IJAAR PUBLISHING®

Engineering Research Journal | ISSN: **2782-8212**
Vol. 3, Issue 9 (September, 2023) | www.ijaar.org/erj

# INDUSTRIAL WASTES: REVIEW OF SOURCES, HAZARDS AND MITIGATION

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## Abstract

*Industrial wastes are unwanted materials generated by human activities in various industries such as mining, contract on, petroleum and metal/food processing. Industrial wastes may be classified on the basis of nature as solid, liquid and gaseous wastes; on the basis of pollution characteristics as hazardous and non hazardous wastes; and on the basis of industrial sector / processes as mine wastes, construction wastes, petroleum/petrol chemical wastes, brewery pharmaceutical wastes; and metallurgical wastes. Hazardous industrial wastes are those wastes that could be harmful or have the potential to be harmful to the health of humous, other organisms or the environment, and requires special precaution in its collection, storage, transpiration, treatment and/or disposal to prevent damage to persons, properties or other organisms. Generally, industrial hazardous wastes have one or more of the following identifiable characteristics, namely: flammable, reactive explosive, corrosive and toxic. Some examples of industrial hazardous wastes and their sources/health hazards include: particulate and acid mine drainage (associated with mine wastes due to coal mining may cause black lung cancer, and water pollution, respectively); drilling mud waste from petroleum crude production may cause pollution of water bodies and land, and hence affect human / aquatic life and land usage; and CO/CO2 , NH3 and H2S associated with gaseous wastes of petroleum crude refinery/processing may contribute to climate change, pollution of surrounding air as well as being toxic to humans). The mitigation measures concerning the generation of industrial hazardous wastes and reduction of their health hazards include: waste minimization; waste recovery and reuse; and waste treatment and disposal.*

**Keywords**: Industrial wastes, hazardous wastes sludge, tailings, gaseous wastes, waste water, pollution, health hazards.



Published *30/09/2023*
Ezeala, H.I., Okeke, O.C., Amadi, C.C., Irefin, M.O., Okeukwu, E.K., Dikeogu, T.C. & Akoma, C.D. (2023). Industrial Wastes: Review of Sources, Hazards and Mitigation. *Engineering Research Journal*, 3(9), 1-26.

## 1.0 Introduction

Industrial wastes are unwanted materials generated by human activities in various industries including mining, construction, petroleum (production and refinery) metal fabrication, food processing and chemical plants (Mekeonnen and Hoekstra, 2016; Etim, 2003). These industrial wastes that may exist as solid liquid and gaseous are one of the most harmful pollutants and if unmanaged adequately may lead to environmental pollution (Hoormweg and Bhada-Tata, 2012; Irefin et al, 2023). Industrialization is generally the leading agent for development as it contributes to economic growth and human welfare. However, the ever-increasing industrial activities generally lead to environmental pollution, especially when the wastes associated with the industrial activities are not properly managed (Firdissa and Soromessa, 2016; Okeke 2000; Watts et al., 2023).

These toxic and hazardous substances generated from these sources can either be purposeful or accidental thereby contaminating the land, air and water (Enger and Smith 2004). The potential health effects of these substances range from minor, short term discomforts, such as headaches and nausea to serious health problems, such as cancers and birth defects (that may not manifest themselves over years), to major accidents that cause immediate injury or death.

According to Roger et al., (1989), proper control of hazardous wastes does cost money, but experience in a number of developed countries suggests that cleaning up the “sins of the past” is much more expensive in the long term. Studies on types of industrial wastes, their impacts and management challenges are not yet adequately discussed. Thus, knowledge of hazardous impacts from industrial effluent on humans and the surrounding environment is very limited (Sima and Restiani, 2018). In addition, it is therefore important to reduce and minimize generation of wastes and develop pollution control measures required to mitigate further contamination of the environment (Teku, 2006; Teklu, 2012).

## 2.0 Sources and Classification of solid wastes

### 2.1 Overview

Industrial wastes may be classified on the basis of nature as solid, liquid and gaseous wastes; on the basis of pollution characterizes as hazardous and non-hazardous wastes; and on the basis of industrial sector/processes as mine wastes, construction wastes, petroleum / petrochemical wastes, food processing/pharmaceutical wastes (Fig 1) (Abiahee et al, 2019; Irefin et al 2023; Okeke, 2000; Kanagamani et al., 2020). Hazardous industrial wastes are those wastes that could be harmful or have the potential to be harmful to the health of humans, other organisms or the environment, and require special precaution in its collection, storage, transportation, treatment and/or disposal to prevent damage to persons, properties or other organisms (Henry and Heinke, 1996).

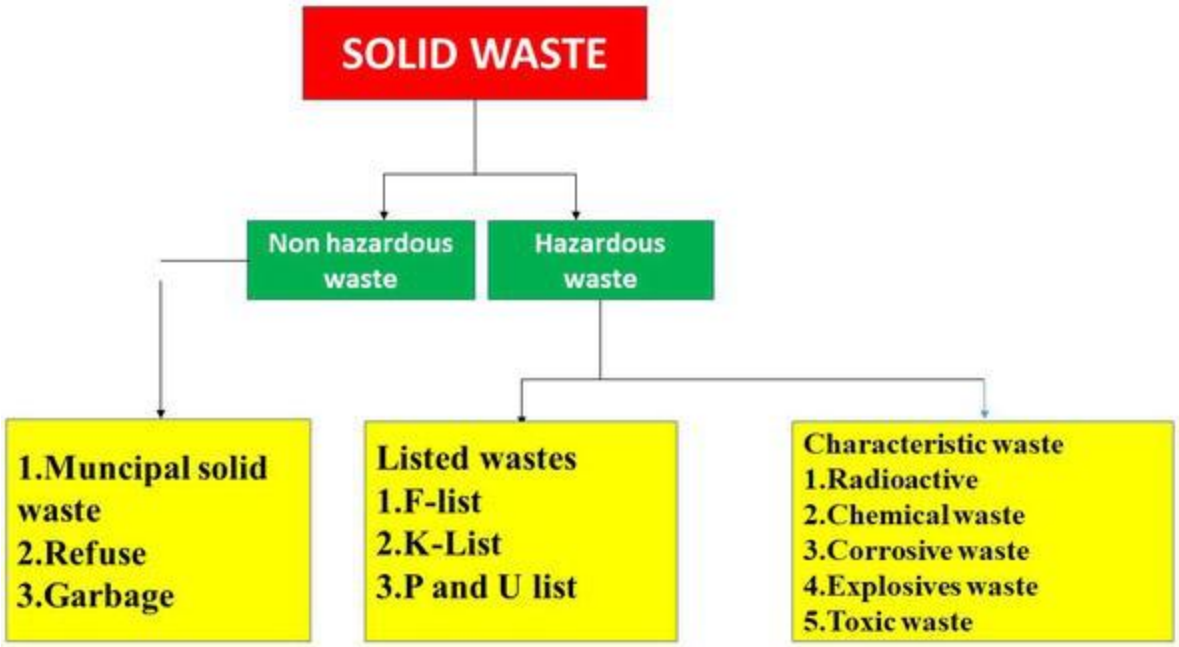



**Figure 1: Classification of solid waste (Kanagamani et al, 2020**).

### 2.2.1 Classification of hazardous waste

Waste characterization is a critical step in determining how a waste should be handled in bulk or in packaged form (Papoutsis et al., 2020). The United States Environmental Protection Agency (USEPA) revealed the following designated list of priority chemicals as hazardous wastes (USEPA, 2005):

i. F-list: This list has to do with hazardous waste generated from non-specific point sources, that is, numerous processes in the industry that led to the generation of the wastes. Examples include solvents used in degreasing, sludge and metal treatment, wastewaters from metal industries and dioxin that contains chemicals.

ii. K-list: This list contains hazardous waste generated by particular industrial processes. Examples include chemical production, pesticide production, explosive manufacturing, etc.

iii. P and U lists: Discarded chemical products, off-specification chemicals, residue from the spillage of materials, and container residues make up this list.

### 2.2.2 Characteristics of hazardous waste.

There are four basic characteristics to look at; ignitability, corrosivity, reactivity, and toxicity (Needleman, 1994).

**2.2.2.1 Ignitability** – According to the (USEPA 2005), "Ignitable wastes can create fires under certain conditions, are spontaneously combustible, or have a flash point less than 60 °C (140 °F). Examples include waste oils and used solvents." A flash point is the lowest temperature at which a substance can evaporate enough to produce sufficient vapor to form an ignitable mixture with the air. Ignitable wastes can be broken down into two categories, solids, and liquids. As stated above, flash point is the most important things to remember when it comes to ignitable liquids. You have to consider other things with solids though. Non liquid ignitables are capable under standard temperature and pressure of causing fire through

friction, absorption of moisture, or spontaneous chemical changes. If ignited, these wastes will burn so vigorously and persistently that they create a hazardous situation.

**2.2.2.2 Corrosivity** – According to the (USEPA 2005), "Corrosive wastes are acids or bases (pH less than or equal to 2, or greater than or equal to 12.5) that are capable of corroding metal containers, such as storage tanks, drums, and barrels. Battery acid is an example." A corrosive can cause skin damage to people and significantly corrode metal. A corrosive hazardous material can be either liquid or solid.

**2.2.2.3 Reactivity** – The (USEPA 2005) defines reactive wastes as, "wastes [which] are unstable under "normal" conditions. They can cause explosions, toxic fumes, gases, or vapors when heated, compressed, or mixed with water. Examples include lithium-sulfur batteries and explosives." Reactive wastes are, in themselves, unstable. They have the potential to form toxic gases, vapors, or fumes which can endanger human health. Some (D003) form potentially explosive mixtures with water. Reactive wastes are capable of detonation or explosive reactions.

**2.2.2.4 Toxicity** – Toxic wastes are defined by the (USEPA 2005) as wastes that are "harmful or fatal when ingested or absorbed (e.g., containing mercury, lead, etc.). When toxic wastes are land disposed, contaminated liquid may leach from the waste and pollute ground water."

## 2.3 Sources of hazardous wastes and their effects on the environment.

There are two (2) major sources of industrial waste pollution and they can be classified as primary sources and secondary sources of industrial waste pollution (Olufunke et al., 2023). The primary source of pollution includes the activities of man from a mere food gatherer and an agriculturist and lately, an industrialist have affected the environment in no small measure while secondary source of industrial waste pollution is not unconnected to the primary source just explained above, they include: industrialization, toxic waste and urbanization etc.

Most Industrial wastes are hazardous, composed of a wide range of materials with varying environmental toxicity. They typically include paper, packaging materials, waste from food processing, oils, solvents, resins, paints and sludge's, glass, ceramics, stones, metals, plastics, rubber, leather, wood, cloth, straw, abrasives etc. and not limited to Agricultural and agro industrial products.

Industrial waste generation varies, not only between countries at different stages of development but also between developing countries, Table 1 shows the widespread distribution of hazardous wastes to which many sectors of the economy are victims of hazardous wastes whether directly or indirectly. The reason behind the increase in environmental depletion is because so many industries in the developing countries lacks the capacity and capability to properly handle these wastes thereby resulting to indiscriminate disposal as the only way to avoid cost and producers associated with proper management.

**Table 1: Some hazardous wastes sources (Modified from Roger et al., 1989).**

| Sector | Source | Hazardous Wastes |
|---|---|---|
| Agricultural land and agro-industry. | Farms, crops, orchards, vineyards, dairies, feedlots. | Pesticides, fertilizers and hazardous veterinary product waste, spoilt foods, agricultural wastes. |
| Health care centers | Hospitals, clinics and medical laboratory. | Pathological wastes, infectious needles, contaminated blood. |
| Commercial wastes | Gasoline stations, dry cleaners and automobile repair and servicing shops (workshops), airports, municipal parks, electrical transformers. | Waste oils, hydraulic fluids, halogenated solvents, polychlorinated biphenyls. |
| Petroleum/ petrochemical wastes | Petroleum extraction processes and utilization | Refining products (fuels and tar), impurities like phenol and cyanides in the waste stream and sludge flushed from the storage tanks. |
| Small scale industry | Metal treating (electro-plating, etching, anodizing, galvanizing), photofinishing, and textile processing, printing, leather tanning. | Acids, heavy metals, solvents, acids, silver cadmium, mineral acids solvent, chromium. |
| Large scale industry | Bauxity processing, oil refining, petrochemical manufacture, chemical/pharmaceutical manufacture, chlorine production. | Red muds, spent catalyst, oil wastes, tarry residue, solvent mercury. |
| Building and construction industries. | Building and roofing materials. | Materials made of asbestos and copper. |
| Mines and mineral processing, electricity generating companies. | Uranium mining and processing. | Spent reactor rods, cloths, rags and wood. |

Some of these substances are classified as probable human carcinogens and are associated with increased tumor rates, organ damages and even death in man.

### 2.4 Effects of hazardous substances on the environment.

Due to poor waste disposal systems mostly by municipal waste management teams; the wastes stockpile and become problematic. This type of dumping waste materials makes the

biodegradable materials to decompose under improper, unhygienic and uncontrolled conditions (Rinkesh, 2018; Duan et al, 2011).

Solid wastes from industries are source of toxic metals, harmful chemicals, and hazardous wastes. When released to the environment, solid wastes can cause physicochemical and biological problems to the environment and human, and may affect the soil productivity and fertility.

### 2.4.1 Effects on land

Pollution results generally as a consequence of man's activity which affects crops, animals, human health and the quality of the whole environment. Thus it is any activity carried out by man which leads to an adverse change in terrestrial environment. The dumping of refuse could be termed the defacement of land and subsequent rendering of the soil non-productive and polluted. Hazardous wastes dumped on land sites, when it rains, the leachates from such refuse dumps contain various contaminants, the most harmful being heavy metals, dissolved organic compounds, and nitrogen (Okeke et al 2016; Kalu et al 2020; Iwuji et al 2016; Islam 2015; Achaw and Dasso-Boatang 2013) (Table 2 and Table 3).

Deteriorating soil quality and decrease in vegetation abundance are also grave consequences of open waste dumping which have resulted in growing public concern (Dawsin, 2000).

Figures 2 and 3 show indiscriminate ancient disposal methods called "open dumps". Open dumps in addition to other effects mentioned earlier lead to deteriorating soil quality and decrease in vegetation abundance. Environmental contamination by components of refuse such as heavy metals like cadmium, lead, zinc and copper has been of great concern in the last decades because of their health hazards to man and other organisms; when accumulated within a biological system. The response of plants to pollutants is especially important since many of these plants are more sensitive than the organisms.



**Figure 2: Open dumps-Mixed wastes. (https://eco-business.shorthandstories.com/child-scavengers-casualties-of-the-philippines-war-against-waste/)**



**Figure 3: Open dumps-empty used oil drums. (Anderson, 2011)**

Plants usually serve as the most sensitive indicators as prolonged exposure to them may destroy a large number of plants communities (Amadi, Okeke and Amadi, 2017). Toxicity can result from a high concentration of an element nutrient intake and can also give rise to abnormal growth, disease or even death.

Also refuse dumps serve as breeding places for diseases-causing organisms such as rats and flies which are the major disease vectors associated with garbage (Figures 2 & 3). Rats, with the assistance of flies are known to be involved in the spread of bubonic plague and urine typhoid fever to humans. Rats may contaminate food with their urine, transmitting leptospirosis, lassa fever and infectious hepatitis. They can transmit salmonella and other intestinal organisms.

Also, hazardous wastes spoil the natural beauty of the land and may interfere with recreational activities. Hazardous solid wastes can also produce unpleasant smell. The free flow of traffic along our streets could also be hindered by the indiscriminate dumping of solid hazardous wastes and can occupy land space that could have been used for other purposes as seen in figures 2&3. Solid waste has the potential to cause sickness and even death. Therefore proper waste management in any society is a matter of urgent attention.

Inherent changes in the application of industrial sludge to land due to contaminations with heavy metals and possible presence of pathogens in raw sludge's cause its prohibition in agricultural lands. Chronic cadmium poisoning causes damage to kidney and heart. Prolong exposure also results in loss of calcium from the bones, which then become brittle and easily break. In Japan for example, a whole village was stricken by cadmium poisoning-known as "Itai-Itai" disease after effluents contaminated rice supplies. Other heavy metals and hazardous substances of interest are Copper, Chromium, Zinc, Lead, Arsenic, and Mercury and Selenium, etc and their effects on man are shown on table 2 below

**Table 2: Some hazardous industrial wastes generate in the petroleum industries, and their potential hazards (harmful effects/and possible control treatment (Islam, 2015; Achaw and Dasso Boatang, 2013)**

| S/No | Waste Type | Source | Potential hazards | Control/Treatment |
|---|---|---|---|---|
| 1 | drilling mud | Petroleum /crude production | Pollutes water bodies and land; affects aquatic life and land usage | Send to secondary party for handling |
| 2 | Sludge | Petroleum/crude production and refinery | Destroys and flora; limits surface water use; renders land unfit for agriculture; and disrupts economic activity such as fishing | Landfill, sold for use as fuel or concrete |
| 3 | Oil contaminated solids | Petroleum/ crude production and refinery / bulk oil storage | Flammable | Landfill |
| 4 | Waste oil | Bulk oil storage | Pollutes surrounding soil and water | Landfill |
| 5 | Spent catalysts | Petroleum / crude refinery | Source heavy metals pollution and posiessing | Landfill |
| 6 | Particulate water | petroleum / crude refinery | pollutes the air and causes respiratory disease | Electromagnetic separations |
| 7 | Process effluent | Petroleum / crude refinery | Pollutions water bodies aquifers and renders land on fit for agriculture m | Multi-stage waste water treatment |
| 8 | Oily waste water | petroleum / crude refinery | Pollutes water bodies, affects flora and fauna; affects land use and human health | Gravity separation waste water plants |
| 9 | Oil free waste water | Flow station/crude production are crude refinery | Pollutes water bodies and aquifers, source of microbial growth | pH adjustment, followed by disposal |
| 10 | $Co/Co_2$ | Flow station crude production and crude refinery | Cause claimant change climate Affects human health, pollutes surrounding air | Flared |
| 11 | $H_2S$ | Petroleum / crude production (flow station and refinery) | Possess very bad odor | Flared |
| 12 | $NH_3$ | Petroleum / crude production (flow station and refinery) | Extremely, Flammable lexic and conossive | Flared |

| | | | | |
|---|---|---|---|---|
| 13 | $No_x$/Noy | Petroleum / crude production (flow station and refinery) | possess bad odor causes acid rain and hence adversely affect aquatic life and land usage | Flared |
| 14 | Spent chemical /discarded or unused chemicals | Petrochemical plants | Flammable and corrosive | Treatment and disposal |
| 15 | Leaked / spilled oil | Bulk oil storage/pipeline | Pollutes surrounding soil and water | pH adjustment treatment and disposal |

**Table 3: Effects of heavy metals and substances on the Environment (Modified after Fordyce, 2000)**

| Heavy metals/substances | Sources | Toxicity/ health hazards |
|---|---|---|
| Cadmium (Cd)<br>Lead (Pb)<br>Mecury (Hg) | Textile processing<br>Mines and mineral processing companies.<br>Chlorine production | Renal and heart diseases, weakens bones and tumors.<br>Neurological disorder, convulsions, kidney and brain disorder. |
| Arsenic (As)<br>Zinc (Zn) | Metal treating (electro-plating, etching, anodizing, galvanizing)<br>Building and roofing materials. | Cancer, skin disease and poisoning.<br>Enzymes and skin disorders. |
| Copper (Cu) | Building materials made of copper. | Gastrointestinal irritant, liver damage. |
| Selenium (Se)<br>Vinyl chloride | Photographic devices, gun cleaning solutions, plastics, paints, anti-dandruff shampoos, vitamin and mineral supplements, fungicides and some types of glass.<br>Plastics manufacturing, air or water at contaminated sites | Hair loss, nervous disorders.<br>Acute effect: Dizziness, headache, unconsciousness, death. Chronic effect: liver, lung and circulatory damage. |
| Polychlorinated biphenyls (PCB)s | Eating of contaminated fish, industrial exposure. | Probable carcinogen; acne and skin lesions. |
| Benzene | Industrial exposure, Glues, cleaning products, gasoline. | Acute effect: drowsiness, headache, death at high levels. Chronic effect: |

| | | |
|---|---|---|
| | | damage to blood-forming tissues and immune system; also carcinogenic. |
| Benzo[a]pyrene | Products of gasoline or other fuels. In smoke and soot | Probable carcinogens, probable birth defects. |
| Polycyclic aromatic hydrocarbons | Exposure to smoke from a variety of sources. | Probable carcinogen; possible birth defects. |
| Benzo[b]fluoranthene | Product of combustion of gasoline and other fuels inhaled in smoke | Probable carcinogen |
| Chloroform | Contaminated air and water. Many kinds of industrial settings. | Affects central nervous system, liver, and kidneys; probable carcinogen. |
| DDT | From food with low levels of contamination. Still used as pesticides in parts of the world. | Probable carcinogens, possible long term effect on liver, possible reproductive problems. |
| Trichloroethylene | Used as a degreaser, evaporates into air. | Dizziness, numbness, unconsciousness, death. |
| Dibenz[a,h]anthracene | Product of combustion in smoke. | Probable carcinogen. |

### 2.4.2 Effects on water

It is a generally accepted fact that the developed countries suffer from problems of chemical discharge into water sources mainly groundwater, while developing countries face problems of agricultural run-off in water sources. On top of these concerns, contamination of water is a big concern after a natural disaster (e.g., tsunamis, earthquakes, hurricanes, floods, and volcanoes) and can influence water quality on a grand scale (Okeke and Uzoh, 2009; Okeke, 2015; Okeke et al 2016).

Secure landfills may not be totally secure even if conscientiously designed. Carefully compacted clay may be very low in permeability but is probably never completely impermeable, especially over long time intervals (Montgomery, 2000). Chemical and biological reactions in the wastes and leachate can rupture or decompose plastic, and the stress caused by the weight of wastes and cover can fracture a clay liner. Leakage from „secure“ toxic waste dumps, in which hundreds or thousands of barrels of concentrated toxic liquid chemicals are stored, have far more potential for harm. Leakage of at least certain volatile organic compounds deemed high priority toxic pollutants like benzene, toluene, vinyl chloride and chloroform have been detected by monitoring wells, e.g: “Mount Trashmore” Landfill in Evanston, Illinois. These pollutants have been confirmed to cause adverse health problems to man. Prevalent high rainfall and shallow water table accentuate problems of pollution from landfills.

"Diseases that human can be exposed from drinking unsafe water range from cholera, typhoid, or Giardia (Denchak, 2018)." Our water supply is threatened with the presence of

asbestos particles, heavy metals like Lead, Cadmium, Arsenic, nitrates and sodium, a variety of chemicals that are known to be carcinogens. Almost all the millions of tons of chemicals improperly disposed off on land will sooner or later find their way to the underground water aquifers if they are fully biograded. These chemicals include toxic synthetic organic chemicals developed with the explosive growth of chemicals and petrochemicals since World War 11 such as Trichloroethane, tetrachloroethane, venylchloride, 1,1,2-trichloroethane, carbon tetrachloride, benzene, xylene, toluene, and methylene chloride.

Some of these substances are essential to the body in trace amounts, mainly for synthesizing enzymes, but it can be toxic in large amounts. According to the "Doctor"s complete guide to Vitamins and minerals, "the tolerable upper intake level of selenium is set at 400mg daily, with 800mcg daily potentially causing toxicity and a dose of 5mg considered lethal for most people. Selenium poisoning has no known antidote, so recognition of the signs and symptoms is essential for survival (Bond, 2016).

Most of these chemicals are petroleum based and are found in gasoline (petrol) septic tank cleaners, deodorants, plastics, spot removers, household cleaners, disinfectants, paints and varnish removers, dry cleaning fluids and degreasing agent etc. These polluting chemicals find their ways to the ground water in many ways-principally by seeping into aquifers from landfills and waste dumps where chemicals are routinely dumped. They also come from septic tanks of sub-urban, urban and rural homes and from ruptured homes, underground petrol and fuel oil storage tanks. There is no easy solution to the polluted aquifers. Restoration is almost impossible; once contaminated, the ground water remains so. Once the chemicals reach the deep recesses of aquifers, they congeal together and their pollutants grow in size and height yearly depending on the shape and composition of the geological structures in the aquifer.

The solution to this problem is that of drilling into deeper less contaminated aquifer. There is no guarantee that the toxic substances in aquifer near the surface will not reach the lower ones. Aeration of the water is another method. Hence the contaminated water is drawn up from the aquifers, passed through a cooling tower and then sprayed by nozzles into the air. In this way, many of the volatile toxic chemicals evaporate before the water hits the ground again and seeps into the aquifer.

Cancers, arthritis, skin irritation, heart disease, damage to the central nervous system, skin rashes, kidney problems and bronchitis etc are the diseases associated with water pollution by chemicals. The amount of contaminated water that can cause sickness to its consumer depends on concentration and composition of the contaminant chemicals.

### 2.4.4 Effects on air

Another major effect of industrial waste is air pollution which results from mining construction and manufacturing activities including burning of fossil fuel (Oyedele et al, 2020; Agbubom and Okeke, 2015; Agubom and Okeke, 2022). This affects the lives of many individuals reason is because it spreads illnesses. Several environmental issues have devastating effects on third world countries as they have insufficient resources to solve this particular problem (Aivalioti, 2014). This also affects the quality of soil as farmers have to deal with this massive problem. Additionally, nitrogen dioxide is one of the common air pollutants found in the air. Air pollutants have devastating effects on the human because it causes various sicknesses, and some such as carbon monoxide may even cause death if large amounts enter the body beyond the level the body can manage; In Nigeria and other parts of the world, there have been a number of reports on sudden death of people and even

entire families due to excessive inhalation of electric generator fumes (mainly composed of carbon monoxide). Ammonia also causes lots of respiratory complications that can be contracted from air. The illnesses that occur from the air pollution include irritation to eyes, skin, throat, or nose. There is also chance of getting Bronchitis or Pneumonia both being extremely dangerous. Commonly, individuals have reported to have headaches, dizziness, and nausea from air pollution (Anderson, 2011; National Geographic (USA), 2011; Narayanan, 2009) (Table 5). The WHO stated that air pollution is the worst risk on human health (Roser and Ritchie, 2017). Air pollution has been around for long time. Indoor air pollution is also risk for human. This type of air pollution is caused by the burning of solid fuels mainly from cooking or heating (Roser and Ritchie, 2017).

**Table 4:** Environmental Pollutants (dusts/particulate matter associated with mining and quarrying and their health hazards / control (Adapted from Narayanan 2009)

| S/No | Pollutants | Source | Health Hazard | Control |
|---|---|---|---|---|
| 1 | Arsenic | Mining | Lung and skin cancer | Use of bag filters scrubbers and electrostic precipitators |
| 2 | Asbestos | Mining | Asbestosis (lung cancer) | |
| 3 | Silica (Quartz) | Quarrying/Aggregated production | Silicosis | |
| 4 | Cadmium | Mining (Associate with zinc-ore) | Kidney Damage | |
| 5 | Chromium | Mining | CNS Deterioration | |
| 6 | Cowel Fly Ash | Mining / Power Generation | Black lung cancer | |
| 7 | Iron | Mining | Nansea and Vomiting | |
| 8 | Lead | Mining | CNS Deterioration | |
| 9 | Nickel | Mining | Bronchial cancer | |
| 10 | Phosphorus | Mining | Gastro-internan disorder | |
| 11 | Vanadium | Mining | Cough, conjunctivitis | |
| 12 | Manganese | Mining (Associated with iron-Ore) | CNS Deterioration | |
| 13 | Zinc | Mining/metallurgy | Toxic | |

### 2.5 Exposure pathways for hazardous wastes.

Apart from health problems caused by contamination of drinking water, toxins can seep into buildings built above hazardous wastes sites, causing indoor air problems, respiratory diseases and chemical sensitivity. Incinerating hazardous wastes can introduce mercury and dioxin pollutants into the environment which can affect the lungs.

An exposure pathway describes the course that a substance takes from the source of the hazardous substance or chemical to the exposed individual or environment (Lippmann, 2015).

The different ways a person can come into contact with hazardous chemicals can be referred to as exposure pathways. Toxic substances can enter our bodies in any of four ways, called pathway of entry. These are: Absorption, Ingestion, Injection and Inhalation.

### 2.5.1 Dermal contact

If a child were to walk barefoot through contaminated soil, the contaminant would contact the skin of the foot. This could cause mild skin irritation, or more serious problems like burns, sores, or ulcers on the outer layers of the skin. Contact with a substance may also occur by spilling it on the skin or brushing against a contaminated object.

Depending on the substance and the condition of the skin, the contaminant might also be absorbed through the skin and poison the body. While some chemicals are not absorbed easily unless the skin is cut, others are absorbed quite readily regardless of the skin's condition. When you are using a material that bears instructions recommending the use of gloves, this is to prevent skin contact or absorption through the skin (also called dermal exposure).

When you work with chemicals, it is particularly important never to put your hand to your eye. Eyes are particularly sensitive to toxic substances: since capillaries are near the surface, the substance can enter the bloodstream more readily. Eye contact with toxic substances can cause irritation, pain, or even blindness.

### 2.5.2 Injection

The most familiar example of injection is that of shots given to administer medicine, in which the skin is punctured with needles so that a substance can enter the body. Injection can also occur accidentally. For example, if the skin were cut by a contaminated can or a piece of glass that had been in contact with a contaminant, the contaminated substance could be injected into the body. This is a very powerful means of exposure because the contaminant enters the bloodstream immediately.

### 2.5.3 Ingestion

If we eat a substance that contains a harmful material, that substance enters our bodies by means of our digestive system. An example of inadvertent ingestion is a battery factory employee who eats lunch in the work area and ingests inorganic lead that has contaminated a sandwich. A more common instance is the child who puts a toxic substance in his or her mouth out of curiosity. We may also ingest residue from chemicals that have been added to our food to kill germs or parasites.

### 2.5.4 Inhalation

It is also possible to be contaminated by toxic substances when we breathe them into our lungs. The amount of air inhaled in a workday can be extremely large, so if we work or live in a contaminated area, we can be exposed to significant quantities of a substance in this way. Some chemicals have excellent warning properties that let us know when they are in the atmosphere. There is the well-known "rotten egg" smell of hydrogen sulfide, for example. But at high concentrations of this gas, our sense of smell is quickly lost. Many toxic substances, such as carbon monoxide, are both colorless and odorless, providing us with no sensory clues that we are being exposed to anything unusual.

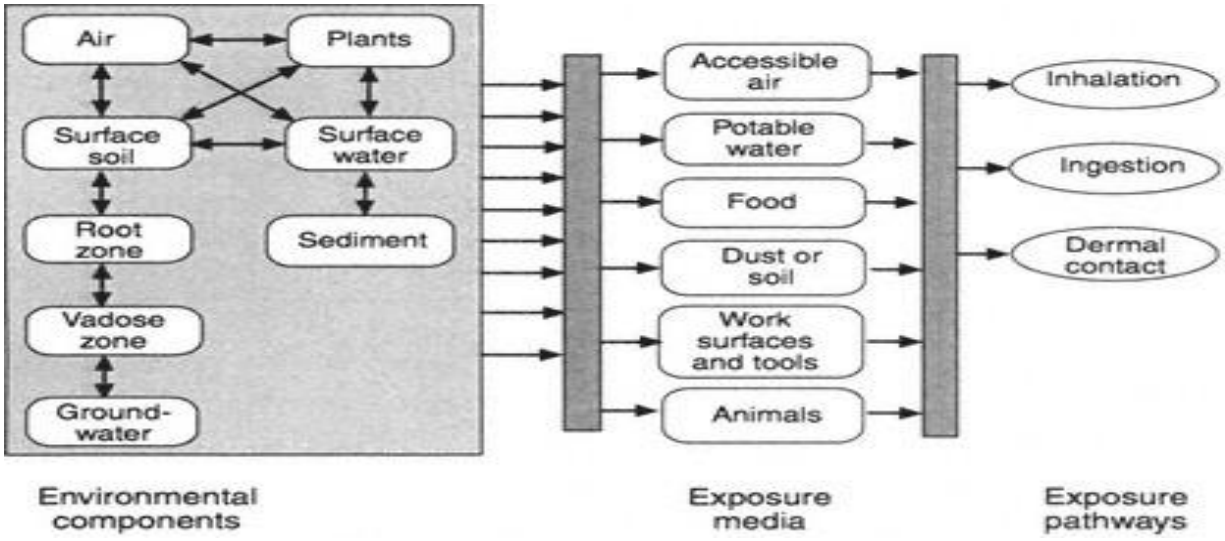



**Figure 4: Schematic diagram of links among environmental media, exposure media, and exposure routes (Eisenberg and McKone, 1998).**

## 3.0 Principles and methods of hazardous waste management

### 3.1 Principles of hazardous waste management

According to Amadi et al., (2017), hazardous waste management is the general term given to the procedures and policies carried out to deal with hazardous waste in a way that it will not pose problems to man and the environment.

Significant reductions in the volume of waste generated can be accomplished through source segregation, process modification, end-product substitution, or recovery and recycle (Amadi et al, 2017; Couto et al, 2013). Originally, hazardous wastes were commonly disposed of by open dumping, open burning, or incineration. Open dumping can contribute to land litter and water pollution, and the end products of open burning and incineration can contribute to air pollution in the form of particulates, nitrogen oxides, noxious odors, and other constituents. In addition, the burning process can produce solid residues which when ultimately disposed can contribute to water pollution and even help to create some small amounts of methane gas.

Municipal incineration with sophisticated energy recovery systems were popular in large European and American cities at the turn of the century, but became extinct due to high operating costs. Similarly, in former years, garbage was reclaimed for dog feed; animal wastes were rendered for fats to manufacture soap and other products. These practices have become less popular because of public health requirements to sterilize garbage, and because of the economies of mixed refuse collection. However, the recovery of paper, metals, and other solid wastes continues to be practiced by scrap dealers whenever economically feasible. In recent years, hazardous solid waste incineration has become less popular because of greatly increased air pollution control requirements.

According to Kanagamani et al; (2020), hazardous waste management is a major challenge in urban areas throughout the world. Without an effective and efficient waste management program, the waste generated from various human activities both industrial and domestic, can result in health hazards and have negative impact on the environment. The following procedure forms a standard waste management strategy in a developed society. Each step play a very important role in ensuring that waste disposal which is the final stage in the management process is achieved without threat to man and the environment.

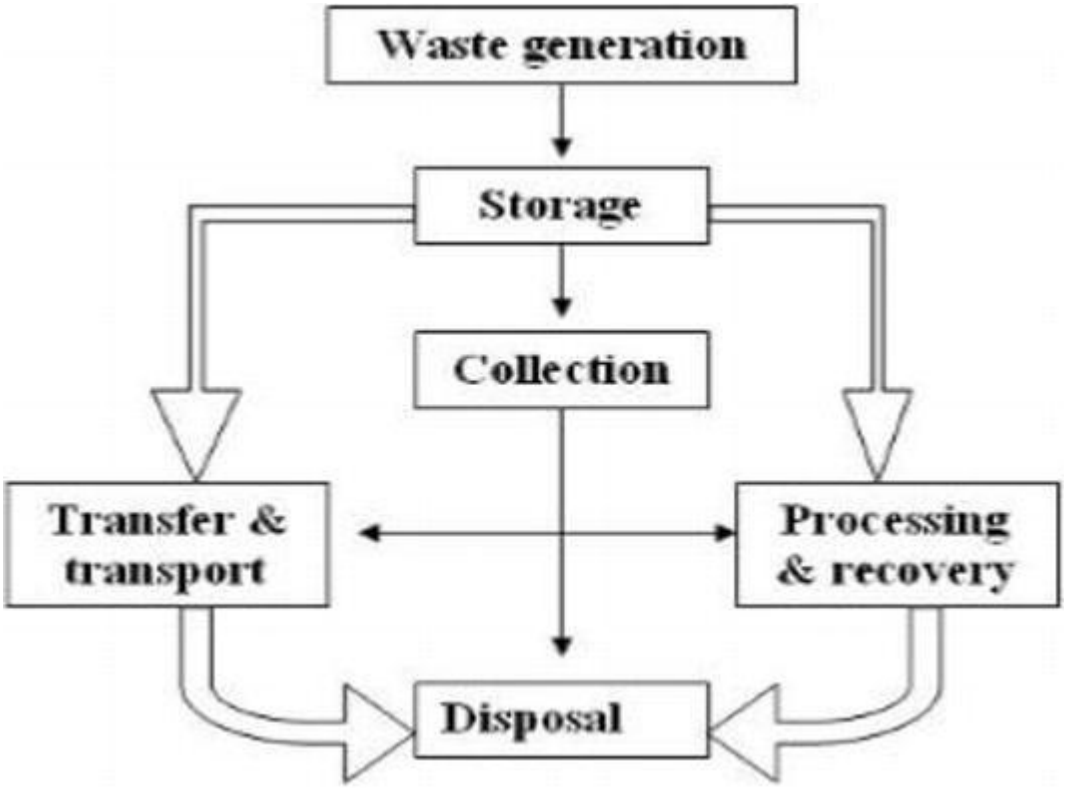



**Figure 5: Various steps involved in hazardous waste management (modified from Kanagamani et al., 2020)**

### 3.1.1 Generation

Generation of solid waste is the stage at which materials become valueless to the owner and since they have no use for them and require them no longer, they wish to get rid of them. Items which may be valueless to one individual may not necessarily be valueless to another. For example, waste items such as tins and cans may be highly sought after by young children.

### 3.1.2 Storage

Storage is a system for keeping materials after they have been discarded and prior to collection and final disposal. Where on-site disposal systems are implemented, such as where people discard items directly into family pits, storage may not be necessary. In emergency situations, especially in the early stages, it is likely that the affected population will discard domestic waste in poorly defined heaps close to dwelling areas. If this is the case, improved disposal or storage facilities should be provided fairly quickly and these should be located where people are able to use them easily. Improved storage facilities include:

i Small containers: household containers, plastic bins, etc.

ii Large containers: communal bins, oil drums, etc.

iii Shallow pits

iv Communal depots: walled or fenced-in areas

In determining the size, quantity and distribution of storage facilities the number of users, type of waste and maximum walking distance must be considered. The frequency of emptying must also be determined, and it should be ensured that all facilities are reasonably safe from theft or vandalism.

### 3.1.3 Collection

In some regions, vacuum collection is used where waste is transported from home or commercial premises by the vacuum along some small bore tubes (Godswill et al; 2023). Collection simply refers to how waste is collected for transportation to the final disposal site. Any collection system should be carefully planned to ensure that storage facilities do not become overloaded. Collection intervals and volumes of collected waste must be estimated carefully.

Waste collection methods widely vary among different regions and countries. Domestic waste collection services are regularly provided by the local government authorities, or by the private companies' for commercial and industrial waste. Some areas and regions, especially those in less developed nations, do not have any formal waste-collection system. Curbside collections the most popular method of disposal in most Canada, New Zealand, United States, European countries, and many other parts of developed world where waste is regularly collected at intervals by specialized trucks. This is usually associated with the curb-side waste segregation. In the rural areas waste might need to be taken to transfer station.

### 3.1.4 Transportation

This is the stage when solid waste is transported to the final disposal site. There are various modes of transport which may be adopted and the chosen method depends upon local availability and the volume of waste to be transported. Types of transportation can be divided into three categories:

i Human-powered: open hand-cart, hand-cart with bins, wheelbarrow, tricycle

ii Animal-powered: donkey-drawn cart

iii Motorized: tractor and trailer, standard truck, tipper-truck

### 3.2 Components /Methods of Hazardous Wastes Management

1. **Making an inventory**: preparing a detailed list of all hazardous waste sources, the characteristics of the wastes and the amount generated of each. The eventory must be complete before the remaining components of the system can be implemented.

2. **Waste minimization:** Reduction in quantity and/or toxicity of hazardous wastes produced; recovery and reuse spent materials; and exchange of wastes with other companies should be undertaken, where necessary

   Specific techniques include:

   i. Improve bookkeeping practice.
   ii. Change production methods.
   iii. Substitute less toxic materials.
   iv. Reduce wastewater flows.
   v. Recycle or reclaim wastes.
   vi. Delist wastes that do not have hazardous characteristics

3. **Storage and transport:** Industries should use special on-site tanks or basins for storage of large quantities of hazardous wastes, or chemically resistant drums for holding smaller amounts of corrosive materials until those wastes can be removed. The stored wastes must be collected at regular intervals by licensed haulers and transporters by tanker truck or rail car (for large volumes).

4. **Spillage**: A well publicized emergency plan should be in place for the protection of human health and the prevention of environmental damage in the event of spills or the release of contaminants. The recovery and safe disposal of spilled wastes, absorbents and contaminant soils must also be considered.

5. **Treatment and disposal**: Where recovery or reuse of industrial wastes is uneconomically or no waste exchange is possible and no off-site facility for hazardous waste disposal is available, an industry must determine what pretreatment, if any, is necessary before the wastes can be safety disposed of on-site or discharged to receiving water or municipal sewers. For some wastes, deep-well or bedrock disposal may be a possible.

   (a) Treatment techniques (U.S. EPA, 1987)

   (i) Physical processes: (Centrifugation flotation sedimentation and filtration use of activated carbon stripping and distillation processes are useful).

   (ii) Chemical processes Oxidation, reduction, precipitation, pH adjustment, ion exchange and stabilization / solidification of sludges and contamination soils.

   (iii) Biological processes: This is generally done in take care of phenols, oils and other refinery wastes and removal of heavy metals (pb, cr cd, etc)

   (iv) Incineration: Theodore and Reneds, 1987 incineration is defined as the thermal oxidation of organic matter into carbondioxide, water and inert ash. Partially combusted inorganic particulate matter (or fly ash), acid gases (such as HCL) and sulphur oxides ($SO_2$ mainly) may also be produced, depending on the feed material and construction conditions. Temperatures in excess of $1200^0$C are generally required. Cement kills, boilers and industrial furnaces have also proven effective for the destruction of organic wastes.

   (b) Disposal Techniques

   (i) On-site treatment and disposal is widely used by industry in North America. In the area, hazardous wastes such as oily wastes and are disposed of on-site in lagoons, evaporation ponds and landfills.

   (ii) Off-site disposal treatment technique has five options, namely: deposition in a separate secure landfill; codisposal with municipal refuse in a sanitary landfill; deep well disposal, bedrock disposal delivery to a hazardous waste treatment facility.

## Secure Landfill

A secure landfill in essence, means that no leachate or other contaminant can escape from the fill and adversely affect the surface water or ground water (Josephson, 1981) Leakage fraud the site is not acceptable during or after operations. No internal or external displacement, which could be brought about by slumping, sliding and flooding is also acceptable. Wastes must not be allowed to migrate from the site (Davis and Masten, 2009). Landfills for hazardous wastes (secure landfills are frequently considered a technology of last resort to be used after every effort made to reduce or eliminate the hazards posed by the waste (Okeke and Akaolisa, 2004; Ireaja et al, 2018). The intent is to bury or alter the wastes so that they are not environmental or public health hazards (Fig 6).

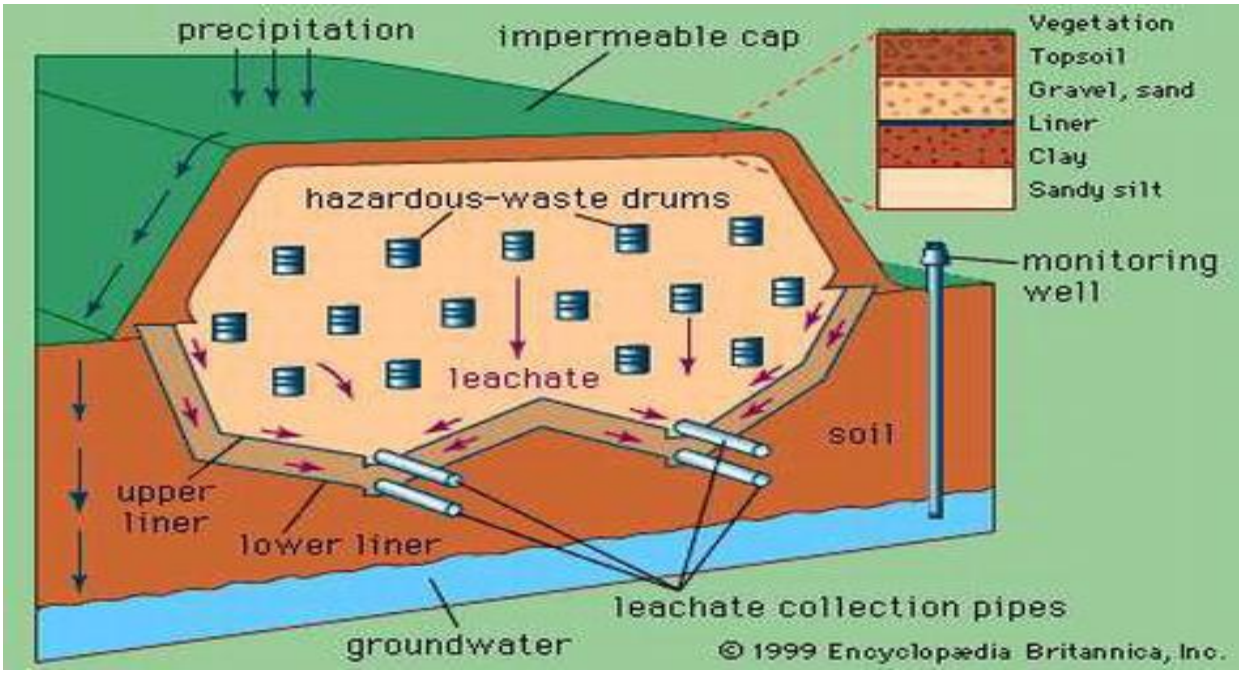



**Figure 6: A secure landfill design for hazardous waste disposal (Encyclopedia Britannica, 2016)**

**Deep well injection/ Disposal**

Deep well injection consists of pumping wastes into geologically, secure faneations. (Fig 5). The general technical requirements of a suitable hazardous waste injection well include (Warner, 1989) (Fig 5):

(i) A saline water bearing formation that is large enough and permeable enough to accept the waste.

(ii) Overlying and underlying state (confine Loyess) that are sufficiently impermeable enough to confine the waste to the injection strata.

(iii) The absence of solution – collapse fealiness, faults, joints, and abandoned wells that might permit the escape of the waste.

Obviously, these requirements imply a rigorous understanding of the geologic and hydrogeologic characteristics of the subsurface.

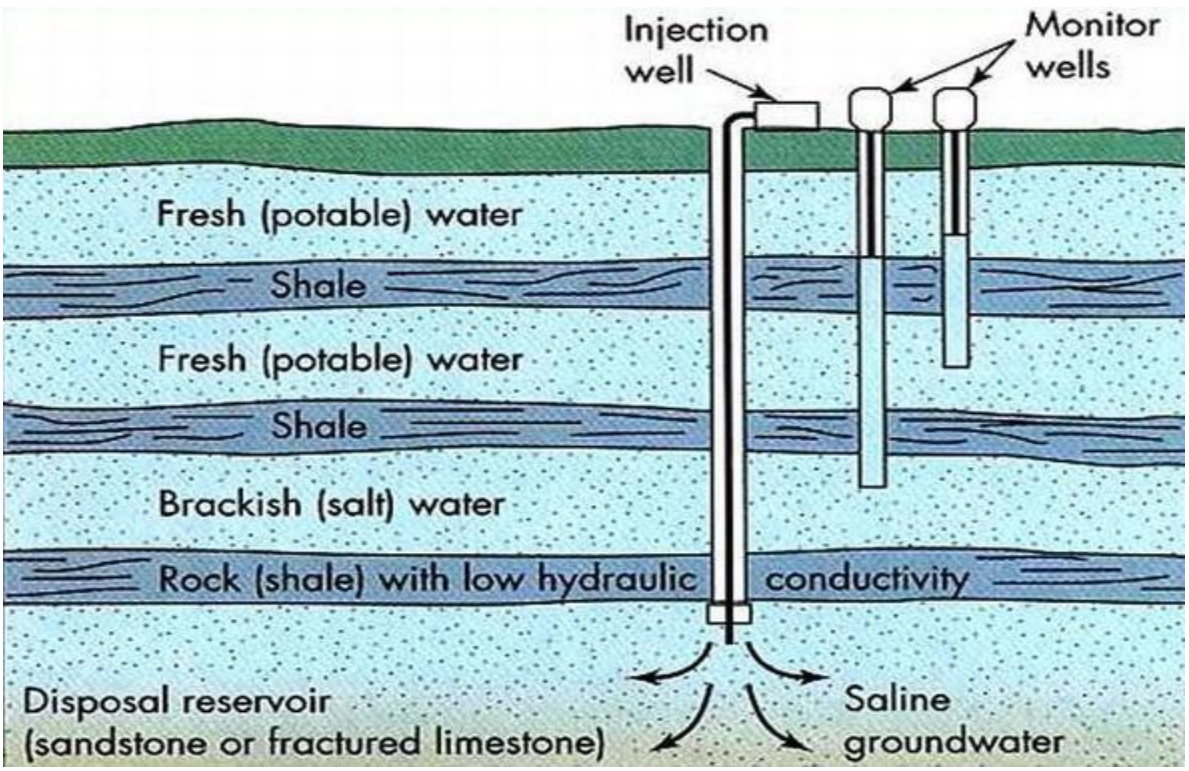



**Figure 7: Deep well disposal method (Source; Linday, 2012)**

### (c) Bedrock disposal

A variety of bedrock types are being investigated as host rocks for solid hazardous waste. The general design of a bedrock disposal site or repository for such wastes is shown in Figure 6. It involves the multiple barrier (or multi barrier) concept: surrounding solid waste with several different types of materials to create multiple obstructions to waste leakage or invasion by ground water. A major variable is the nature of the host rock as well as some potential drawbacks. The waste forms envisaged for disposal are vitrified high-level radioactive wastes sealed into stainless steel canisters, or spent fuel rods encapsulated in corrosion resistant metals such as copper or stainless steel. The most widely accepted plans are for these to be buried in stable rock structures deep underground. Many geological formations such as granite, volcanic tuff, salt, thick basalts such as the Columbia River plateau basalt or shale will be suitable (Salma, 2012).

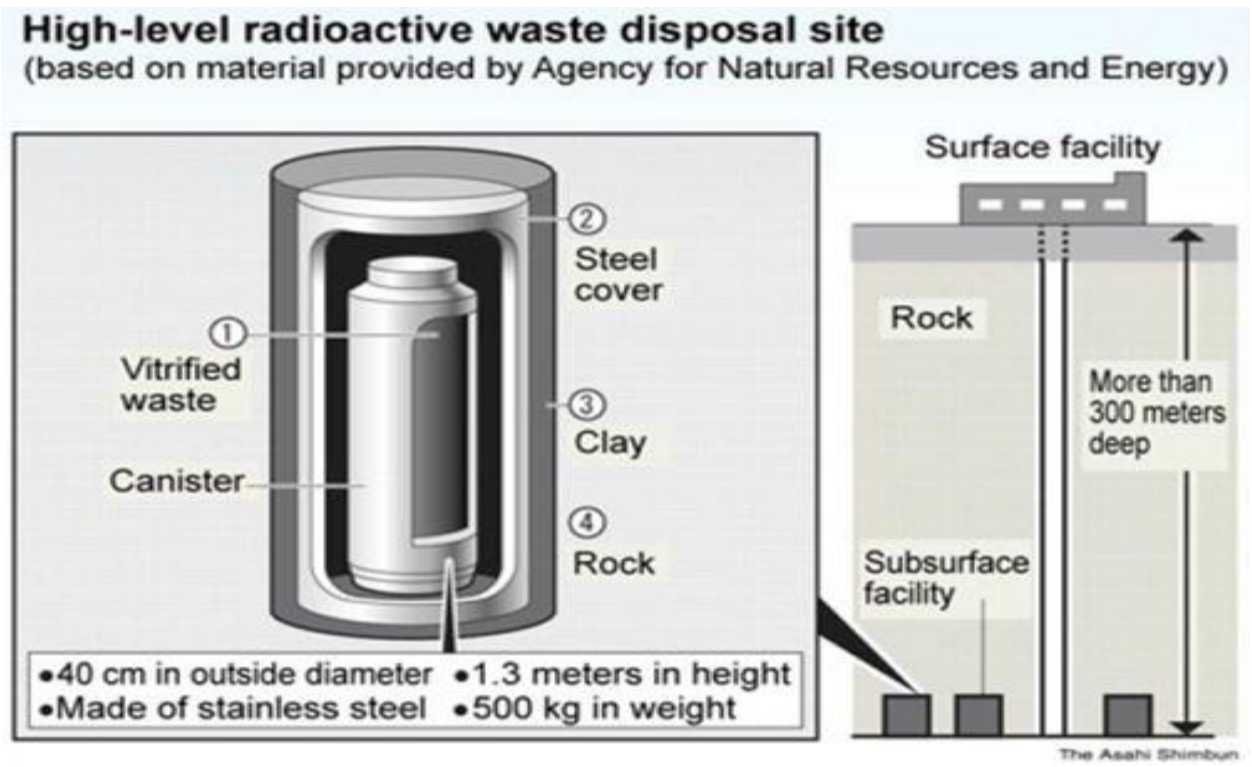



**Figure 8: Bedrock disposal of solid hazardous wastes (Source: Rajakumar, 2016)**

## 4.0 Case history

### 4.1 Mine waste: sources, problems and mitigations (Abiahu et al; 2019)

Mine wastes are unwanted, currently uneconomic, solid and liquid materials found at or near mine sites. They are one of the world's largest waste streams, and they often contain high concentrations of elements and compounds that can have severe effects on ecosystems and humans. Extraction is the first phase of mining, which consists of the initial removal of ore from the earth. Opencast mines are more pollution intensive as they generate much higher quantities of waste than underground mines. Once the ore is brought to the surface, it is processed to extract the mineral, which itself generates immense quantities of waste.

As the higher grade mineral deposits are getting exhausted, the mineral industry is generating more and more quantity of waste, as they have to now depend on lower grades of reserve. For example, in the United States, the copper ore mined at the beginning of the 20th century consisted of about 2.5 percent usable metal by weight; today that proportion has dropped to 0.51 percent.

Mine wastes include overburden, run-of-mine rock, waste rock slurry and tailings from the preparation/beneficiation or extraction plants. Wastes that have the potential to generate acid mine drainage as a result of metal mining activity include mine material such as spent ore from heap leach operations, tailings, and waste rock units, including overburden material. Sub-surface mining often progresses below the water table, so water must be constantly pumped out of the mine in order to prevent flooding. Tailings piles or ponds, mine waste rock dumps, and coal spoils are also an important source of acid mine drainage. Metal mines may generate highly acidic discharges where the ore is a sulfide mineral or is associated with pyrite, and copper mines are often major culprits of acid mine drainage. Acid mine drainage is considered a serious long-term environmental problem associated with mining (Akcil and Koldas 2006).

Acid mine drainage (AMD) is produced when sulphide-bearing material is exposed to oxygen and water (Akcil and Koldas, 2006). The production of Acid mine draining usually but not excessively occurs in Iron sulphide aggregate rock. Although the process occurs naturally, mining can promote AMIS generation simply through increasing the quantity of sulphides example:

$4FeS_2 + 11H_2O + 15O_2 = 4Fe(OH)_3 + 8SO_4^{2-} + 16H^+$ - Akcil and Koldas (2016)… 1

The Environmental problems associated with mining are diverse includes removal of vegetation, top soil over burden / waste rock ad the inevitable natural consequences which manifest in many ways such deforestation, climate change, erosion, air and water pollution and health hazards. Acid mine drainage may arise from both surface and underground mining. Acid mine drainage usually contain high value of heavy metals (Arselic, Cyanide, Mercury lead).

According to Chaturvedi and Patra (2016), and Johnson and Bradshaw (1977), commonly used approach to management of mine wastes include:

i. returning the materials to site;

ii. dumping into lake or ocean;

iii. containment of the tailings in an embracement; and

iv. treatment and disposal of acid mine drainage

## 5.0 CONCLUSION

Industrial wastes are unwanted materials produced by human activities in various industries including mining, construction, petroleum, manufacturing and metallurgical/mineral processing. Thus, the wastes may be referred to as mine wastes (such as tailings and acid mine drainage); construction wastes (such as asbestos, stones and concrete); chemical wastes associated with petrochemical plants (such as pesticides and fertilizers); pharmaceutical/ food industry wastes (such as infectious needles, food, heavy metals); and petroleum industry related wastes (such as drilling mud, sludge, waste water and oil-contaminated solids and gaseous emissions ($NH_3$, $H_2S$, $CO_2$, CO and SOx/Noy at the refineries).

Industrial wastes may be classified as solid, liquid or gaseous on the basis of nature; and as hazardous or non hazardous on the basis of pollution characteristics. Hazardous industrial wastes are harmful or have the potential to be harmful to environment organisms or health of humans. Generally, they possess one or more of these characteristics: flammable, corrosive, reactive/explosive and toxic (cause illness to humans). Some of these health hazards include pollution of water bodies/land by drilling mud and sludge (solid industrial waste from the petroleum industry) and acid mine drainage/tailings (solid/liquid from mining), thereby making the water unfit for drinking (due to heavy metal pollution in particular), and the land unfit for agriculture.

The harmful effects (hazards) of these wastes may be reduced/ controlled (mitigated) by reduction in the amount of wastes produced at the factories/industries (waste minimization) recovery and reuse of wastes produced (waste recycling); and treatment and disposal of the wastes using secure landfill or deep well injection technique.

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