Chapter 2
Earth Science in Environmental Management

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1 Introduction

Since the industrial revolution our environment is increasingly affected by anthropogenic impact. An in-depth knowledge of earth science and geo-ecosystems is required to protect the environment and landscapes for the future generations. Environmental management integrates knowledge from natural science disciplines such as physical geography, landscape ecology, remote sensing, bio-geochemistry, environmental geochemistry to name a few with thorough understanding of earth science. The primary earth science topic that needs to be addressed in environmental management can be divided into natural processes and anthropogenic processes. For example, volcanic eruptions, earthquakes, landslides, natural coastal processes disrupt living conditions and need constant monitoring and aftermath management from both social and environmental point of view. On the other hand, increasing population pressure is depleting freshwater and fossil fuel resources, modifying natural landscapes, producing colossal amounts of wastes and releasing toxic chemicals in the environment. Anthropogenic activities are constantly modifying our environment, which are directly impacting our food, water quality and climate. In this chapter, we will discuss both the natural and anthropogenic activities that are affecting our environment in tandem with their associated environmental problems and risks.

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P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_2

2 Freshwater

Freshwater is any naturally occurring water with salinity <0.5% and <500 parts per million (ppm) of dissolved salts. The source of freshwater is atmospheric precipitation in the form of mist, rain and snow, and are stored in ice caps, glaciers, ponds, lakes, swamps, rivers and as groundwater. There is a common misnomer that freshwater is synonymous with drinking water (or potable water). However, in reality, much of the earth's freshwater needs treatment before drinking. Human activity has threatened freshwater reserve by polluting and depleting groundwater reserve by overdrawing.

With increasing population pressure, there is growing reliance on groundwater for farming and drinking purposes. Groundwater overdraft occurs when groundwater use exceeds recharge amount of an aquifer. This leads to a decline in groundwater level. In case of fine-grained sedimentary rocks, groundwater fills up the pores and is in part responsible for holding up the ground. Overdrawing of groundwater from such types of sedimentary bed rock results in aquifer compaction leading to land subsidence. Ground-based measurements of land subsidence can be made over small spatial scales, but remotely-sensed observations are essential for spatially comprehensive mapping of deformation over large regions. This regional scale subsidence scenario is occurring in several groundwater basins in California. Approximately, 5200 square miles of land surface has been affected by subsidence in the San Joaquin Valley alone and has been identified as the single largest human alteration of the earth's surface topography. Drought conditions exacerbate subsidence rate due to over withdrawal of groundwater by farmers. Land subsidence up to 52 mm/year has also been recorded in Northern Beijing where groundwater drawdown and geological structure control the subsidence values (Zhu et al., 2015). Inelastic compaction of aquifer system from declining water table has resulted in land subsidence in Hangzhou-Jiaxing-Huzhou Plain in China (Cao et al., 2013), New Jersey, USA (Sun et al., 1999), Emilia-Romagna coastland, Italy (Teatini et al., 2006), Mekong Delta, shared by Cambodia and Vietnam (Erban et al., 2014), Konya Closed Basin (Ustun et al., 2010) to name a few. In India, land subsidence averaging 13.53 mm/year has been reported in Kolkata city and east Kolkata wetlands due to overdraft of groundwater (Sahu and Sikdar, 2011). It is estimated that 1 metre drop in the piezometric head corresponds to a mean subsidence of 3.28 cm.

Land subsidence can have several immediate and visible as well as long-term effects. The greatest effects can be seen in infrastructural damage of manmade structures such as roads, railways, bridges, pipelines, buildings etc. that traverse a subsiding area. In California, water conveyance structures such as the California Aqueduct are gravity driven. Hence, a slight change in gradient of the land can affect groundwater flow capacity. While the above-mentioned effects are visible, which generally can be repaired, the long-term damage is caused in the aquifer capacity to hold water. Most aquifer compaction due to low piezometric surface is irreversible. Hence, even if the piezometric surface rises the aquifer does not revert back to original configuration. Additionally, land subsidence affects topography, which are manifested in wetland migration to lower elevation and erosion/deposition patterns of rivers to attain the new equilibrium.

Land subsidence in coastal region coupled with sea level rise poses a great threat to the population living in the coastal areas. For example, most part of Mekong Delta, shared by Vietnam and Cambodia lies within <2 m of current sea level. Compaction of sedimentary layers due to groundwater extraction is causing land subsidence at an average rate of 1.6 cm/year (Erban et al., 2014). Land subsidence is calculated to be ~0.88 m (0.35–1.4 m) by 2050 if pumping continues at present rates, and anticipated sea level rise will be ~0.10 m (0.07–0.14 m) by 2050. This additive effects water sea-level rise due to global climate change with the regional pumping – induced land subsidence will cause subsurface saline intrusion, damage to infrastructure and increase in the depth and duration of annual flooding.

3 Toxic Chemicals in the Environment

According to US EPA (United States Environmental Protection Agency), 10 chemicals or sources of major public health concern are air pollution, arsenic, asbestos, benzene, cadmium, dioxin and dioxin like substances, inadequate or excess fluoride, lead, mercury and highly hazardous pesticides. In this chapter, we will discuss the sources and pathways of arsenic and fluoride, both being geogenic and needs thorough understanding of earth science.

Arsenic (As) contamination in the groundwater is a serious problem in India and Bangladesh. The Ganga-Meghna-Brahmaputra (GMB) basin is one of the worst arsenic affected regions due to the presence of high concentrations of this toxic metalloid within the upper 50 m depth of aquifers. Geochemical characteristics of aquifers in regions drained by these three rivers have indicated natural groundwater arsenic contamination (Chakraborti et al., 2010). In the 1970s, UNICEF and the World Bank dug thousands of wells in the GMB plain as a solution to provide safe drinking water (Ravenscroft et al., 2005). Prior to 1970s, Bangladesh had the highest infant mortality rate in the world owing to ineffectual water treatment and sewage systems (Hunter et al., 2010). Arsenic is a Group 1 carcinogen as there is sufficient evidence for their carcinogenicity in humans. The World Health Organization (WHO) recommended maximum permissible limit for arsenic in drinking water to be 10 $\mu g\ L^{-1}$ (micrograms per litre). However, due to economic considerations most developing countries including India, still use the former WHO-recommended concentration of 50 $\mu g\ L^{-1}$ as their national standard (Ng et al., 2003).

Unlike other heavy metal pollutants such as mercury and lead, origin of arsenic in groundwater is geogenic that has been accentuated by anthropogenic perturbations. Two principal hypotheses about the origin of arsenic have been suggested. The first hypothesis suggests that the arsenic is derived from the oxidation of As-rich pyrite in the shallow aquifer as a result of lowering of water table due to over extraction of groundwater for irrigation. Arsenic is present in certain sulphide minerals such as pyrites that are deposited within the aquifer sediments (Smedley and Kinniburgh, 2002). Over withdrawal of groundwater lowers the water table below arseno-pyrite (FeAsS) deposits that gets oxidised in the vadose zone and releases arsenic as arsenic adsorbed on iron hydroxide. During subsequent groundwater recharge, iron hydroxide releases arsenic in groundwater. However, the main drawback of this hypothesis is the scarcity of source of arseno-pyrite and preservation of the sulphide mineral in the sediments during long transport (Fazal et al., 2001). A thorough search on Indian geology suggests that arseno-pyrite does not occur as an exclusive mineral deposit and present in small concentrations in base metal deposits. Moreover, the sediments of the Ganga Delta Plains had their provenance in the hills of North Rajmahal. It is highly unlikely that the long riverine transport and exposure to the atmosphere will preserve the sulphide minerals in the sediments. As an alternate hypothesis, it was suggested that arsenic was present in the ferric hydroxide coatings of the aquifer sediments under reducing conditions that got desorbed. The ferric hydroxide were either primary $Fe(OH)_3$ formed during diagenesis or secondary formed during the oxidation of pyrite (Ghosh and Singh, 2009). Irrespective of the exact nature of the source, it was ascertained that the quantity of arsenic present in groundwater (50–3200 μg/L) and adsorbed on the sediment (~8–18 ppm) are extremely large and have caused huge health implications in India and Bangladesh (Lowers et al., 2007).

In the rural affected areas of the GMB plain, besides drinking route exposure, the As contaminated groundwater, which is mainly used for irrigation purpose is also responsible for the entry of As in the food chain. Rice being a kharif crop, requires heavy rainfall for its cultivation. But during the dry season, the paddy cultivation is solely dependent on irrigation by groundwater in rural Bengal, since the sources of surface water regimes become dry during that period (Rahman et al., 2007). Prolonged use of As contaminated groundwater for irrigation practice in a particular land, results in a huge amount of As accumulation in the soil and eventually in the entire paddy plant via its root system. According to the translocation theory (Abedin et al., 2002; Liu et al., 2004), the As translocates and accumulates in paddy grains, which is the edible part of paddy. The grain is marketed either as raw or as sunned rice, which is directly prepared by hulling, or parboiled rice that is prepared by light boiling of paddy using contaminated water, followed by mechanical hulling to obtain parboiled rice. This post-harvesting treatments of the grain using As contaminated water causes additional increment of As in parboiled rice. According to a study, carried out in the fields of Deganga, North 24 Parganas, West Bengal, India, half boiled whole grain showed an increase of 43% in As concentration from that of raw whole grain, and a final increase of 61% was noticed in the full boiled whole grain. A concurrent increase of As concentrations in the water at half boiled and full boiled stages were also observed. An increase of 1.2% and 7.56% of As concentrations were found in half boiled and the full boiled water samples (Chowdhury et al., 2018, 2019). Such increment in As concentrations in the water samples after cooking of rice samples has been reported previously (Ohno et al., 2009). Besides the As contaminated groundwater used for drinking purpose, rural population is also exposed to a huge amount of As accumulating through different cereals and vegetables grown in the affected zones. This has been proved by observing the As concentrations in urine, hair and nail of the population exposed to As contamination in nine affected districts of West Bengal (Rahman et al., 2003).

Arsenic has several toxic effects on human bodies on short-term as well as long-term exposures. Biologically, the trivalent arsenite (As^{3+}) is significantly more toxic than the pentavalent arsenate (As^{5+}), including the ability to induce amplification of genes in mammalian cells. Once absorbed, As combines with haemoglobin rapidly and localises in blood within 24 h and then redistributes itself to various organs like the liver, kidney, lung, spleen and gastro-intestinal (GI) tract, with lesser accumulation in muscles and nervous tissue. After accumulation of a small dose of As, it undergoes methylation primarily in the liver to mono-methyl arsenic acid (MMA) and dimethyl arsenic acid (DMA), which are excreted along with the residual inorganic As in the urine (Kapaj et al., 2006). The most common species of inorganic As, As^{3+} and As^{5+} in the environment show their toxicity in different levels. After entering the cell, As^{5+} substitutes for phosphate in phosphorylation, which leads to the production of unstable arsenical by products like ADP-As^{5+}, which causes the disruption of ATP (adenosine 5-triphosphate) synthesis (Rosen et al., 2011). These unstable arsenical by products spontaneously hydrolyse to ADP and As^{5+}, preventing ATP production. Likewise, other metabolic processes like ATP-dependent transport, glycolysis, pentose phosphate pathway (PPP) and signal transduction pathways (two component and phosphor lay systems, chemotaxis etc.) are also disturbed. On the other hand, As^{3+} has a very strong affinity for sulphydryl groups (Silver and Phung, 2005). Arsenite reacts with cysteine groups and also glutathione, thioredoxin and glutaredoxin, which are present on the active sites of many enzymes, which control intracellular redox homeostasis, DNA synthesis and repair, sulphur metabolism, protein folding and xenobiotic detoxification. Arsine gas binds to red blood cells (RBC), causing haemolysis by damaging the membranes (Čerňanský et al., 2009). Besides, the use of As for a short period of time leads to acute toxicity while exposure for a longer period of time causes chronic toxicity, the symptoms of which are explained in details in Table 2.1.

To prevent further calamities associated with As toxicity, development of mitigation strategies for its remediation is extremely important and an absolute need of the hour (Purakayastha, 2011). Among several ways of remediation including physical processes like immobilisation, stabilisation etc. and chemical process like coagulation, co-precipitation, oxidation, ion-exchange etc., bioremediation (which includes phytoremediation and microbial remediation), is an emerging alternative and has good public acceptance (Lim et al., 2014). Phytoremediation, the use of green plants to remove or degrade contamination from soils and surface waters, has been proposed as a cheap, sustainable, effective, and environmentally friendly approach, alternative to the conventional remediation technologies (Raskin and Ensley, 2000). Phytoremediation is advantageous as this technique helps in treating a variety of contaminants over a diverse range of environment. Phytoremediation also does not require skilled technicians or highly expensive equipment, making it easier to implement. There are various mechanisms of phytoremediation like phytoextraction (which includes phytoaccumulation, phytosequestration and phytoabsorption), phytostabilisation or phytoimmobilisation, phyto-volatilisation, phytodegradation and

Table 2.1 Types of arsenic toxicity and its symptoms

Type of toxicity	*Symptoms*
Acute toxicity	Gastrointestinal (GI) signs: Vomiting (often with blood) and severe cholera like diarrhoea (may be with blood or rice-water like); dehydration and hypovolemic shock.
	Cardiovascular effects: Myocardial dysfunction, ventricular dysrhythmias, diminished systemic vascular resistance, capillary leakage.
	Central nervous system (CNS) manifestations: Seizures, encephalopathy, coma and cerebral oedema.
	After an acute poisoning Alopecia and Mees lines might occur subacutely.
Chronic toxicity	Manifests as a classic dermatitis (hyperkeratosis, 'dew drops on a dusty road' appearance), peripheral neuropathy (usually painful, symmetrical paresthesia with stocking-glove distribution), Melanosis, Keratosis, Arsenicosis.
	Hepatic and renal damage (multi-organ involvement).
	Obliterative arterial disease of lower extremities (blackfoot disease).

(Chakraborti et al., 2004)

phytofiltration (Akhtar et al., 2013; Yadav et al., 2018). Bioremediation by microbes (bacteria, fungi, yeast, algae) is an effective method, which is mainly concerned with the use of natural or engineered microbes which are capable of oxidizing, reducing, volatilising or immobilising As through bio-sorption, bio-methylation, bio-stimulation, bio-augmentation, complexation and siderophore-based amelioration (Lievremont et al., 2009). It is advantageous because it includes simple, natural processes, which are highly specific, less expensive, can be carried out on site, as well as causes complete degradation of a wide variety of contaminants (Leung, 2004).

4 Fluoride

Fluoride, an inorganic pollutant of natural origin, is an essential element required in minute quantity (0.5 mg/L) for the formation of dental enamel and mineralisation of bones of human beings. The main source of fluoride contamination of groundwater is geo-chemical in origin and it causes toxicity when ingested in higher doses (Bell and Ludwig, 1970). The tolerance limit of fluoride in drinking water as specified by WHO is 1.5 mg/L. Fluorosis has affected about 70 million people in 25 countries globally and has been reported in 62 million people drinking fluoride contaminated drinking water in India (Kannan and Ramasubramanian, 2011). In the states of Delhi, Rajasthan, Uttar Pradesh, Gujarat, Punjab, Haryana, Bihar, Orissa, Madhya Pradesh, Jammu and Kashmir, Himachal Pradesh, Andhra Pradesh, Tamil Nadu, Kerala, Maharashtra and Karnataka, high concentrations of fluoride (>1.5 ppm) have been reported (Susheela, 2001). Fluoride was first detected in India, in Nellore, Andhra Pradesh in 1937 (Shortt et al., 1937). The concentration of fluoride in groundwater depends on the physical, chemical and geological characteristics of the aquifer, the acidity and porosity of the rocks and soil, temperature and the depth of wells. Due to these large number of variables, the range of fluoride concentrations in groundwater varies from under 1.0 mg/L to >35.0 mg/L (WHO, 1984).

The primary anthropogenic sources of fluoride include fertilisers, combusted coal and industrial waste with phosphate fertiliser (Farooqi et al., 2007). However, fluoride may enter into human body systems through water, food, cosmetics (like toothpaste), drugs and medicines (containing NaF), organofluoride compounds like Freons (CFC, Teflon) etc. (Hiyama, 2013). Groundwater is primarily contaminated due to weathering and leaching of F^- containing minerals present in the rock bed which act as potential geogenic source of fluoride (Handa, 1975; Edmunds and Smedley, 2005; Sreedevi et al., 2006). The most common rock forming mineral containing fluoride is CaF_2 as it is abundantly available on the earth's crust. Moreover, since fluoride ions (F^-) and hydroxyl ions (OH^-) are both negatively charged and have the same ionic radius, F^- can easily replace OH^- in most of the rock forming minerals. According to one hypothesis, the main reason behind the leachability of F^- from the minerals containing fluoride is the production of carbonate ion (HCO_3^-) in the soil. Occurrence of carbonates and bicarbonates in the soil is due to formation of CO_2 from weathering of common rock forming minerals. This CO_2 reacts with rainwater to form carbonate ion.

$$CO_2 + H_2O = H_2CO_3$$

$$H_2CO_3 = H^+ + HCO_3^-$$

$$HCO_3^- = H^+ + CO_3^{2-}$$

This alkaline water may be able to mobilise fluoride from its minerals like CaF_2.

$$CaF_2 + 2HCO_3^- = CaCO_3 + 2F^- + H_2O + CO_2 \left(\text{Handa, 1975; Banerjee, 2015}\right)$$

The primary mechanism of fluoride toxicity begins with the binding of fluoride with calcium ions leading to hypocalcaemia, further leading to osteoid formation. On binding with Ca, it disrupts glycolysis, oxidative phosphorylation, coagulation and neurotransmission. It may lead to hyperkalemia due to extracellular release of potassium by inhibiting Na^+/K^+ ATP-ase. Fluoride may further lead to hyper salivation, vomiting and diarrhoea by inhibiting cholinesterase (Chouhan and Flora, 2010). Fluoride, being highly electronegative has affinity towards uracil and amide bonds, thus damaging the structure of DNA leading to genotoxic effects (Li et al., 1987; Dhar and Bhatnagar, 2009). It also suppresses the activity of enzymes like DNA polymerase, affecting replication and repair (Aardema and Tsutsui, 1995). Fluoride concentration within the range of 0.5–1.5 mg/L prevents tooth decay, but above 1.5 mg/L, it has adverse effects on health as described in details in Table 2.2.

Fluorosis is the pathological condition that arises due to long-term exposure of elevated levels of fluoride. Dental fluorosis results in porous and opaque enamel resembling white chalk colour instead of the normal creamy white translucent

Table 2.2 Adverse health effects of different fluoride concentration ranges

Concentration of fluoride (mg/L)	*Adverse health effects*
1.5–4.0	Dental fluorosis
4–10	Skeletal fluorosis
>10	Crippling fluorosis

colour. The enamel and dentin become structurally weak and prone to breakage with deposition in the roots of the teeth or the pulp chamber giving rise to yellowish spots, specks and blotches with brown pits (Dhar and Bhatnagar, 2009). Skeletal fluorosis mainly leads to increase of bone density, brittleness of bones, rheumatic pain, arthritis in bones and muscles with bending of the vertebral column due to fluoride uptake of 4–8 mg/L. This is followed by sporadic pain, stiffness of joints, headache and weakness of muscles (Ghosh et al., 2013). Fluoride, on long-term exposure causes neurological damage especially in children resulting in crippling fluorosis, which leads to an irreversible and hopeless state of disorder, which further results in loss of work and livelihood, social aloofness and loss of will to live due to inability to meet high medical costs (Mullenix et al., 1995; Guan et al., 1998). Therefore, it can be said that fluoride if not ingested in the right proportion, can take the shape of a widespread threat to the people worldwide.

Various mechanisms of removal of fluoride from groundwater have been reported of which, coagulation (Reardon and Wang, 2000), ion exchange (Singh et al., 1999), adsorption (Raichur and Basu, 2001), precipitation, membrane technology (like reverse osmosis) are common. For adsorption, activated carbon, silica gel, calcite and alumina are mainly used as adsorbents. It is a very cost-effective method and can remove fluoride with upto 90% efficiency (Muthukumaran et al., 1995; Yang et al., 1999). In coagulation, fluoride ions in the water are precipitated by limewater ($Ca(OH)_2$).

$$\mathrm{CaO} + \mathrm{H_2O} = \mathrm{Ca(OH)_2}$$

$$\mathrm{Ca(OH)_2} + 2\mathrm{F^-} = \mathrm{CaF_2} + \mathrm{H_2O}\ (\text{Azbar and Türkman, 2000})$$

In Nalgonda method, F^- contaminated water on treatment with alum and lime slurry, results in flocculation, which is then followed by sedimentation and filtration.

$$\mathrm{Al_2(SO_4)_3 \cdot 18H_2O} = 2\mathrm{Al^{3+}} + 3\mathrm{SO_4^{2-}} + 18\mathrm{H_2O}$$

$$2\mathrm{Al^{3+}} + 6\mathrm{H_2O} = 2\mathrm{Al(OH)_3} + 3\mathrm{H^+}$$

$$\mathrm{Ca(OH)_2} + 2\mathrm{H^+} = \mathrm{Ca^{2+}} + 2\mathrm{H_2O}$$

$$\mathrm{Al(OH)_3} + \mathrm{F^-} = \mathrm{Al-F}\ (\text{complex})$$

$$Ca(OH)_2 + F^- = CaF_2 \text{ (Parker, 1975; Meenakshi and Maheshwari, 2006)}$$

By ion-exchange process, fluoride can be removed from water by a strongly alkaline anion-exchange resins with ammonium ion and the reaction takes place as follows (Meenakshi and Maheshwari, 2006):

$$\text{Matrix} - NR_{3+}Cl^- + F^- \rightarrow \text{Matrix} - NR_{33+}F^- + Cl^-$$

Besides, defluoridation of groundwater can be done by several ways like chemical, electrode and solar defluoridation. In chemical defluoridation, calcium chloride ($CaCl_2$) reacts with Na_2HPO_4 to produce TCP (tri calcium phosphate). This TCP reacts with F^- to form a strong chelate, hence separating the F^- from water (Zhang et al., 2011). In electrode defluoridation, direct current is passed through F^- contaminated water resulting in anodic dissolution of aluminium, producing poly aluminium hydroxide (nAl$(OH)_3$), which on reaction with F^- produces Al-F complex, followed by sedimentation and filtration (Mameri et al., 1998). Solar defluoridation follows the same principle as the previous one, except for the use of photovoltaic cells (PVC) instead of passing current through fluoride contaminated water (Andey et al., 2013).

5 Fossil Fuel and Mining

Fuel formed by natural processes from the remains of dead organisms (such as oil and natural gas) and plants (such as coal) through anaerobic decomposition are collectively termed as fossil fuels. Typically, it takes millions of years to form fossil fuel from the biomass. In spite of continuing formation of fossil fuels, they are considered non-renewable resources as humans are rapidly depleting the viable reserves and it takes millions of years to form new reserves.

The environmental impacts of fossil fuel mining and combustion are multifarious. Fossil fuel combustion produces the most important greenhouse gas carbon dioxide (CO_2) along with nitrogen oxides, sulphur dioxide (SO_2), volatile organic compounds (VOCs), particulate matter (PM) and heavy metals. While CO_2 is the key component in global temperature rise, nitrogen oxides and SO_2 cause acid rain, VOCs and PM cause health effects such as asthma, respiratory diseases etc. Carcinogenic heavy metals such as arsenic, cadmium and chromium are emitted from fossil fuel combustion and adhere to the breathable and respirable size fraction of PM. The respirable size fraction, $\leq PM_{2.5}$ are readily trapped by the alveoli of the lungs and mixes with the blood stream (Dockery and Pope, 1994). Particulate-bound transition metals are known to generate reactive oxygen species (ROS) within cells through Fenton and Haber Weiss reactions (Betha et al., 2013). Evidences indicate that ROS is the key player in normal cell signal transduction and cell cycling. Mercury is a by-product of coal combustion (Sun, 2019) and gets deposited in the environment after emission. Inorganic mercury is converted to methyl mercury, known to be a neurotoxin by sulphate reducing bacteria under anaerobic conditions that bioaccumulates and biomagnifies in food chain (Benoit et al., 1999).

Coal (and minerals, metals and gemstones) are mined and extracted from the earth. Mining generates large amount of wastes that are discharged in the environment. Mining is of two types: surface mining and underground mining. During surface mining, the covering vegetation and if necessary, layers of bed rocks are removed. Surface mining causes loss of biodiversity, erodes the soil, reduces the fertility, alters landscape and generates huge quantities of wastes called tailings. Tailings are generally toxic and produced as slurry and are commonly dumped into water bodies polluting the water and destroying the biota. Besides the above-mentioned environmental hazards acid mine drainage (AMD) in some instances is the primary pollutant of surface water. According to United States Environmental Protection Agency (US EPA), in the mid-Atlantic region AMD degraded >4500 stream miles destroying aquatic life and restricting stream use for recreation and public drinking water purpose. AMD is highly acidic water with elevated levels of dissolved metals drained from surface or deep coal or metal mines and coal refuse piles. When sulphide minerals such as pyrite (FeS_2) come in contact with air or water, they get oxidised to sulfuric acid (H_2SO_4) and acidify groundwater and nearby surface water, which in turn solubilise metals. The overall reaction involved in the formation of AMD is as follows:

$$4FeS_2 + 15O_2 + 14H_2O = 4Fe(OH)_3 + 8H_2SO_4$$

Precipitation of ferric hydroxide causes bright orange colour to water and rock. AMD can be treated either through chemical treatment such as by calcium oxide (CaO) or anhydrous ammonia or by passive treatment through creation of limestone channel or wetlands. CaO is alkaline in nature and increases the pH of AMD. This causes many of the metals to precipitate as carbonates and hydroxides. Ammonia is a strong base and once injected into AMD reacts rapidly and increases the pH. Often AMD is treated in free-flowing channel lined with coarse limestone that precipitates metals and adds alkalinity to the water. Wetlands act as natural sinks of metals. The dense plant root system catches the suspended solids and flocculated particles as they pass through the wetlands. However, the best method to treat AMD is prevention. This can be done by using proper reclamation method, which prevents air and/or water from reaching the pyrite material.

Hazards are associated with oil and gas exploration, storage and combustion. During oil drilling, there are risks of blowouts, encountering unanticipated high overpressure, drill pipe and hole shearing by mobile salt etc. When crude oil is released uncontrollably or accidentally an oil well blowout occurs. During the blowout even a small spark coming in contact with the oil can lead to catastrophic disasters. Sometimes the weight of the overlying sedimentary rocks along with the interstitial pore fluids exert enormous pressure and result in compaction of the oil-bearing formation. Unless there exists a communication with the surface, this situation results in unanticipated high overpressure in the oil-bearing formation and can cause a well to blow out or become uncontrollable during drilling. The enormous pressure of rock formations around an oil reservoir is counteracted by the use of mud around the drilling site, which helps to balance the hydrostatic pressure. If this balance is upset, water, gas or oil can infiltrate the wellbore or even the drill itself and this can quickly escalate into a blowout if not promptly identified and addressed. To manage such an infiltration, the drill entry point is immediately isolated by closing the well. A heavier fluid is injected to reach a balance by increasing the hydrostatic pressure. Ultimately, the infiltrated fluid or gas is evacuated in a controlled and safe manner. Salt formations encountered during drilling operations pose a serious threat. Salt is an exceptional rock as it flows by creep in the subsurface (Weijermars et al., 2014). The load-factor tolerance and drag forces of wellbore casing is carefully calculated using a range of salt viscosities and creep rates. Before designing a well casing passing through salt, the probable range of creep forces of moving salt needs to be considered when calculating safety margins and load-factor tolerance of the well casing.

The largest hazard during transportation and storage of oil is the oil spill, which is the release of liquid petroleum hydrocarbon into the marine ecosystem due to human error. Oil spill on land can also occur. Crude oil can be spilled from drill rigs, offshore platforms, tankers etc. Spill can also occur from refined petroleum products such as gasoline and diesel and heavier fuels such as bunker fuels used by large ships. Till date, the most disastrous oil spill was off the coast of Alaska in 1989. This occurred when Exxon Valdez, an oil tanker owned by Exxon Shipping Company, hit an underwater reef (Prince William Sound's Bligh Reef) at midnight and spilled millions of gallons of crude oil and is considered one of the worst human-caused environmental disasters. Due to the remoteness of the location, clean-up efforts were delayed. Three decades after the oil spill, Prince William Sound appears to have recovered on the surface, but digging a shallow hole into certain Alaskan beaches brings up oil to the surface. Oil penetrates into the mammalian fur and bird feathers, reducing their buoyancy in the water, insulating ability and making them more vulnerable to temperature fluctuations. During preening, the oil on skin and feathers is ingested and affects the liver function and causes kidney damage.

Cleaning an oil spill is a humongous effort and depends on the accessibility of the spill site, type of oil spilled, the temperature of the water etc. Physical clean ups of oil spills such as vacuum and centrifuge method, dredging, beach raking can be expensive. Instead bioremediation with the bacteria such as *Alcanivoraxor* and *Methylocella silvestris* have proved to be helpful in breaking down and removing oil.

6 Landslide

Landslide is the movement of a mass of rock and debris along a hill slope under the direct influence of gravity. In most cases, landslides are triggered by natural causes such as earthquake, volcanic eruption, forest fire, excessive rainfall and weathering and erosion of the rocks that make up the hill slope. However, human causes can also trigger landslides.

Mining, deforestation, clear cutting, land use, water management and vibration are some of the human-induced causes of slope failure. Vibrations emanating from blasting activities during mining can weaken soils in areas susceptible to landslides. During timber harvesting along a slope, old trees are cleared that decimates the existing root structure that binds the soil and prevents weathering. Most of the landslide occurs during or after heavy rainfall. Heavy water laden slopes readily succumb to the forces of gravity. Hence, water supply and wastewater drainage patterns need to be carefully designed for heavily built towns on hill slope to prevent future landslides.

The best way to manage landslide is to prevent it from destroying properties and lives. Before construction on hill slopes, soil type analysis and ground assessment should be done for the property to determine how susceptible it would be to ground movements. If the area is prone to past landslides, chances are high for future occurrences. Such areas should be avoided. Planting trees and vegetation help stabilise soil on slopes. In many cases, there are structural deformation symptoms before a land slide. Close monitoring of such occurrences such as tilting of fences, utility poles or trees, seepage of groundwater in new locations, ground bulging at the base of the slope, new cracks developing in bricks, plasters and foundations can hint towards slope instability and eventual failure.

7 Volcanoes

Although volcanic eruptions are more predictable than earthquakes, there is very little if anything that man can do to prevent or alter the hazardous events happening. Some of the hazards associated with volcanic eruptions are volcanic earthquakes, directed blast, tephra, volcanic gases, lava flows, pyroclastic flows and lahars.

Earthquakes are caused by stress changes in solid rock due to injection of magma into surrounding rocks. Volcanic activity related earthquakes can produce ground cracks, ground deformation and damage to manmade structures. During a volcanic eruption, the rock fragments that are ejected into the atmosphere are called tephra. How far the tephra will travel away from a volcano depends on the height of the eruption column, air temperature, wind direction, speed etc. Tephra produces a wide range of hazards. The electrically charged ejected material often produces lightning in the atmosphere and there are reports of human casualty by lightning from volcanic eruption clouds. Ballistically shot large tephra from the volcano can hit people and cause injury and death and cause property damage. Tephra can damage crops and cause famine. After the eruption of Tambora, Indonesia in 1851, that ejected 151 km^3 of ash into the atmosphere, 80,000 people died due to famine. The fine particles of the pyroclastic flow, the ash, have multifarious hazards. Ash fall can disrupt electricity and telephone communication lines, bury roads, start fires, clog drainage and sewage systems. Ash can trigger respiratory problems and decreases visibility.

Accumulation of ash on the roof of flat-topped buildings lead to roof collapse. An erupting volcano releases water vapour and gases into the atmosphere. The gases include carbon dioxide (CO_2), sulphur dioxide (SO_2), hydrochloric acid (HCl), hydrogen fluoride (HF), hydrogen sulphide (H_2S), carbon monoxide (CO), hydrogen gas (H_2), ammonia (NH_3), methane (CH_4) and silicon tetrafluoride (SiF_4). These gases when leached from the atmosphere produce acid rain. Lava flows are the least hazardous of all processes in volcanic eruptions because they do not move very fast decreasing chances of human casualty. The distance a lava flow will travel depends on the flow temperature, viscosity of the lava that depends on silica content, extrusion rate and slope of the land. For example, a cold lava flow will not travel far and neither will one that has a high silica content. On the contrary a basalt flow like those in Hawaii have low silica contents and low viscosities so they can flow long distances. The primary hazard of lava flow is property damage. The Hawaiian town of Kalapana was destroyed by lava flows in the 1980s. Lava flows buried cars and burnt homes and vegetation. Electricity and water connections were cut off from the community. Pyroclastic flows and lahars are the greatest volcanic hazards. More people have died due to these hazards than any other volcanic hazard. When the rock masses erupted from a volcano mixes with water and discharged gas, they become fluidised and move downhill in response to gravity. Pyroclastic flows can burn and destroy manmade structure and vegetation. When pyroclastic flow mixes with excess water they form lahars. During 1991 Mount Pinatubo eruption, the pyroclastic flows transformed into lahars as they moved along river valleys.

People living in arears close to volcano relies on the monitoring network. The United States, Italy and Japan are the leaders in this field. For example, the 1991 Pinatubo eruption at Philippines could be precisely predicted by USGS due to increasing SO_2 emission and accordingly areas close to the summit were evacuated. After an eruption, the ash stays in the air and environment for long. To prevent breathing of volcanic ash and fumes, people wear masks with filters or place wet cloth over their nose and mouth. Past old pyroclastic flow deposits are likely places of new flow trajectories if the volcano erupts. Hence, it's advisable to avoid habitation building on old pyroclastic flow paths.

Several methods such as building retention basins, tunnels, concrete structures etc. have been used to stop or detour lahar flows. However, very often they have succumbed to the furious nature. Like most other disaster management strategies, the best preventive measure is to establish a warning system with seismometers to detect a signal as lahars move down the valleys.

8 Earthquakes

Earthquake is sudden rapid shaking of the ground surface. Ground shaking can occur due to several reasons. The most common and widespread are the movements along tectonic plate boundaries. The earth's crust is composed of seven large lithospheric plates and numerous smaller plates. The continuous movement of the tectonic plates cause built up of pressure along the plate boundaries. When stress is sufficiently great it is released in a sudden jerky movement resulting in seismic waves that propagate through the ground to the surface and cause the ground to shake. Earthquakes caused by plate tectonics are called tectonic quakes. Earthquake can also occur due to active volcanism or caused by human activity. Volcanism-related earthquakes are not as powerful as tectonic quakes with shallow hypocentre and they are generally felt in the vicinity of the epicentre. Human activities or errors such as tunnel construction, dam failure etc. can cause ground shaking however they are not as intense or wide spread as tectonic earthquakes.

Disaster related to earthquake can cover hundreds of thousands of square kilometres. The ground shaking causes structural damage, loss of life and injury to innumerable people. In summary, one severe earthquake can disrupt the social and economic structure of the affected area. For example, on 26th December 2004, an earthquake measuring 9.3 on the Richter scale in the Indian Ocean caused severe damage to Banda Aceh, Sumatra. The damage was not because of ground shaking but generation of tsunami waves that killed at least 230,000 people from >10 countries around the Indian Ocean including Indonesia, Sri Lanka, India and Thailand. It is impossible to prevent earthquake; however, it is possible to mitigate the effects and to reduce loss of life, injuries and damage. Community awareness and participation through earthquake drills and public awareness programs are the first steps in earthquake mitigation. Japan is considered to be the leader in earthquake disaster management as it sits on one of the most seismically active plate boundaries of the earth. All buildings in Japan are required to have an earthquake resistant structure. For example, skyscrapers abide by strict building codes that rest on Teflon to allow the building foundation to slide ever-so-slightly during a tremor. Aftermath of earthquakes are managed by Japan Medical Association Teams and Disaster Medical Assistance Teams and work round the clock over a broad area during the initial 72 h that is considered as the golden hour to save life and trapped people under collapsed structure. Besides providing medical assistance in the affected areas, critical patients are air lifted from the disaster areas and transported to nearby medical centres. As for tsunamis, steps have been taken in the Pacific to establish a warning system as tsunamis have a unique wave frequency.

There has been increasing efforts to predict an earthquake to minimise the loss of lives and properties. An earthquake does not happen all of a sudden, instead they tend to form a complex network of interacting faults. Close monitoring of seismic activities on the fault network can lead to successful earthquake prediction. For example, in Indonesia, Neural Network for Earthquake Prediction Based on Automatic Clustering for earthquake prediction is used to closely monitor motion at plate boundaries. In spite of continued efforts, earthquakes are much less predictable than volcanic eruptions.

9 Radon Exposure

Radon (Rn) is a colourless and odourless gas produced as an intermediate short-lived product during radioactive decay of uranium (U) and thorium (Th) to lead (Pb). The three radioactive isotopes ^{238}U, ^{235}U and ^{232}Th decay to ^{206}Pb, ^{207}Pb and ^{208}Pb with half-lives of 4.468 billion years, 704 million years and 14 billion years. During these decay reactions, radon is produced as short-lived intermediate product. Radon itself is the immediate decay product of radium. The most stable radon isotope is ^{222}Rn with a half-life of only 3.8 days. However, as uranium and thorium are two most abundant radioactive elements in the earth's crust with long half-lives, radon is continuously produced. International Agency for Research on Cancer labelled radon gas as carcinogenic to humans. After inhalation, radon emits radiation that damages the inside of our lungs and increases the risk of lung cancer (Field et al., 2000).

In this section, we will discuss natural accumulation of radon in buildings and occupational health hazard of miners from radon exposure. Radon emission will depend on the bedrock nature. For example, igneous and metamorphic rocks such as granite, gneiss and schist have high concentrations of uranium and thorium as compared to limestone. Hence, buildings built on granitic or schistose bed rock or used as building materials will have more radon exposure. Entry points of radon into buildings are through cracks in solid foundations and walls, cavities inside walls etc. Ground floor and basement are most affected. Radon accumulation can vary from one room to the other in the same floor and building and can change with wind conditions and atmospheric inversion. Commercially available radon testing kits are easy to use and cheap and are recommended to use before purchasing a house particularly with basement. The kit includes a collector that the user hangs in the lowest habitable floor of the house for 2–7 days. As the half-life of radon is only 3.8 days, the gas built up can easily be mitigated by improving ventilation system of the house. In the 1940s and 1950s, miners in uranium and other hard rock mines were exposed to radon and reports of lung cancer among non-smoking miners poured in from Czech Republic, Australia and United States. Since then mining conditions have been improved by redesigning the ventilation system, and in the present-day radon gas levels inside uranium mines have fallen to levels similar to the concentrations inhaled in some homes.

10 Conclusions

The estimated growth of world population is >90 million per year, of which 93% is in developing countries. The ever-increasing demands for food, space and better living conditions cannot be supported by the earth's natural resources without degrading human life quality. With the growing population, there will be growing need for land, food, freshwater, fossil fuel and industrial growth. To provide food, existing agro system will need more fertilisers and pesticides for better yield further polluting the environment. Excessive use of groundwater for drinking and agriculture are depleting water table and causing water pollution. Treated surface water should be explored as an alternative source. Finding alternate sources of energy to generate electricity has become a mandate in the present world. To reach the global warming goal of well below 2 °C as set by the Paris Agreement, decreased emission of greenhouse gases from industries and vehicle exhausts is required. Land clearing for agriculture and mining degrades ecosystems, leads to extinction of thousands of species and de-stabilises natural ecosystems. Natural disasters such as volcanic eruptions and earthquakes are unavoidable. A large part of the earth's population lives in seismically active zones and around active and dormant volcanoes. These people rely on prediction networks for evacuation and general preparedness post an earthquake or volcanic eruption to handle the aftermath. In summary, a sound knowledge of the science behind the natural and human induced environmental disaster is essential to better understand the causes, deal with the crisis and find mitigation ways to alleviate the lives of tens of thousands of people affected by the situation.

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