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Environmental Impacts of Mineral Resource Exploitation and Use

M.Kaya
Osmangazi University, Technological Research Center (TEKAM), Eskişehir, Turkey

ABSTRACT: Human beings are facing a global mineral resource crisis. The earth's finite supply of minerals İs being used by a population that is growing faster than at any time in history. To make matters worse, mineral consumption İs growing even faster man the population. Although we need more minerals to supply society, we are becoming increasingly aware that their production and use pollute the planet. The effects were once local in scale, but have now become truly global, with mineral consumption implicated strongly in global wanning, acid rain and destruction of the ozone layer. There is concern mat the earth is reaching its limit of mineral-related pollution. Human beings cannot ignore this crisis. This paper reviews the environmental impacts of mineral resource exploitation and use.

1 INTRODUCTION

We live İn a time of rapid changes in world population and technological innovations. Technological changes are occurring at unprecedented rates, which are projected to increase İn the years ahead. These forces, combined with the desire of hundreds of millions of people in developing countries to raise their standard of living, are resulting in increasing demands for food, minerals, construction materials and energy. At the same time, there is increased recognition of human influence on the global environment and increased concerns about the long-term consequences of resource exploitation on nature and the ultimate habitability of the world.

2 THE FOUNDATION OF SOCIETY: MINERALS

The world is constantly in a state of change. In order to meet the needs of a growing population, we must employ old and new techniques. The new technologies are more productive, but require the use of greater amounts of resources. All materials (fuels, metals, water, etc.) needed for modern society are derived from the earth's crust, whetiier directly or indirectly. Our civilization is based on mineral resources. These resources are like air - of no great importance until you are not getting any. Most of the machines, appliances and furniture that make life comfortable are made of metals and powered by fossil fuels. World population grew slowly until about 1500 A.D. Increasingly rapid growth from around 1800 had raised the population to 2 billion by 1930 and 4 billion by 1975; it had exceeded 6 billion by 2000. Exploitation must be carried out m such a way that the environment is not so fouled and irretrievably spoiled that we ruin the planet upon which we live (Craigh et al., 1996).

2.1 *Materials we use*

Natural resources can be classified into two groups: renewable and non-renewable resources. Renewable natural resources are replenished on short time scales of a few months or years. For example, wind, hydraulic and solar energies. Non-renewable resources are contained in the earth in fixed quantities and are not replenished by natural processes operating on short time scales. Examples are oil, natural gas, coal, metals and mineral products produced from the earth. The formation period of oil, gas, metals and minerals is very long (i.e., over tens of millions of years), vastly slower than the rates at which we mine these materials. The resources we obtain from the earth's crust today are products that have accumulated over the last billions of years. Most non-renewable natural resources are also mineral resources, both organic and inorganic in origin. Resources can also be classified into three major use groups: metallic, energy and non-metallic mineral resources.

Metals can be subdivided into two classes, on the basis of their occurrence in the earth's crust. The geochemically abundant metals are those that individually constitute 0.1% or more of the earth's crust by weight (such as Fe, Al, Mn, Ti, Si, Mg, etc.). Geochemically scarce metals are less than 0.1% by weight of the earth's crust. These are Cu, Pb, Zn, Mo, Hg, Ag, and Au. Mineable deposits of scarce metals tend to be smaller and less common than mineable deposits of abundant metals. The second major group İn resource classification is energy minerals. Some resources, such as fossil fuels and radioactive minerals (U, Th), are non-renewable resources. Other energy resources, such as running water and solar heat, are renewable. The third group of resources contains all of these material substances, excluding the metals and energy minerals. Such resources include minerals used as sources of chemicals (halite, borax), plus minerals used as raw materials for fertilizers (phosphates, nitrates). This group also contains industrial minerals used as paints, fillers, abrasives, drilling mud, construction and building materials, etc. Water and soil are vital to the production of food.

2.2 *Mineral production as apart of GDP*

A good indication of the role of mineral production in economic activity in any country can be obtained by comparing the value of mineral production and gross domestic product (GDP) (Keşler, 1994).

Table 1 % GDP obtained fiom mineral production

% GDP	*Countries*
35	Kuwait
25-20	S. Arabia, Namibia, Zaire, PNG
20-10	Zambia, Mexico, Zimbabwe, S. Africa
5-2	Brazil, Sweden, USA, Japan
1	Turkey

As can be seen from Table 1, raw material production makes up less than 2% of GDP in the U.S. and Japan, but İs greater than 25% in Kuwait and S. Arabia. In spite of the low percentage in the U.S., America is the world's leading producer of 19 mineral commodities. The impact of minerals on the global economy is enormous. Not including recycled material, world primary fiiel production and metal production are worth about $700 and $500 billion, respectively, and primary industrial mineral production is worth about $150 billion. The value of world raw and processed mineral exports ranges from $400 to $600 billion annually, a quarter of all exports.

3 ADEQUACY OF WORLD RESERVES AND CONSEQUENCES OF THEIR EXPLOITATION

The two systems of forces of the sun's external heat energy and the earth's internal heat energy maintain a geochemical dynamic balance. The formation of the earth's resources is a consequence of these geochemical cyclmg processes. One of the major consequences of our exploitation of natural resources is mat we are interfering with me balance of some natural geochemical cycles (for example, carbon/sulfur cycles).

Geological, engineering, environmental and economic factors control mineral availability. The adequacy of world mineral reserves and resources is strongly affected by consumption, stockpiles and recycling. Figure 1 shows the adequacy of world mineral reserves based on 1992 production data (Keşler, 1994). The reserves of 18 out of 53 minerals will be adequate for more than a century. For example, coal, Fe, bauxite, Ch, V and Pt are in this group. However, another ten minerals, including diamonds, Ag, Pb, Zn and S, have only 10 to 25 years' life remaining. Cu, Mn and oil have a life expectancy of 25-50 years.

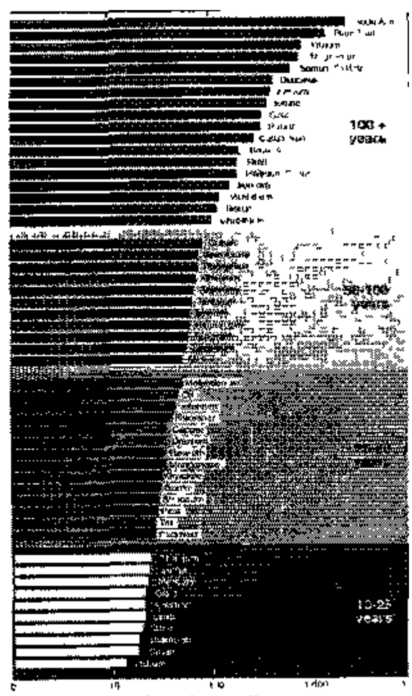

Figure I. Life expectancy of elements/minerals

The chemical elements that we use in modem society number 86. Many of them are used in compounds in which their presence is not evident but is essential. Only three elements (C, N and O) and four noble gases (Ne, Ar, Kr and Xe) can be extracted from the atmosphere. Seven elements (H, K, Ca, C, N, P and I) can be derived from biological materials. Eighty-one elements can be exploited from mineral resources and derived from the ocean or salt-bearing brines. Thus, it is apparent that most of the chemical elements we use in modem society are derived only from minerals and brines.

The earth's resources have been used by all cultures throughout history. The earliest uses of the earth's resources involved water, salt and simple tools made from rocks. The quantities of various mineral resources used by particular societies vary widely but generally correspond per capita to the nation's degree of development and standard of living. According to the U.S.B.M., each American citizen consumes about 18.8 tons of mineral resources each year. The Umted States total mineral resource consumption is about 5000 million metric tons per year.

The production and use of every natural resource, from the clearing of forests and tilling of fields to the mining of metals and burning of fossil fuels, causes changes that may be large or small, local or global, pleasant or unpleasant. They may be given such names as pollution or environmental degradation or may be called disasters, but they are all consequences of the exploitation of natural resources. The second half of the 20^{Lh} century has seen a rapidly growing awareness in scientists, political leaders and the public of the importance and complexity of environmental problems. In many instances, people have suddenly recognized that the activities we once viewed as beneficial, such as changing waterways, draining wetlands, clearing forests and burning fossil fuels, can damage the environment.

3.1 *How exploiting resources affects the environment*

Mining, quarrying, dredging, drilling and extracting from wells are all activities that have a marked impact on the landscape and environment. Directly linked to these activities are problems concerned with the disposal of water products. Smelting and refining of the ore also causes series environmental problems.

3.2 *Mining and quarrying methods*

The method used to extract minerals depends on the deposit size, shape, depth beneath the surface and grade. A choice is made between surface mining and underground mining. Surface mining, which accounts for about 2/3 of the world's solid mineral production, generally involves open pit mining or strip mining. Open pit mining is an economical method of exploiting large tonnages of reserves and achieving high rates of production. The waste material overlying the deposit (overburden) must be thin enough to be removed.

Surface mining is less expensive, safer and involves fewer complications with air, electricity, water and rock handling. However, surface mining has a greater environmental impact than underground mining. Surface mine production may be as high as 100,000 t/d, while the underground mine production rate may be 10,000 t/d. Thus, surface mining operations disturb the surface more seriously. Quarrying refers to an open pit mine from which building stone or gravel is extracted (Craigh etal., 1996).

In open pit mines, extraction proceeds by drilling, blasting, loading, transporting and dumping the ore out of the pit At the world's largest open pit mine at Bingham Canyon, Utah, every day 400,000 tons of ore plus overburden are removed. In strip mining of coal, clay, bauxite, tar sands, phosphates, iron ores, etc., overburden is removed and dumped to the rear and the ore is scooped up and loaded into trucks.

Deep mines are extracted using underground mining methods. In most mines, ore extraction and mine development involve drilling and blasting, and removal with mechanical diggers onto underground railway cars or dump trucks that reach the surface through a shaft or adit. Groundwater pumping, ventilation, roof support with timbers, waste rock removal, the inherent dangers of rock falls and cave-ins, fires, and the build-up of poisonous or explosive gases are some disturbances to the environment around underground mines.

Hydraulic mining uses high-pressure water jets to wash soft sediments down an incline toward some form of concentration plant, where dense mineral grains (such as gold) and soft mineral grains (such as clay/kaolin) are separated. However, hydraulic placer mining in California in the 1860s yielded large amounts of gold, but dramatically altered the nature of the rivers and the bays into which they flow.

Solution mining (leaching) involves dissolving the ore (Au, Ag, U, S, NaCl, etc.) with a liquid (water, cyanide, etc.). If the ore is extracted on site with solution mining, it is called in-situ leaching. This method is used to recover low-grade Cu, Au, and U ores.

3.3 *Environmental impacts of mining and quarrying*

Much of the impact of mining and quarrying is obvious. The disruption of land otherwise suitable for agricultural, urban or recreational use; the deterioration of the immediate environment through noise and airborne dust; and the creation of ore of the most dangerous environments for workers and potentially hazardous for the public are all environmental problems associated with mining. However, mining is a relatively short-term activity, and much can be done both to limit environmental damage during mining and to restore the land when mining operations are complete. Today, in many countries, legislation has been enacted at nearly all levels to ensure that extreme restrictions could make mining completely uneconomical. Unfortunately, the absence of adequate controls over some mining activities in the past has left numerous scars on the surface of the earth and led to resistance among many members of the public toward new mining activities in their areas.

Fortunately, many underground mines leave little evidence of their presence, even after mining operations have ceased. They are usually filled by percolating ground water over time, but the rocks are usually strong enough to hold in spite of abandoned mine openings and passageways. Sometimes the old mines can be put to very good use. Old underground mines can be used as storage areas for grains, seeds, burial of nuclear wastes, and truck parking (Craigh et al., 1996).

When an open pit mine closes, a large hole remains with no readily available waste rock to fill it. The pit slopes are often too steep for plantation. If the water table is high enough, the bottom of the pit may flood, creating an artificial lake. Therefore, very large open pit mines are difficult, if not impossible, to reclaim. Smaller open pits may be filled with waste rock. In some places, surface mines can be reclaimed to form small lakes and wetlands mat support fish, birds and other wildlife. Underground mines do not lead to such drastic disruptions of the surface as open pit and strip mining, but a new hazard known as subsidence can be encountered. Subsidence under towns and roads can leave homes uninhabitable and transportation severely disrupted.

In addition to the impact that mining activities may have on the, landscape, the environment may be disrupted over a wider area by changes İn the distribution and chemistry of surface waters or ground water. An example of mis is acid mine drainage, which is the drainage produced when iron sulfide minerals are exposed to oxidation by moist air to form H2SO4 plus various other sulfate compounds and iron oxides. Pyrite and marcasite in coals, and pyrrhotite in metallic mineral deposits are me cause of H2SO4 when these minerals are exposed to air in underground mines, open pits or the dumps of waste material left by mining operations. Water passing through the mines or dumps becomes acidified, later finding its way into rivers, streams or the local groundwater system. Many streams can be affected by abandoned mine works.

3.4 *Disposal of mining wastes*

Nearly all mining operations generate waste rock, often in very large amounts. Strip mining waste can be used in reclamation, but an alternative method of disposal must be found for underground mining operations and most kinds of open pit mining. Usually, this simply involves dumping the wastes İn piles at the surface next to the mine workings. Sometimes, die waste rock is put back into me openings created by the mining {backfilling). Piles of waste rock may be dangerous because of the possibility of sliding. Alternatives to the dumping of mining wastes, such as the use of them to fill land, are likely to be expensive and impractical in most cases. Waste dump slopes can be lowered and revegetation can be achieved.

3.5 *Dredging and ocean mining*

Dredging involves removing unconsolidated material from rivers, streams, lakes and shallows seas with machines such as bucket-ladder dredge, dragline dredge or suction dredge. There is no mechanical pollution from dredging, but the process disperses large quantities of fine sands and silt having severe effects on fish and other wild life that require clean water to survive. Ocean mining for Mn nodules involves significant disruption to ocean water and biological system. Currents, sedimentation patterns and erosion patterns are changed by ocean mining operations (Craig et al., 1996).

3.6 *Well drilling and production*

Drilling wells are used to explore and produce oil, gas, brine, geothermal fluids. Blow out and fire hazards can create severe pollution. Oil and brine spillage and seepage must be carefully controlled.

4 PROCESSING AND SMELTING ORES

Ores require processing after removal from the earth. Such processing is usually done at or near the sites of mining. Mined metals constitute 30% in many Al and Fe ores down to as little as 0.000001 % in me case of Au. The amounts of metal extracted from one metric ton of typical ore range from as much as 250 kilograms for iron ores to as little as 1 gram for gold ores. The amounts of waste left for disposal are greater than the quantities of the metals extracted (Fig. 2).

In many operations, size reduction (crushing and milling) for liberation and beneficiation for concentration are performed. Large quantities of waste gangue material, known as tailings, are dumped in the form of fine-grained slurry into ponds or lakes for settling. Clean water may be recirculated.

Prior to smelting, some sulfide ores are roasted and then pure metal can be recovered by smelting. Cu-Ni sulfide ores are directly smelted to a matte, and then conversion with air is applied. Air oxidizes sulfur to sulfur dioxide and changes iron to an oxide.

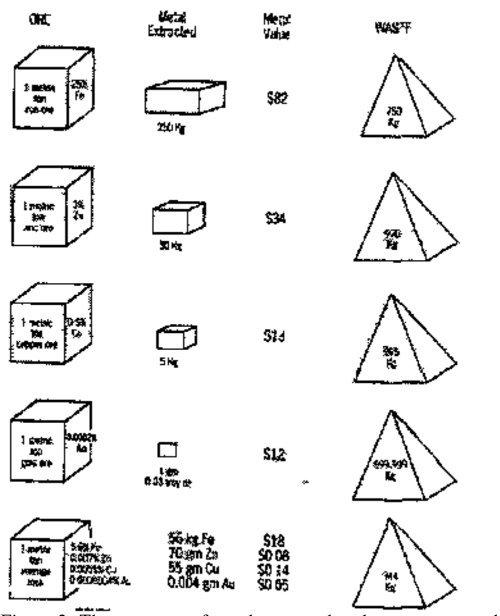

Figure 2. The amounts of metal extracted and waste generated during processing

Smelting and other kinds of pyrometallurgy are very significant sources of air pollution because smelters may emit substantial off-gases, such as SO2, CO2 and particular matter (PM). Small quantities of toxic metals, such as As, Pb, Hg, Cd, Ni, Be and V, may be released. Today, Au/Ag is produced by cyanide leaching (hydrometallurgy). Cyanide solutions are highly toxic and their accidental release into the environment can kill many animals and plants.

4.1 *How using resources affects the environment*

The burning of fossil fuels in power stations, homes and automobile engines results İn gases, particles and excess heat being emitted into the environment. The use of nuclear fuels generates toxic radioactive waste products requiring special disposal. Oil refining and metal/mineral production also generate wastes and pollutants.

4.2 *Acid pollution*

The most important pollutant of the hydrosphere is acid $(H^4\}$ in the form of acid rain and acid mine drainage. Acid mine drainage results from the decomposition of pyrite, usually catalyzed by bacteria (Fe^{*2} to Fe) to produce iron hydroxide, and dissolves H^+ and $S0_4$~ (Table 2). 95% of the acid mine drainage in the U.S. comes from coal mines or waste piles, which contain small amounts of pyrite.

Acid mine drainage formed by dissolution of pyrite dissolves more pynte, thus accentuating the effects. As the acid water moves downstream, it mixes with less acid water, causing dissolved iron to precipitate as oxides, winch produces further acid. Acid water produced by these reactions can dissolve other metal sulfides and leach metals that are adsorbed on the surfaces of clays and poorly crystallized minerals (see Table 2).

4.3 *Burning fossil fitels*

The burning of fossil fuels in automobiles, power plants and heating systems creates air pollution. The burning of solid waste and smelting also generates air pollution. Figure 3 shows the effects of the sources of air pollution. Acid rain is die product of reactions between atmospheric water and CO2, SO2 and NC\. Possible reactions are shown in Table 2. Acid ram dissolves limestone and lime readily:

$$CaCO_3 + H^+ = Ca^{+2} + HCO_3^- \quad (D$$

$$CaO + H^+ = Ca^{+2} + OH^- \quad (2)$$

Acid rain speeds up the decay of buildings, sculptures and other structures (Kaya, 1998).

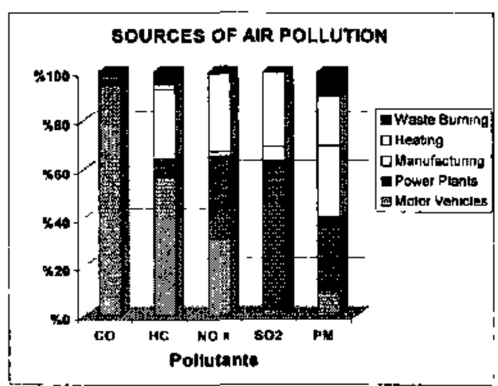

Figure 3. Sources of air pollution

Igneous and metamorphic rocks which consist of largely silicate minerals react slowly with acid:

$$2KAISi_30_8+2H^++H_20=2K^4+Al_3Sİ205(OH),,+4Si02$$

Global temperatures have increased by 0.5 °C since the early 1900s. The increase is related to $C0_2$, CIL,, H_20 vapor. NO^, CFC and other greenhouse gases, which absorb infrared radiation that would otherwise radiate from the earth into space, thus heating the surface of the planet (Keşler, 1994).

Table 2. Reasons for and sources of pollution and environmental effects.

Reason for Pollution	*Pollution Sources*	*Pollutants and Reactions*	*Environmental Effects*
Acid Mine Drainage	Coal mines Waste piles	$2FeS_2+2H;0+70_2= 4H^* +S0_4'+2Fe'^2$ $Fe^{*!}+3H,0$ -» $Fe(OH)_3i + 3H^+$ $ZnS+-3H;0=Zn^{'\hat{i}}+S0_4"^2$ $Clay-Me'^2+H^*=Clay-H"+Me"$	Pollutes hydrosphere Dissolves metals Leaches metals
Burning Fossil Fuels	Motor vehicles Power plants Heating Systems Burning solid wastes	$S \rightarrow SO_2 \rightarrow SO_3$ $SO_3+H_2O \rightarrow H_2SO_4$ $NO+0.5H_2O+0.75O_2 \rightarrow HNO_3$ CO_2/CFC/$CFCl_3$ CO_2 HC compounds, soot Particulate matter (PM), fly ash Lead compounds Toxic matter and gases	Air Pollution } Acid rain Destruction of ozone layer Greenhouse effect (atmospheric heating) Thermal pollution
Eruptions, Fires, Decay	Volcanoes Forest fires Vegetable decay	SO_2 NO_X	Acid Rain Damages vegetation Damages fish growth Leaches nutrients from soil Deterioration of metals, lime stones and paints
Disposal of Nuclear Waste Products	Mining and processing of Uranium ores Manufacture of nuclear fuels/weapons Use of fuels in nuclear power stations	Radioactive emissions Radon gas emission Waste products	Radioactive radiation

4.4 *Disposal of nuclear wastes*

The mining and processing of uranium ores, the manufacture of nuclear fuels, the use of fuels in nuclear power stations, and nuclear weapons manufacture all generate waste products requiring disposal. The long-term disposal of radioactive wastes is still an unresolved problem.- Low-level wastes generally have radioactivity less than 1000 times the acceptable level in the environment. Large quantities of this type of waste are produced at uranium mines. In practice, the tails are usually dumped at or near the mine and stabilized by earth cover and vegetation. Large volumes of low-level waste is also produced in nuclear power stations, research laboratories, hospitals or other nuclear industries. These wastes are usually sealed in drums, burned in incinerators and buried beneath a meter of soil. Some low-level wastes have been cast into concrete, put into sealed drums and dumped into deep ocean. Radon, radioactive, odorless and colorless, is gas produced by the decay of uranium and thorium. Radon can escape into the atmosphere as vapor or can be dissolved in ground water. Radon in all forms is harmful to humans. High-level radioactive wastes from the nuclear power industry account for roughly 95% of the radioactivity, but only about 0.1% of the volume of waste generated. High-level nuclear wastes are solidified/vitrified. After being sealed in concrete and stainless-steel canisters, solidified waste can be stored in vaults or reinforced shielded buildings above ground. Solidified wastes can be disposed in the ocean, by burial beneath deep ocean sediments or by deep burial in land. Several countries have already made decisions on the geological environment for long-term high-level waste disposal (e.g., Belgium - clay; Germany - Salt; Sweden and India - granite). (Craigh et al., 1996).

5 CONCLUSIONS

The environmental impact of natural resource exploitation in the United States was estimated by the Environmental Protection Agency (EPA). Recent data for atmospheric pollution in the U.S. show that mineral production accounts for about 30% of Pb, 25% of PM, 18% of SO*, 13% of volatile organic compounds (VOC), 3% of CO and 2% of NO* emissions. For the three major pollutants to which mineral production makes a major contribution, mining is the most important PM source, smelting is the most important SO* source and crude oil and natural gas processing the most important NO* source. However, the proportion of emissions generated by mineral resource extraction has significantly declined in the last few decades in the U.S. (EPA, 1991)

The total use of land by mining throughout the world between 1976 and 2000 was about 37,000 km^2, or about 0.2% of the earth's land surface. About 60% of disturbed areas are used for excavation and the remaining 40% are used for disposal of overburden and similar wastes. Modern materials such as plastics, polymers, ceramics and composites are introduced to the market. These materials are often in competition with conventional minerals in the form of substitutes. The recycling of some material (such as glass, metals, some industrial minerals, plastic, etc.) also decreases environmental problems. Recycling is the perfect form of mineral reuse.

As a result, miners have to exploit and use minerals in an environmentally friendly way because the globalization of environmental concerns presents complex ethical problems that we have just begun to address. Today, miners cannot ignore the concern that the earth is reaching its limit of mineral-related pollution.

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