

Acid mine drainage from mining areas contains toxic substances, and pollutes the soil and water. Numerous instances are known from all over the world whereby the rivers down stream of mines have been rendered virtually devoid of life. In Feb. 2000, leachates from the cyanide wastes of an Australian-operated gold mining company in Romania entered the Danube river through the Tizsa (a tributary), and caused an ecological disaster. For several tens of kms. of the stretch of the Danube river in Hungary, and Yugoslavia, hundreds of tonnes of dead fish were found floating in the waters, and the birds which ate the fish also died. The wastes from the Outukumpu copper mine in Finland killed fish in the Ruutunene River and Sismaervi Lake 10 km downstream. Fish appeared again when the pollution has been cleaned up. In the northern areas of the Russian Republic, fish have stopped spawning near mines, and polar foxes, lemmings and willow grouse have left the mining areas. Wild reindeer evidently dislike the pollution so intensely that there are instances of their going 150–200 km away from the mining areas. When the lakes in the mining areas are polluted, birds are known to desert their traditional nesting sites on the lakes.

Coal mines generally use timber for roof support. Experience shows that a coal mine with a production of (say) 400,000 tonnes per annum, uses 9000 to 12,000 m^3 of timber, which is usually obtained from the local forests. Thus, local forests tend to disappear unless tree crops are grown to provide the wood needed on a continuing basis. Dewatering of the mines may lead to significant changes in the vegetation in the mining area.

Plants are particularly susceptible to atmospheric pollution. The intensity of photosynthesis is adversely affected by pollutants such as, sulphur dioxide, carbon monoxide and hydrocarbons, which cause necrosis of leaves, inhibition of growth and early leaf fall. Eventually, the plants wither and die. Space photographs clearly show the devastation of the vegetation caused by mining in different parts of the world (e.g. nickel mining in Sudbury, Canada, and zinc mining in Norway).

5.3 HYDROGEOLOGICAL AND GEOTECHNICAL FORECASTING

In any branch of human activity, wisdom lies in anticipating the shape of things to come, and being prepared to face the eventualities that may arise. This philosophy holds good for the mining industry as well. The principles of hydrogeological and geotechnical forecasting are summarized as follows (Vartanyan, 1989).

Hydrogeological forecasting: Hydrogeological forecasting involves (1) forecasting the cones of depression during the dewatering of the deposits, (2) evaluation of the effects of dewatering on the existing and proposed water abstractions, (3) forecasting the effects of dewatering on the surface run-off, (4) forecasting changes in the quality of the drainage, (5) forecasting the groundwater pollution from the mining effluent ponds, etc. Hydrodynamic, balance and hydrogeological analogue methods, etc. are used for the purpose. The hydrodynamic methods, which are based on the resolution of the infiltration continuity equation for various initial and boundary conditions, yield satisfactory results if the rock structures are fairly homogeneous. The hydrogeological analogue method makes use of the similarity in the hydrological settings between a mining situation for which considerable operating data is available, and the mine to be studied. It is not necessary that the two mines should be of similar size; it is enough if the hydrological settings are similar (Vartanyan, 1989; Wood, 1981; Day et al., 1984).

Forecasting geotechnical conditions: Forecasting geotechnical conditions involves the evaluation of the "possibility and extent of subsidence, displacement and cave-ins at the ground surface; land-slides and collapses of natural and man-made slopes; evaluating the weathering qualities of rocks, their ability to withstand long-term loading (for the siting of the waste tips and tailings storage), future compaction of rocks, change in the strength characteristics, development of karst, bulging, deformation of waste tips, etc." (Vartanyan, 1989, p. 82). Evidently, the forecasting has to take into account the mining practices, such as roof caving, back filling, leaving pillars behind, etc. The analogy method is widely used to forecast geotechnical changes, i.e. whatever happened in a similar kind of mine under similar geotechnical conditions, is likely to happen in the mine in question. Apart from mathematical simulation, mechanical simulations using materials similar to those in the mine can be used to forecast the safe excavation angles and the ground surface effects.

The strength of the rock determines its susceptibility to slide, to undergo dislocation, to be fractured and to resist weathering. It is estimated on the basis of the following parameters: uniaxial compressive strength (C_u or σ_c), the uniaxial tensile strength (T or σ_T) in the dry and water-saturated state; peak or residual shear strength (τ); the ultimate strength in bending (σ_{bend}) and the rock hardness ratio (Sergeev, 1984, quoted by Vartanyan, 1989; Farmer, 1983).

Hazard zoning is a part of the Preparedness Systems for the mitigation of hazards (see Aswathanarayana, 1995, Chap. 9 of "*Geoenvironment: An Introduction*"). Hazard maps may be prepared on the basis of the geotechnical properties of rocks, CHAPTER 6

Mining and health hazards

6.1 INTRODUCTION

Mining is undoubtedly the most hazardous industrial occupation. For instance, during the period 1980–89, mining ranked as the number one in USA with respect to the average annual rate of traumatic fatalities (with the rate of 31.91 for 100,000 workers), as against 25.61 for the construction industry, 23.30 for the transportation/communications/public utilities industries, and 18.33 for the agriculture/forestry/fishing industries. There are two kinds of health impacts associated with mining: immediate impacts such as accidents, and accumulative and progressive impacts such as stress and pneumoconiosis. Opencast mining is generally less hazardous than underground mining. Industrialised countries tend to use highly automated mining systems, which not only employ lesser number of workers (who have to be highly skilled), but also have the effect of drastically reducing the hazards to which they are exposed. Developing countries cannot afford such high-tech mining systems, so much so that mining accidents are a common occurrence in developing countries such as China and India.

Health hazards in mining are described with reference to coal mining. There are four types of health hazards (see the excellent account by Chadwick et al., 1987, p. 203–236, from which the following account has largely been drawn).

1. Physical hazards, e.g. coal dust, silica dust, excessive heat, noise, heavy physical work, contorted body posture,
2. Chemical hazards, e.g. carbon dioxide, carbon monoxide, methane, nitrogen oxide gases,
3. Biological hazards (applicable in some developing countries), e.g. fungus, hookworm,
4. Mental hazards, e.g. shift work, constant danger.

The 3 km deep, Kolar gold mines of south India, constitutes an unusual case where all the above problems are evident at one place, namely, rock bursts, high thermal stress, gas and dust explosions, fires, inundations, hookworm infection, etc. (Pai & Shenoi, 1988).

6.2 DUST HAZARDS

Dust is the cause of the many of the cumulative health hazards in the mineral industries, and is hence dealt with in some detail.

The main sources of dust in the mining operations are:

Point sources: (1) Ore and waste loading points in trucks, railroad cars, etc. (2) Ore chutes in the haulage systems (bin, conveyors), (3) Screens in outdoor crushing plants, (4) Exhaust from dedusting installations, and (5) Dryer chimneys.

Dispersed sources: (1) Waste dumps, (2) Ore stockpiles, (3) Haul roads, (4) Tailings disposal.

The main natural and artificial dusts, associated sources and possible health disorders are summarized in Table 6.1 (source: Archer et al., 1987, p. 171).

Table 6.1 Main natural and artificial dusts, associated sources and possible disorders (source: Archer et al., 1987, p. 171).

Dust type	Possible source	Possible disorders
Silica (crystalline and amorphous)	Mining, quarrying, sand blasting, abrasives, glass making, etc.	Silicosis
Coal	Mining, transportation and use, smoke from the burning of arsenious coal for domestic cooking	Silico-anthracosis, coal worker pneumoconiosis, arseniasis
Asbestos	Asbestos cement, insulation, friction materials (brakes, clutches, etc.), floor-tiles	Asbestosis, and pleuropulmonary cancer
Fibrous zeolite	Volcanic tuff	Pleural cancer
Fibrous clays	Quarries, drilling mud, pharmaceutical industry	Fibrosis
Talc	Mining, rubber industry, lubricants, pharmaceutical industry	Talcosis
Kaolin	Quarrying, ceramic industry	Kaolinosis
Bentonite	Quarrying, drilling	Fibrosis
Aluminium, alumina	Bauxite mines, ceramics, abrasives, paint, metallurgy	Fibrosis
Barytes	Mining, metallurgy, pharmaceutical industry	Barytosis (pneumoconiosis due to accumulation)
Beryllium compounds	Metallurgy, aeronautics industry, nuclear industry, solid fuel	Beryllosis (granulomatosis)
Iron oxides	Iron mines, foundries, steel plants	Silico-siderosis, siderosis
Nickel	Mining, polishing	Fibrosis, lung cancer
Chromium	Mining, polishing, electrochemistry	Fibrosis, lung cancer
Cadmium	Mining, polishing, electrochemistry	Fibrosis, urinary tract cancer
Manganese	Mining, polishing, foundries	Fibrosis
Titanium, tantalum, wolfram carbides	Polishing	Fibrosis, lung cancer
All metals	Welding	Fibrosis, lung cancer
Synthetic mineral fibres	Thermal and acoustic insulation, composite materials	Fibrosis?
Airborne ash	Coal and oil fired plants, incineration of household and industrial wastes	Fibrosis? Cancer?
Volcanic ash	Volcanic eruptions	

6.2.1 Aerosols

Aerosol particles range in size from sub-microscopic to almost visible, and they are characterized by a wide variety of chemical compositions. They are mainly responsible for the haze, which affects the visibility in the industrial areas in Europe and North America.

The distribution of the size of the aerosols is log-normal. Consequently, most of the aerosols are in the 0.01–10 μm range, with the mean around 1 μm. Depending upon the size and nature of the particles, an aerosol may be called "dust" (diam. > 1 μm) or "fume" or "smoke" (0.01–1 μm). Mists (d > 40 μm) and fogs (d = 5–40 μm), are liquid droplets. Aitken nuclei (d < 0.2 μm) are small hygroscopic particles or condensation nuclei. The size ranges of different aerosols are given in Figure 6.1 (source: Fergusson, 1990, p. 208).

Iron, aluminium, manganese and chromium are generally found in the form of coarse particles (around 1.5 μm), whereas cadmium, lead, zinc and antimony occur in the form of smaller particles (d < 0.25 μm). The particle size distributions in respect of trace metals are customarily expressed in terms of Mass Median Diameter (MMD), which is defined as the particle size for which 50% of the mass occurs on larger, and 50% occurs on smaller, particles. For copper, MMD for marine air is 0.8 μm, and general (rural to urban) air is 1.8 μm.

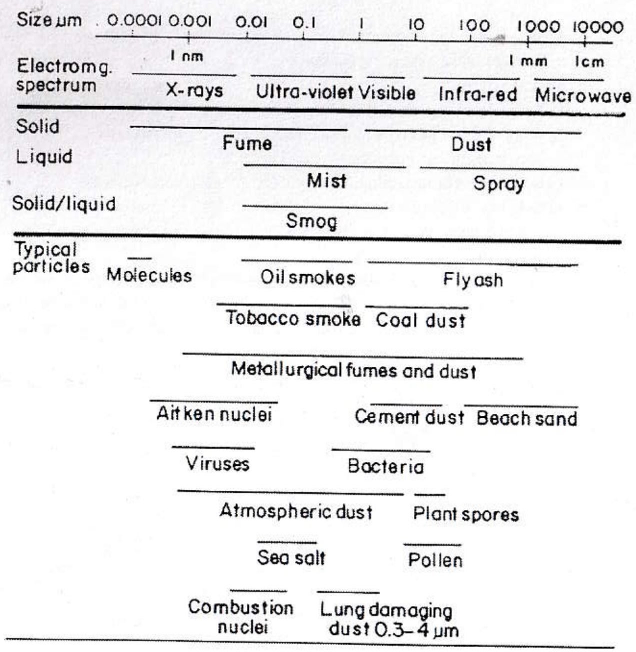

Figure 6.1 Size ranges of different aerosols (source: Fergusson, 1990, p. 208).

Coarse particles are generally produced by mechanical processes (such as, disintegration of minerals). On the other hand, fine particles are produced by condensation processes. The fine particle mode can be subdivided into nuclei mode and accumulation mode.

<0.3 μm: Nuclear mode, involving condensation nuclei, secondary particles. Brownian motion is the principal controlling force. The particles get removed by adsorption on larger particles.

0.3–3.0 μm: Accumulation mode. Important for fly ash. Small-sized particles (<0.1 μm) coagulate to form larger particles, the movement and contact being controlled mainly by Brownian motion. The number of particles decreases as a consequence of coagulation. For particles <0.01 μm, the decrease is 50% in an hour, and for <0.05 μm, it would take a day to bring the number down by 50%. Both soluble and insoluble types adhere to the surfaces.

>3.0 μm: Coarse particle mode, involving large dust particles. Gravitational settling and particle motion are the principal controlling forces.

Anthropogenic aerosols are dominated by comparatively finer particles (<2 μm). In contrast, natural particles such as wind-blown or re-entrained dust is typically >2 μm.

Aerosols can be transported for long distances, of the order of hundreds of kilometers. In the ice-cores of Arctic and Antarctic, the lead level for 1965 (0.15–0.42 ng/kg) is markedly higher than the pre-1940 levels (<0.08 ng/kg). This is attributed to the transport of lead from distant industrial sources.

The concentration of a trace metal in air, C_a, is related to the condensation nuclei by the following equation:

$$C_a = ke_n\,\eta/L \qquad (6.1)$$

where k = transfer constant, whose value ranges from 1.0 to 6.0 g/m^3, e_n = mass fraction of the aerosol used in condensation nuclei, η = a factor linked to the evaporation below the cloud, and L = Liquid water content of the cloud.

The total emission of particles in the atmosphere has been estimated to be 2608 million tonnes per year. Out of these 89% (2312 Mt/y) are of natural origin (derived from sea salt; soil dust; gas particle conversion from hydrogen sulphide, nitrogen oxides and ammonia; photochemical, from terpenes, etc.; volcanoes; and forest fires). The emissions from man-made sources are estimated to be 11% of the total emissions, (about 296 Mt/y), distributed as follows:

Particles:	92 Mt/y
Gas particle conversion: sulphur dioxide	147 Mt/y
Nitrogen oxides	30 Mt/y
Photochemical, from hydrocarbons	27 Mt/y
Total	296 Mt/y

The circulation of the particles in the atmosphere would depend upon their size and the altitude at which they are generated. Particles may remain in the lower atmosphere for about 5 days, in the troposphere for a month, and in the stratosphere for 2–3 years. This enables them to travel for long distances.

6.2.2 *Dust hazards in coal mining*

Dust is a serious hazard in coal mining. Coal and some stone dust are produced in the process of drilling, cutting, crushing and blasting of the coalface. The dust gets airborne due to ventilation, shoveling, transport and human movement. Only fine dust particles of diameter 0.5–5 μm are respirable. Anthracite (hard coal) particles are more hazardous than particles of soft coal (e.g. lignite).

Respirable coal particles pass through the upper airways, and finally settle down in the respiratory branchioli. There they accumulate and form nodules. Exposure to respirable coal dust over a period of years leads to the incidence of Coal workers' Pneumoconosis (CWP, also known as Anthracosis or Black Lung). X-ray examination is the principal method of diagnosing CWP. Simple CWP will not progress when once there is no more exposure to coal dust. But the complex CWP keeps on getting progressively more and more serious, leading to emphysema and heart failure.

Silicosis is caused by the respiration of free silica (quartz) particles in the dust. The respirable particles have diameters of less than 5 μm. Although small quantities of free silica particles may occur in the dust in the underground mining, the risk from them is greater in the opencast mining. When the silica particles reach the lung alveoli, they are attacked by microphages, leading to the formation of fibrotic nodules ("simple silicosis"). In due course, the nodules coalesce to form large fibrotic masses called conglomerates. Simple silicosis may not show any clear symptoms, but patients suffering from conglomerate silicosis invariably suffer from shortness of breath. X-ray examination of the lungs is the standard procedure for the diagnosis of silicosis.

The Kolar gold mines in southern India, and the Rand gold mines in South Africa began production at about the same time, around 1880s. The nodular type of silicosis which was highly prevalent in the Rand mine workers, had minimal incidence in the case of Kolar mines. This is attributed to the extent of exposure to silica dust (Pai & Shenoi, 1988). In the case of Rand, both the lode and host rock was quartzose, whereas in the case of Kolar, only the lode is quartzose, whereas the host rock is amphibolitic. The free silica percentage of the quartz reef averages about 90%, and that of amphibolite, about 50%, with the aggregate having a free silica percentage of 52–55%. There is therefore sharp difference in regard to the aggregate free silica percentage between Rand (~90%) and Kolar (52–55%).

The International Labour Organization (ILO), Geneva, has developed elaborate classifications for pneumoconiosis and silicosis, for clinical and epidemiological purposes. The characterization of the lung function is based on the parameters of Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV_1). If unchecked, the conglomerate silicosis may lead to emphysema and heart failure.

The composition of the dust varies from mine to mine. Anthrcosilicosis is a mixed disease caused by the inhalation of both coal and silica dust. Simple anthrocosis may degenerate into Progressive Massive Fibrosis (PMF).

Workers suffering from silicosis become highly susceptible to the dreaded disease of tuberculosis. Such an infection is hard to treat, as the fibrous and scar tissues impede the penetration of antituberculostatica. No wonder that 25% of the silicosis deaths are attributable to silicotuberculosis.

Bronchitis among the mine workers is attributable to the inhalation of relatively coarse dust particles of the diameter 5–15 μm. Such particles are too large to go into the lungs. When inhaled, these particles get stuck in the upper airways. Constant irritation by such particles leads to infection, coughing and production of sputum.

Statistics show that in a number of countries one out 8 workers suffers from CWP and silicosis, and one out three workers suffer from bronchitis. In USA, during the period, 1970–77, Federal Black Lung Compensation was awarded to 420,000 coal mine workers who were totally disabled because of CWP. A survey during 1974–77 by the National Coal Board of U.K. found that about 7% of the British Coal Miners were suffering from CWP. It has been reported that the incidence of CWP in India may be as high as about 16%.

6.2.3 *Dust in steel industry*

The steel industry is notorious for the large quantities of visible fumes and clouds of dust. The problem here is one of quantity of dust, rather than the toxicity of dust. Two categories of dusts can be recognized in the steel industry (UNEP, 1986, p. 36):

1. Coarse particles (diam. 10–100 μm) produced in the course of mechanical operations, such as crushing, screening, and charging of raw materials – these settle down fairly rapidly.
2. Particulates (less than 1 μm diam.) produced in the course of high temperature metallurgical processes such as, blast furnaces, steel making, oxygen scarfing. These remain suspended in air for long periods.

6.2.4 *Pathological effects of mineral dusts*

Toxic particles, such as silica, can cause severe fibrogenic reaction. In industrialized countries, the incidence of pneumoconiosis has been kept under control by improved dust control techniques. Asbestosis and pleuropulmonary cancer arising from exposure to asbestos particles in the construction materials, have emerged as the principal health hazard arising from mineral dusts. In USA, there have been cases of whole school buildings being completely demolished because asbestos products have been used in their construction.

Soot or carbon black, which is the waste product of incomplete combustion in private or industrial buildings and incinerators, is the most visible dust, although not necessarily the most harmful. Air near the industrial areas may contain particles of metal oxides, silicate and inert dust. Exposure to fibrous minerals, such as, chrysotile, amphiboles, attapulgite, diatomaceous earth, bentonite, sillimanite, etc. in the course of their mining, fabrication and use, leads to the development of various kinds of fibroses.

6.2.5 *Fibrogenetic effects*

The biological activity and hence the pathological effect of mineral dust particles depend upon the extent of their penetration, retention and clearance.

Some mineral particles, such as those of carbon, iron and barium, have limited biological effect. When inhaled in large quantities, they accumulate and cause pneumoconiosis around the terminal repository bronchioles. On the other hand, the inhalation of fibrous mineral particles causes pulmonary fibrosis. Fibrogenic pneumoconiosis is caused by the inhalation of fibrous minerals such as silica, and asbestos, and metals such as beryllium, aluminium, nickel, cadmium and manganese. In the case of mixed dusts, the more the content of silica, the more pronounced is the fibrosis.

Electron microscopic images (×300) allow us to distinguish between the interstitial fibrosis of the lung associated with pleural fibrosis, and the nodular or massive hyaline fibrosis found in silicosis. This may be a manifestation of the difference in the penetration and clearance of the two kinds of dusts.

It has been observed that fibrous particles lodged in the lung tend to be surrounded by a ferrous protein sheath. This probably represents an effort by the body to detoxify the toxic fibres.

6.2.6 *Carcinogenic effects*

Several epidemiological and experimental studies have indicated that asbestos is the direct cause of pleural or peritoneal mesotheliomas, besides being a co-factor in inducing bronchopulmonary or gastro-intestinal cancer. There is epidemiological evidence to suggest that chromium, nickel, arsenic and cadmium and their complexes are carcinogenic in man. It has been reported that the toxic and carcinogenic effects of the fibres are not only dependent upon their type and size, but also on their chemistry, particularly surface chemistry. Experiments with animals suggest that the carcinogenicity of metals depends upon their crystal structure and state of ionization.

Table 6.2 (source: Chen et al., 1999) summarizes the health effects of arsenic in mineral dusts as observed in some countries.

Low-rank coals invariably contain pyrite. Arsenic may substitute in pyrite (FeS_2) or may be found in the form of a separate mineral, arsenopyrite (FeAsS). In Guizhou province of China, coals have very high arsenic content (9600 mg/kg). When such high-As coal is used for cooking, keeping warm, and drying of grain, arsenic content of the ambient kitchen air rises to 0.003–0.11 mg/m^3. Exposure to this environment leads to the absorption of arsenic by the respiratory tract, skin, and digestive tract (Zheng et al., 1994, quoted by Sun et al., 1999).

About 30,000 workers in the copper smelting and arsenic mining industries are exposed to high-As aerosols. The tin mine workers in the Yunnan province are exposed to high-As aerosols – the cancer incidence among these workers is 716.9 per 100,000,

Table 6.2 Health hazards due to exposure to arsenical dusts.

Area	Source	Population at risk	Non-cancer manifestations	Cancer manifestations
Guizhou province, China	Burning of high-As coal	200,000	M/K, G, P	S, Li
Yunnan, China	Metal smelting	100,000		S
Toroku/Matsuo, Japan	Metal smelting	217 patients	M/K, D, G, B, P	A, S, Lu, U, K
Ronpibool, Thailand	Tin mining	1000 patients	M/K	A

M/K – melanosis/keratosis; D – dermatitis, G – gastroenteritis; B – bronchitis; P – polyneuropathy; A – all sites; S – skin; Li – liver; Lu – lung; U – urinary bladder; K – kidney; P – prostate.

which is 82 times that of the controls. The average As content in the lungs of the cancer patients was found to be 43.33 mg/kg.

Carcinoma of the lung is associated with inhalation of arsenic dusts. Instances are known from Southeast Asia where lung cancer is attributed to As in drinking water. In the Xinjiang province of China, both arsenic and fluoride contents are high in the drinking water as well as in the coal used for burning. This led to the concurrent endemicity of arseniasis and fluorosis among the populations.

Coal is the principal source of energy in China. China is the largest producer of coal in the world (1235 Mt in 1998). With increased industrialization, and with people aspiring for a higher standard of living, consumption of coal-fired thermal energy as also the use of coal in home heating, has been growing rapidly. There is a price for this. It has been said that nine out of ten most polluted cities in the world are in China, and one out of three deaths in China is due to contaminated air and water (*Time*, USA, Nov. 8, 1999).

Two or more mineral substances may interact together, some times antagonistically, and more often synergistically. The inhibition of quartz by carbon, aluminium or polymers is an example of the antagonistic interaction. When sulphur dioxide is adsorbed on soot particles in the atmosphere, the toxic effect of sulphur dioxide gets intensified due to synergism. A possible mechanism for the operation of synergism is as follows: when the solid particles are lodged in the lung tissues, the adsoptive capacity of the solid particles allows them to retain the gaseous or soluble substances adsorbed on them. It is also possible that through their surface properties, the solid substances act as catalysts, accelerating or facilitating some processes. They may also serve as vectors of toxic substances, penetrating the cells more readily.

6.2.7 *Analytical methods*

As the mineral dust particles tend to have a size range of 1 mm to 1 μm, the usual practice is to study the individual particles for their size (which determines their aerodynamic properties, and respirability), shape (whether the particle is fibrous), mineralogy, chemical composition and speciation, isotopic characteristics, etc. At least two characteristics of a mineral dust particle, namely, morphology and chemistry, need to be determined.