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Heavy Metals and Pesticides as Hazardous Wastes and Strategies for Minimizing their Hazards

Okrikata, E.[1], Nwosu, L.C.*[,2]

[1]Department of Biological Sciences, Federal University, Wukari, Taraba State, Nigeria
[2]Department of Crop and Soil Science, University of Port Harcourt, Rivers State, Nigeria
*Corresponding Author's E-Mail: luke.nwosu@uniport.edu.ng

ABSTRACT

This review focused on heavy metals and pesticides as hazardous wastes and the strategies for minimizing their effects. Industrialization and environmental dynamics have resulted to rising hazardous wastes. There is an urgent need to develop strategies for sustainable management of hazardous wastes. These classes of wastes placed heavy liability on man and the environment. The present work has articulated important details on the subject, and provided insights on the important measures for minimizing their hazards.

Keywords: Industrialization, Environmental dynamics, Sustainable management, Hazards.

1. Introduction

The generation of hazardous waste products and materials is inevitable as it is the outcome of processes (e.g., manufacture of products, pest control/pesticides application, consumption of products, mining/extraction of raw materials, and waste management) through which materials are either made or used. The speedy development, advancement and revolution of industrial technologies have greatly increased the generation of hazardous wastes. Global record indicates that the last century experienced a number of massive dumping of hazardous wastes into the environment (Liu and Liptak, 2002).

In Nigeria for instance, the incidence of 1988 in which some Italians dumped about 4,000 tons of hazardous wastes packaged in drums and sacks in Koko village, Bendel State which gravely affected the health of the residents in the area is still fresh in the memories of some (Ikhariale,1989). Since hazardous wastes are mobile, dumping is unacceptable as it poses higher risks. Hence, highly regulated and appropriately conducted disposal, destruction, reuse, or recycling is being advocated where their (hazardous wastes) production is unavoidable - this is largely the case in the present, as we live in a chemical world accentuated by high use of materials due to population growth, urbanization, global trade/economic interests, and increased availability of energy. No doubt, our daily lives are awash with chemicals many of which are hazardous or potentially hazardous.

The bulk of hazardous wastes are generated from petrochemical, chemical, metal, and mining industries. Solvents, wastewater, and ash are common hazardous wastes produced by industries. Those generated by municipal sources includes; garden pesticides, medical wastes, cleaning materials, paints, batteries, and automobile oils. Aside polluting the environment and thereby threatening the ecosystem, hazardous wastes adversely affect human lives and livelihood either directly or indirectly. The negative impact of hazardous wastes on the environment are mostly irreversible, or reversible at high cost – manpower and financial. Despite these, annually, over 400 million tonsof hazardous wastes are produced worldwide (U.S. EPA, 2012a).

Aside some solvents, paint wastes, acids, and petroleum wastes; heavy metals such as cadmium and mercury are classified as hazardous wastes. More so, in some countries, some pesticides are referred to as hazardous, acutely hazardous or regulated wastes if they require specific procedures for disposal. More specifically, cancelled, unused and/or recalled pesticides are categorized as hazardous wastes. This paper thus succinctly explores the sources and classification of hazardous wastes in general and, specifically overviewed the hazards of heavy metal and pesticide contamination. Additionally, the options for minimizing the risks posed by them are outlined. But an important question to deal with first is; what is hazardous waste?

1.1 Definitions of Hazardous Wastes

Though technically different, the terms toxic and hazardouswastesare frequently used interchangeably. A toxic waste commonly refers to a waste which is poisonous and capable of causing death or severeinjury to humans and other animals by interrupting normal body functions when absorbed or ingested (Bilitewski*et al*., 1997). The guidelines of the Nigerian Federal Environmental Protection Agency - FEPA (1991) describes hazardous waste as by-products of society that can endanger human health and/or the environment when mismanaged and possesses one or more of the following characteristics: ignitable, corrosive, reactive, explosive or toxic. Hence, all toxic wastes are hazardous and not the other way.

The United States Resource Conservation and Recovery Act (RCRA) of 1976 defined hazardous waste as any waste material (gaseous, liquid, or solid) that due to its concentration, quantity or chemical, physical, or infectious characteristic is capable of causing or substantially contributing to an increase in mortality, severe irreversible illness, or incapacitating reversible illness; or pose a substantial present or potential danger to human health or the environment when inappropriately treated, transported, stored or disposed of, or otherwise managed. Despite the differing views on the definition of hazardous wastes in different climes, a generic definition of hazardous wastes conveys the idea of wastes or combinations of wastes that pose a substantial immediate or future danger to humans or other living organisms, or natural resources owing to their non-degradable or persistent nature, and can bioaccumulate, be toxic, be radioactive or may otherwise cause deleterious cumulative effects.

1.2 Characteristics of Hazardous Wastes

Hazardous wastes may exhibit one or more of the following characteristics in their behavioral pattern: Reactive, Explosive, Ignitable and Flammable, Corrosive, Toxic, Radioactive, and Persistent.

1.3 Generic Descriptions of Hazardous Wastes

Hazardous wastes contain inorganic or organic elements that may cause explosion, fire, infection, corrosion, acute or chronic toxicity, birth defects, mutations, cancer, or damage to natural resources or the ecosystem. The utility or location of a substance may determine whether or not it is perceived a hazardous waste. For instance, if an industry discovers a productive use for a particular hazardous waste in its process of manufacturing, the substance may become a valuable raw material. This can be seen from the perspective of pesticides which are gainfully used for pest control but, adjudged hazardous wastes if unused, discarded, left-over, or after leaching into ground or surface water.

Wastes generated from industrial, commercial, domestic, agricultural, healthcare and institutional/research activities including different types of discarded chemicals could constitute hazardous wastes. Examples include some pesticides, heavy metals, metal finishing wastes, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), painting wastes, cleaning solvents, dioxins, spent acids and bases, sludges from air, and water pollution control units. Included in the list are substances that ordinarily are not thought as hazardous e.g., batteries (can contain metals like cadmium and lead as well as acids and bases), fluorescent lamps and thermostats (contain mercury), computer monitors with cathode ray tubes (contain lead), fluorescent lamps and thermostats (contain mercury), and demolition and renovation wastes (can contain lead-based paints) (WHO, 2013). By reason of their hazardous contents, the aforementioned substances/materials are categorized as hazardous wastes.

2. Classification of Hazardous Wastes

Hazardous wastes are classified into 4 distinct types namely: Listed, Characteristic, Universal, and Mixed wastes.

i. **Listed wastes:** This waste type has been specifically categorized and listed by various governments/regulatory organizations as hazardous. It is made up of 4 lists organized into 3 groups:

a. F-list (non-specific source wastes): They do not originate from a specific industry or manufacturing/industrial process. The list is largely made up of by-products of different manufacturing/industrial processes. Examples are spent halogenated solvents used for cleaning and degreasing, and wastewater treatment sludge from electroplating processes as well as dioxin wastes. They are mostly acutely hazardous.

b. K-list (source specific wastes): In contrast with F-list, K-list is made up of some wastes from specific industries such as petroleum refining, wood preserving, primary and secondary metals manufacturing, and the manufacturing of industrial chemicals, pigments, pesticides, inks, explosives, and veterinary pharmaceuticals. This waste specifically includes sludges, wastewaters, spent catalysts, still bottoms, and residues from the listed industries.

c. P-list and U-list (discarded commercial chemical products): This includes discarded commercial chemical products which were not used. Certain discarded pesticides and pharmaceutical products e.g., warfarin (rat poison), endrin, benzene, formaldehyde, vinyl chloride, and arsenic trioxide fall under this list.

ii. **Characteristic wastes:** These are wastes that largely do not fit into the categories listed above/are not specifically listed, but are classified as hazardous wastes because they exhibit at least one of the following characteristics: ignitable, corrosive, reactive, toxic, and infectious. Figure 1 shows the symbols of these characteristics.

a. Ignitable wastes: These can create fires, are spontaneously combustible, and have a flash point of $< 140^oF$ ($< 60^oC$). Examples are waste oils, alcohol, gasoline, and acetone.

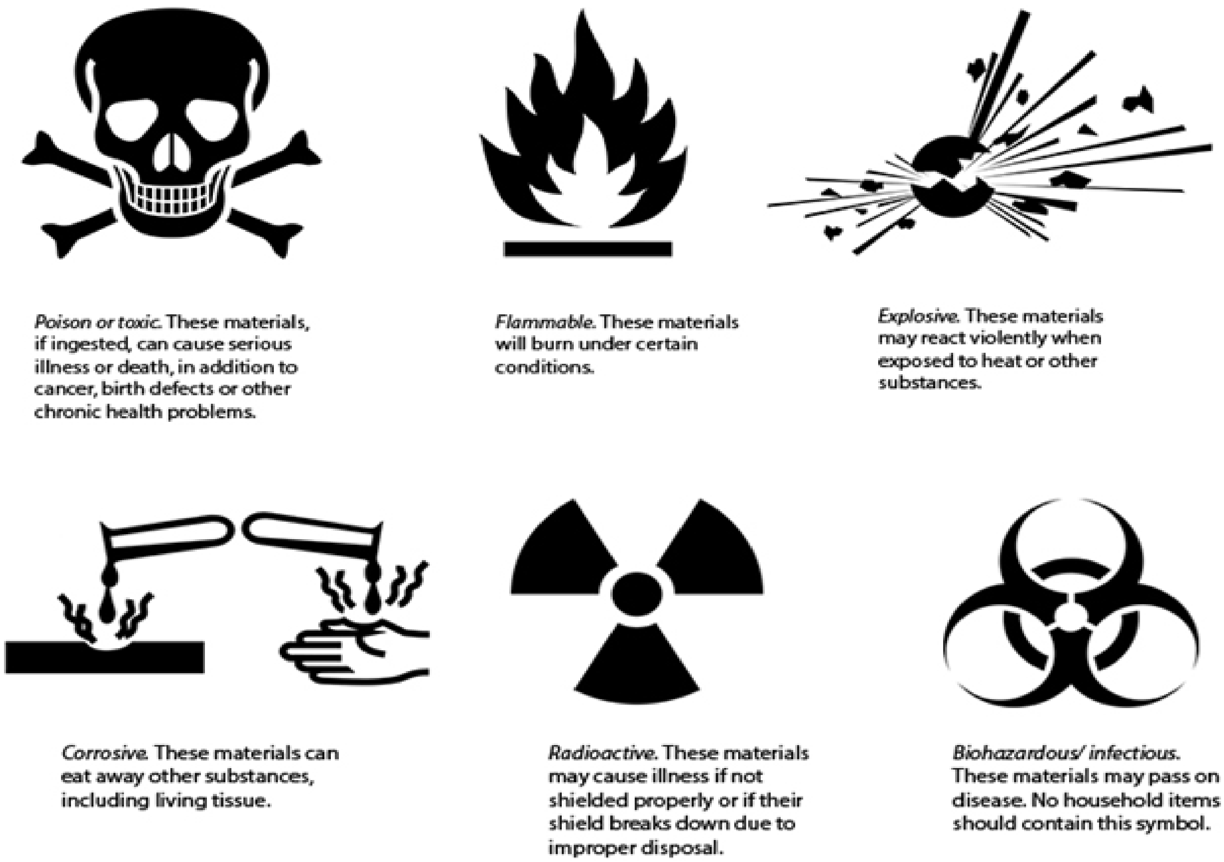
b. Corrosive wastes: These are usually acids and bases which can corrode/breakdown metals. They have a pH of < 2.0 or > 12.0. Examples are battery acids and rust removers.

c. Reactive wastes: These are ordinarily unstable substances and can explode, or release toxic fumes, vapors, or gases when compressed, heated, or mixed with water. Examples are unused batteries, lithium-sulphur batteries, explosives, some chemicals, obsolete munitions, wastes from manufacture of dynamites, and firecrackers.

d. Toxic wastes: These are capable of causing injury to life or death when absorbed or ingested. Examples are synthetic pesticides and heavy metals. When toxic wastes are disposed on land, they release poisonous substances that leach into the groundwater and eventually enter the food chain.

e. Infectious wastes: These are also called biohazards and can cause diseases to living organisms including human. A number of wastes generated by dentists, healthcare centers, and hospitals are infectious. Some wastes generated from agricultural activities are also infectious.

iii. **Universal wastes:** These are made up of commonly used materials that contain hazardous wastes. These wastes include pesticides (suspended, recalled, or cancelled pesticides), batteries (e.g., nickel-cadmium batteries, lead-acid batteries, mercury, and silver cells containing batteries), mercury containing equipment (e.g., mercury switches, mercury thermostats, sphygmomanometers, barometers, and mercury lamps), used electronics (e.g., televisions, laptops, desktops, monitors, scanners, printers, radios, photocopying machines, compact disk players, telephones, and stereos).



iv. **Mixed wastes:** These are hazardous wastes with radioactive components (i.e., a mixture of hazardous waste with radioactive waste). Mixed wastes can be generated from processes where chemically hazardous materials are used in conjunction with radioactive materials. Theses wastes are generated from hospitals, industrial and nuclear power plant facilities through processes such as research/pesticide research, pharmaceutical, medical diagnostic, biotechnology, and nuclear power plant operations. Examples are blood labeled with radionuclide, or radioactive contaminated chloroform/phenol.

Figure 1: Symbols of hazardous wastes

(**Source:** https://www.open.edu/openlearncreate/mod/oucontent/view.php?id=80576&extra=thumbnailfigure_idm45621728739744)

Hence, hazardous wastes can include things such as heavy metals, chemicals, or substances generated as byproducts during manufacturing processes, as well as discarded household products like cleaning fluids, paint thinners, and old batteries.On the other hand, a pesticide is a hazardous waste only when its sole active ingredient is found on the P or U list or it exhibits a hazardous waste characteristic.

2.1 Sources of Hazardous Wastes

There are various sources of hazardous wastes. Wastes generated from discarded commercial products in the form of solid, liquid, or gas could constitute hazardous wastes. Manufacturing of products for either consumption or further industrial applications are major sources of hazardous wastes.

As such, any source that discharge solid, liquid, or gas wastes that suits the definition of hazardous waste (as discussed above) can be regarded as a source of hazardous waste. These sources include;

i. **Oil spillage:** This is the release of liquid petroleum hydrocarbons or their derivatives into the environment. These products are usually highly inflammable and toxic to the environment. Oil spillage can take place either on land or in water bodies. In Nigeria, the occurrence of crude oil spillage is common to hear. This can be released from oil tankers, drilling rigs, offshore platforms, or oil wells. Refined petroleum products (e.g., diesel, gasoline, or kerosene), or their by-products, bunker fuels, and waste oil can also be spilled. Oceans are frequently polluted by oil spills, run-offs, routine shipping, and dumping of oils. Spills on land are largely through well blowout or pipeline vandalism/rupture (Enegide and Chukwuma, 2018).

Oil spills can be catastrophic to marine wildlife such as fish, birds, and mammals. Since oil cannot dissolve in water, a thick sludge is formed in the water which suffocates fishes, penetrates the feathers of the marine birds thereby hindering flight, and suppresses the insulating ability of mammals - making them prone to impacts of temperature fluctuations. Oil spillage also obstructs light from photosynthetic aquatic plants. Aside contaminating drinking water, oil spillage limits soil fertility and crop productivity. Depending on the type of oil spilled, the type and extent of exposure; health effect on humans include, eye and skin irritation, respiratory and neurologic problems, and stress. Oils can be biomagnified in the food chain and disrupt physiological activities of many organs. It can also cause cancer, mutation, hemorrhage, and weaken reproductive capacity.

ii. **Gas flaring:** This is a conscious and controlled open-air burning of natural gas that cannot be processed for use or sale due to economic, or technical reasons (Peterson *et al*., 2007). The outcome is plumes of smoke and flames which brightens up the skies like a thick fog. Gas flaring has been reported to emit over 350 million tons of CO_2 equivalent/year. Nigeria which is highest at gas flaringin the world, flares over 313 million standard cubit feet of gas annually which in turn emits about 16.5 million tons of CO_2 (World Bank, 1995). The flaring of natural gas in the Niger Delta of Nigeria has increased the destruction of life (plants and animals) and resulted to a significant rise in climatic temperature. It has also resulted to acid rains with the resultant rendering of farmlands wasted/unproductive. Flaring liberates methane which is a greenhouse gas that traps heat in the air. The released methane is smelly and exposure causes nausea, headache, cancer, dizziness, lung damage, weakness, vomiting, and loss of coordination in humans and animals. Gas flaring has also been linked to reproductive and neurological problems. It pollutes rain water and destroys aquatic animals. Where crops survive the impact of flaring, their yields are grossly suppressed.

iii. **Electronic Devices and Appliances:** The speedy growth of technology and usage of electronic devices is creating humongous amount of electronic waste (e-waste) globally. Electronic waste or e-waste is constituted when an electronic device/product/equipment (which may be working or reparable) is discarded after it has been used or broken, and destined for either reuse, resale, refurbishment, salvage and recycling for material recovery, or disposal. E-waste products may have exhausted their utility value through replacement, redundancy, or breakage (Bhat and Patil, 2014). Components of electronic scraps e.g., central processing units (CPUs) contain potentially dangerous materials e.g., cadmium, lead, beryllium, brominated flame retardants, or polychlorinated biphenyls (PCBs). E-waste is made up of large household appliances (e.g., electric fans, air conditioners, refrigerators, hot plates, washing machines, and dish washers); small household appliances (e.g., toasters, pressing irons, hair dryers, coffee makers, clippers, and vacuum cleaners); Information Technology equipment (e.g., monitors, photocopiers, phones, laptops, printers, and scanners); consumer electronics (e.g., televisions, radios, musical instruments, amplifiers, and stereo equipment); lamps and luminaries; toys; tools; medical devices (e.g., radiotherapy equipment and pulmonary ventilators); monitoring and control instruments (e.g., smoke detectors, heating regulators, and thermostats); batteries and accumulators; automatic dispensers (for hot and cold drinks and money).

E-waste differs from conventional municipal wastes because aside complex combinations of toxic materials (e.g., lead, beryllium, and mercury which pose serious environmental risks to the air, water, soil, and wildlife), it also contain many recoverable precious and valuable materials which can be recycled e.g., gold, silver, copper, platinum, palladium, iron, aluminum, and plastics. The world's population discarded about 49 million tons of e-waste valuing $64.6 billion in 2016 (the bulk of which were dumped in landfills - only about 20% were recycled). E-waste regeneration is estimated to reach about 57 million tons in 2021 (Leung *et al*., 2018). Although electronic gadgets are indispensable appliances, their hazardous effects on the environment cannot be ignored. E-waste is particularly harmful due to toxic chemicals that pool into the ground below the landfills (by leaching) when buried. This contaminates the groundwater and bioaccumulate in the food chain. Health dangers have also been associated with inhalation of toxic fumes as a result of burning e-waste. Risks are exceptionally high in developing countries where a large chunk of e-waste is dumped, and more on children.

Research has shown that inhaling toxic chemicals (such as dioxins, furans, and acids) and/or direct contact with hazardous e-waste materials in whatever form (either directly during recycling, or indirectly, through environmental contamination) could lead to stillbirths, reduced birth weight, spontaneous abortion, premature births, bone loss, mutations, abnormal thyroid function, neuro-behavioral disturbances, increased lead levels in the blood, and decreased lung, liver and kidney functions (Nnorom and Osibanjo, 2008).

iv. **Mining Processes:** Mining of minerals requires three processes which are extraction, beneficiation, and processing. Extraction is the removal of ore from the earth. The next process is beneficiation which entails working the ore into a more useable form. Lastly, mineral processing removes the desired mineral from the remaining ore. The first two processes produce large quantities of waste. However, the last phase produces most of the hazardous waste (U.S. EPA, 2012b). Mine wastes which are commonly stored in heaps or mounds pose a threat to communities in various ways. Leachate from acid drainage, tailings and oxidization of heavy metals can be moved by surface runoff to lakes and streams, or may pollute the aquifer, thus contaminating drinking water or harming aquatic life. Contaminated soils are often transported by wind and deposited on surrounding environments such as public parks, residential buildings, and surface water.

Crude mining activities expose rivers and farmlands to toxic chemicals such as sulphur, lead, arsenic, mercury, and cyanide which are dangerous to humans, and the environment. In the northern part of Nigeria for instance, mining activities produces large amounts of toxic wastes which are basically sent into water bodies not minding or ignorant of health and environmental consequences. Many local communities in Zamfara State of Nigeria use mercury amalgamation method to extract gold. This method produces and exposes residents of the communities to different hazardous wastes such as lead. Exposure to natural radiations released by radioactive minerals is another key source of health hazards. It has been shown that pyrochlore, monazite, and xenotime obtained as by-products of tin mining in Jos, Plateau State of Nigeria are radioactive - strange deaths have been ascribed to high level of radiations emitted by monazite-rich sand used for building residential houses in the area (Aigbedion, 2005).

v. **Households and Municipals:** This is largely post-consumer products which fit as hazardous waste when discarded. It comprises household chemicals and other substances which the owners no longer use. Examples are consumer products sold for personal care, home care, automotive care, pest control, and other purposes such as pesticides, batteries, garden products, paints, household cleaners, solvents, fingernail polish remover, some cosmetics, used motor oils, antifreeze, and shoe polish. Some home smoke detectors are also listed because they contain some amount of radioactive isotope called americium. These substances can also induce changes in other forms of waste by reacting directly with or by altering the redox environment.

vi. **Agricultural Sources:** Some hazardous wastes are produced due to agricultural activities. It includes residues from growing and processing of raw agricultural products like crop plants (e.g., fruits and vegetables), poultry, meat, and dairy products. Examples are pesticides, fertilizers, silage plastics, oils, manure, human and animal pathogens, nitrogen, salts, feed additives, certain metals, meat processing, leather tannings, and slaughterhouse wastes that if not properly managed can be hazardous to plants, animals and/or even human life, partly attributable to their transmission and transformation through the food chain.Pesticides are used for pest management; but can bioaccumulate in the soil where they become toxic to pollinators and beneficial microbes. Most pesticides are soluble in water and as such can leach into the underground water and penetrate food products causing serious health issues such as Alzheimer's disease, cancer, birth defects, Parkinson's disease, and reproductive disorders. Pesticides can also kill none target organisms (Okrikata and Oruonye, 2012; Hu *et al*., 2003).

Overapplication of farm inputs like fertilizers and manures have been shown to have adverse effect on the growth of crop plants. Animal faeces can be a reservoir for pathogenic organisms. Infectious diseases have also been shown to be transmitted from animal excreta to man, or from animal to animal. For instance, *Salmonella dublin* which is essentially pathogenic to cattle can cause septicemia and meningitis in humans with children being more susceptible than adults. Similarly, *S. typhimurium* is infectious against many species of animals and even human.

vii. **Biomedical Sources:** These are hazardous medical wastes that, when improperly disposed, couldbe dangerous to health and the environment. It also poses occupational health hazards to healthcarestaff who handle the wastes at either the point of generation, management (i.e., segregation, treatment, transport, and storage), and/or disposal.About 15% of wastes generated by healthcare activities are hazardous as they are infectious, radioactive, or toxic. Incineration/open burning of healthcare waste can emit furans, dioxins, and particulate matter which are dangerous to health and environment. Improper disposal of healthcare waste can also release drug-resistant micro-organisms. Contractable diseases due to improper handling of biomedical wastes include; cholera, Hepatitis B, Acquire Immune Deficiency Syndrome (AIDS), tuberculosis, typhoid, Severe Acute Respiratory Syndrome (SARS), and also diseases incidental to exposure to Radioactive materials (Deepak, 2019).

The different categories of biomedical wastes include:

a. **Infectious waste:** Waste contaminated with blood and other bodily fluids (e.g., from discarded laboratory samples), pathogens (e.g., fungi, bacteria, and viruses) or parasites. Also included are wastes from autopsies, surgeries, or waste from infected patients (e.g., bandages, swabs, and disposable medical devices).

b. **Pathological waste:** Includes tissues, body fluids, blood, organs, body parts, human fetuses, and animal carcasses.

c. **Genotoxic waste:** This includes cytotoxic drugs used for cancer treatment and their metabolites, urine, vomit, or feces from the patients treated with cytotoxic drugs, chemicals, and radioactive materials. Genotoxic wastes have teratogenic, mutagenic, and carcinogenic properties.

d. **Chemical waste:** Include corrosive, toxic, inflammable and/or reactive reagents, disinfectants, sterilants, and solvents used for laboratory preparations. Additionally, heavy metals in medical devices (such as mercury in broken thermometers, blood pressure gauges, and amalgam), lead in reinforced wood panels for radiation proofing in radiology units, and cadmium in discarded batteries makeup this list.

e. **Radioactive waste:** Include products contaminated with radionuclides such as radioactive diagnostic and radiotherapeutic materials.

f. **Sharp waste:** Includes needles, syringes, scalpels, saws, broken glasses, infusion sets, knives, blades, or other items that can puncture wounds or cause cuts.

g. **Pharmaceutical waste:** Includes expired, spilt, unused, and contaminated pharmaceutical products, vaccines, drugs, and sera.

viii. **Industrial Sources:** This waste is generated by industrial or manufacturing processes. This has been a serious issue since the industrial revolution. Industrial waste is generated at every stage (production, use and disposal) of products. This waste may be ignitable, corrosive, toxic, or reactive, and if not well managed, can present serious health and environmental problems. Table 1 outlines hazardous wastes generated by industries.

Table 1: Hazardous waste generated by industries

Industry	Type of waste generated
Chemical manufacturers	Strong acids and bases; spent solvents; reactive waste
Construction industry	Ignitable paint waste; spent solvents; strong acids and bases
Leather products manufacturing	Waste toluene and benzene
Metal manufacturing	Sludges containing heavy metals; cyanide waste; paint wastes containing heavy metals; strong acids and bases
Paper industry	Paint waste containing heavy metals; ignitable solvents; strong acids and bases
Petroleum refining industry	Wastewater containing benzene or other hydrocarbons; sludge from refining process
Printing industry	Heavy metal solutions; waste inks; spent solvents; ink sludges containing heavy metals; spent electroplating wastes

Source: Adapted from U.S. EPA (1986)

ix. **Radioactive Sources:** This was partly discussed above under sources of biomedical waste. It is also called nuclear waste and includes a variety of radionuclides whichoccurs in a variety of chemical and physical forms. It is generated from nuclear reactors, hospitals, research facilities, fuel processing plants, production of radioisotopes, application of radioisotopes, decontaminationand decommission of nuclear installations, and nuclear research.Therefore, any activity that produces or uses radioactive material is capable of generating radioactive waste. Radioactive waste is hazardous because it releases radioactive particles, which if mismanaged can be dangerous to human health and the environment. Pollutionof water and soil by radionuclides due to natural processes, discharges from nuclear installations, nuclearweapon testing, disposal of nuclear waste, and sometimesnuclear accidents poses grave danger to the ecosystems.

3. Hazards of Heavy Metal Contamination

A key group of chemicals present in toxic wastes are the heavy metals. These are metallic chemical elements with relatively high density (atomic weight are 5 times ≥ that of water) and are poisonous or toxic at comparatively low concentrations. They are metal that are largely not degradable/destroyable in the environment, but may change their form through chemical reactions, or interaction with microbes (Wang *et al*., 2005). Most heavy metals are soluble in fats and get attached to some particles, or get embedded in minerals. Those most commonly known are Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), and Zinc (Zn). They can enter human bodies through air, water, food, and contact with contaminated soils or materials. Some heavy metals (e.g., copper, zinc, and selenium) are trace elements and so essential in maintaining the metabolism of the human body. The steel, automobile, and electronic industries use over 20 types of heavy metals in their manufacturing processes (ISRI, 2002). Heavy metals are dangerous because they are prone to bioaccumulation thereby causing health and ecosystem stress. Below is a brief description of common heavy metals and their effects;

a. **Arsenic:** It is generated from the processing of a variety of ores such as those of gold, lead, copper, nickel, and zinc. It is also found in ashes derived from coal combustion and on earth in small concentrations. Arsenic enters water, air and land via leaching, water-runoff, and wind-blown dust. The bulk of arsenic in the atmosphere comes from burning of fossil fuels. Human activities (e.g., smelting and mining) are the main processes through which arsenic is spread in the environment. Fish that contain high amounts of inorganic arsenic may pose health danger to humans. People who live in areas/farmlands where arsenic-containing pesticides have been applied in the past or in houses with arsenic preserved woods may also be at risk of arsenic poisoning which may result to miscarriages, infertility, immune suppression, skin disturbances, brain and deoxyribonucleic acid (DNA) damage. Large oral doses (> 60,000 ppb in water) of inorganic arsenic can lead to death; lower oral doses (ranging from about 30-30,000 ppb in water) may cause irritation of the intestine and stomach, with symptoms such as nausea, vomiting and diarrhea (Wang *et al*., 2005). Other effects of inorganic arsenic intake are fatigue, impaired nerve function, delirium, sore throat, irritated lungs, abnormal heart rhythm, and decreased production of red and white blood cells. Inorganic arsenic in surface water can cause mutation in fishes and eventually be biomagnified in the aquatic food chain. Plants also absorb arsenic which could lead to bioaccumulation in the food chain.

b. **Cadmium:** It is mostly found in the earth's crust in combination with zinc. It is an important byproduct of zinc, copper, and lead extraction; and an important constituent of batteries, pigments, pesticides, and fertilizers. Aside human activities such as manufacturing processes; cadmium is released into the environment via volcanoes, forest fires, and weathering of rocks. Food is an important route of cadmium intake into the human body (cadmium hardly enters the body via skin). Examples of cadmium-rich foods are leafy vegetables, grains, potatoes, sunflower seeds, cocoa, shellfish, mushrooms, liver, and mussels (Waalkes, 2000). Cadmium waste from industries end up in the soil, those from household wastes enters the air via combustion. Burning of fossil fuels also releases cadmium into the air. Production of phosphate fertilizers is also an important source of cadmium emission. Phosphate fertilizer application releases cadmium into the soil which may eventually pollute surface waters. Cadmium can be picked up by plants from the soil and can bioaccumulate in the food chain. Tobacco smoking significantly expose humans to higher levels of cadmium (tobacco leaves accumulates high levels of cadmium from the soil) as the smoke transports cadmium into the pulmonary system. High exposures can also occur when people live near waste sites and factories that release cadmium into the air, or when people work in metal refining industries. Inhalation of cadmium can damage the lungs severely or even cause death (Adelagun*et al*., 2013). Cadmium can also accumulate in the kidneys; damaging the nephrons. Other health effects of cadmium include; bone fracture, diarrhea, stomach pains, vomiting, infertility, immune suppression, and psychological disorders.

c. **Chromium:** It is a naturally occurring element in rocks, plants, animals and soil. It combines with other elements to form various compounds. It is mined as chromate ($FeCr_2O_4$) ore and mainly used in chrome-plating and metal ceramics. Exposure is via eating, drinking, inhalation, and skin contact with chromium or chromium compounds. It exists in different forms including Chromium (0), Chromium (III), and Chromium (VI). A trace amount of Chromium (III) is needed for human healthy living and this occurs naturally in foods like fruits, vegetables, yeasts, beverages, nuts, and meats (Velma *et al*., 2009). Chromium is also found in some consumer products such as leather tanned with chromic sulfate, stainless steel cookware, and wood treated with copper dichromate. Natural processes and human activities (e.g., chemical, textile, leather manufacturing, electroplating industries, and coal/natural gas combustion) are important means through which chromium enters the air, soil, and water. Chromium-containing hazardous waste facility and cigarette smoke also release chromium into the atmosphere (Helena, 2012). Depending on the concentration and type of chromium compounds, health effects associated with exposure include; shortness of breath, asthma, wheezing, cough, skin rashes, eye irritation, ulcer, anemia, infertility, tumors, disruption of metabolisms, kidney and stomach problems, diabetes, heart problems, and edema. Higher amounts of chromium in surface water can damage the gills of fish in the water. Ordinarily, the physiology of crops is such that they suppress chromium uptake to levels that are low enough as not to cause harm. However, when the concentration of chromium in the soil rises, higher amounts can be picked up which eventually enters the food chain (Velma *et al*., 2009).

The hexavalent - Chromium (VI) is the most toxic of all the chromium forms. It is mostly a product of industrial processes such as chromate pigments in paints, inks, dyes, plastics; fumes from welding stainless steel; chrome plating etc. Aside the aforementioned ailments which are known to be associated with chromium toxicity, the hexavalent chromium is a confirmed carcinogen (nasal, lung, and sinus), mutagen, and also causes diseases such as gingivitis and periodontitis.

d. **Copper:** It occurs at low levels naturally in plants, animals, and the environment and spread through natural processes (decaying vegetation, sea spray, forest fires, and wind-blown dust). Humans use copper extensively in industries and industrial related activities (such as; mining, wood production, metal production, phosphate fertilizer production, electrical equipment production, roofing, plumbing, and alloy processing), and agriculture. It is widespread in and near mines, landfills, and other waste disposal sites (Wu *et al*., 2017). Copper compounds largely settle and get bound to soil particles or water sediments. Soluble copper compounds are the most dangerous to human lives. Living organisms including humans and other animals take in low levels of copper daily through food, water, air, and skin contact with copper-containing substances. This is important as copper is one of the essential trace elements needed by living organisms. Even though the human physiology is capable of dealing with sizable amount of copper, exposure to very high amounts (as experienced by smelters or people that live near smelters who process copper ore into metals) largely via inhalation of high copper-containing dust may cause severe health issues. Contact with copper-containing fungicides is also an important exposure route. Health issues associated with long-term exposure include; dizziness, diarrhea, stomachache, headache, decline in intelligence in children, metal fume fever, Wilson's disease, irritation to the eyes, mouth and nose. High uptakes may cause kidney and liver damage, and even death. Some copper deposited on land (mainly via gravity, rain, and snow) attach strongly to minerals and organic matter which limits their mobility and entrance into groundwater (Wu *et al*., 2017). Copper does not degrade in the environment and this favors accumulation in plants and animals – however, plant survival on copper-rich soil is very limited and this threatens crop production on farmlands. Copper also negatively influences the activities of earthworms and soil microbes thereby suppressing the decomposition of organic matter. Animals (mainly sheep) have been reported to absorb health-damaging concentrations of copper (copper toxicity) from copper polluted farmlands.

e. **Lead:** It is a heavy, bluish-gray, low melting metal that occurs naturally in the earth's crust. It usually occur as lead compounds – combined with two or more other elements capable of changing form by interacting with sunlight, air and water. Metallic lead is resistant to corrosion. Lead and lead alloys are often found in cable covers, ceramic glazes, pipes, storage batteries, ammunition, and sheets used to shield radiations. Lead compounds are also used in dyes, paints and caulk. Tetramethyl lead and tetraethyl lead (banned for use in gasoline in many countries due to toxicity) may likely still be in use in gasoline for off-road vehicles and airplanes. A number of developing countries may still be using them with limited if any regulation despite their well-knownhealth effects. Most of the lead used by industries originates from mined ores or from recycled batteries, or scrap metals. Lead can also be released into the air by burning oil, coal, or wastes. Lead was hitherto used as pesticide additive. Lead particles that are small in size travel long distances and are removed from the air by rain or gravity onto the land or surface water. On the soil, lead sticks strongly to soil particles and remains in the top layer of the soil, and may enter water bodies via run-off. Lead may remain stuck to sediments in water or soil particles for many years. Environments where lead are commonly found includes; near roadways, old orchards, old houses, mining sites, around incinerators, industrial sites, near power plants, landfills, and hazardous waste sites. People living around these environments may be exposed to lead or lead-containing compounds through inhalation, eating food, drinking water, or swallowing lead containing dirt or dust. Studies have shown that insignificant amount of lead can enter the body via skin. Lead contamination of plants and animals may result to bioaccumulation in the food chain. A small amount of lead is found in cigarette smoke and significant amount may be contained in fruits, vegetables, grains, seafood, soft drinks, and meats. Lead toxicity disrupts the nervous system mainly (Adelagun*et al*., 2014). It causes weakness in ankles, wrist, and fingers. It can also cause increase in blood pressure and anemia. High levels can lead to sperm production suppression, kidneys damage, brain damage, and ultimately death; in pregnant women, miscarriage may result. Children are however more vulnerable to lead poisoning.

f. **Mercury:** It occurs naturally in the environment in several forms which could be inorganic, organic, and metallic/elemental. The combination of mercury with elements such as chlorine, oxygen, and sulphur forms inorganic mercury and common examples found in the environment are; mercuric chloride and mercuric sulphide. Organic mercury compounds occur when mercury combines with carbon and a common example in the environment is methylmercury. Metallic mercury on the other hand is a shiny, silver-white metal which is liquid at ordinary temperature. It is the pure or elemental form of mercury – not combined with any other element. Mercury enters the environment from normal breakdown of minerals in soil and rocks, and from volcanic eruptions. Human activities (such as mining, smelting, burning of fossil fuels, waste incineration, manufacturing, and burning of medical wastes) have increased the release of mercury into the environment.

The level of mercury in the atmosphere is ordinarily very low to pose health risks; however, since the industrial revolution, the level is said to have risen by 3-6 times higher. Some inorganic mercury compounds are used in fungicides, bactericides, and fertilizers; while others are used in cements, skin-lightening creams, antiseptics, disinfectants, dyes, paints, and even as preservatives in some drugs. Inorganic mercury hardly accumulates in the food chain as they are generally taken up at a comparatively slower rate and efficiency. Some microbes and natural processes can change mercury from one form to another in the environment. A typical example is the formation of methylmercury which easily builds up in some fresh and salt water fishes and marine mammals, and readily bioaccumulate in the food chain. Liquid metallic mercury has many uses; it is used in producing caustic soda and chlorine gas and for extracting gold from ore. It is also used in manufacturing barometers, batteries, thermometers, and electrical switches. Mercury vapor can be changed into other forms of mercury in the air and moved to the soil or water bodies via snow or rain and remain there for a long time attached to small particles in the soil or water. The amalgam used in silver-colored dental fillings contain about 50% metallic mercury which is slowly released due to corrosion, chewing and grinding motion. The estimated release is 3-17 microgram/day and this level of exposure arguably does not necessarily pose any health risk. In some parts of the world, metallic mercury is used for some herbal or religious/spiritual rituals/practices. These uses may expose users or others to health risks incidental to inhalation of mercury vapors in contaminated air. The longer the inhalation period, the greater the health risk will be. It is not certain whether exposure to inorganic mercury could lead to nerve or brain damage as they do not readily enter the brain from the blood. However, it has been shown that exposure to inorganic mercury can damage the kidneys, stomach, and intestine. It has also been shown that people who ate seed grains treated with methylmercury or fish contaminated with methylmercury, or other organic mercury compounds developed permanent kidneys and brain damage. Exposure to sufficiently high metallic mercury has also been associated with permanent brain damage. Exposure to high levels of metallic mercury on short-term (a few hours) may damage the linings of the mouth and irritate the airways and lungs. Lower levels exposure to mercury vapor over a long duration (many years) could cause damage to the mouth and lungs, and heart in the case of children. Symptoms associated with high level of organic mercury or metallic mercury vapors include; nervousness, shyness, tremors, changes in vision, difficulties with memory, deafness, muscle incoordination, and loss of sensation.

g. **Nickel:** It is a hard, silvery-white, ductile, and malleable metal with desirable properties for alloy preparation. It is readily alloyed with iron, zinc, chromium and copper to make metal coins, jewelries, and stainless steel. Nickel also readily combines with other elements e.g., chlorine, oxygen and sulfur to form compounds many of which are soluble in water. Nickel compounds are used to color ceramics, make some batteries, metal plating, and used as catalysts. Nickel occurs naturally in the earth's crust in combination with other elements. It is also released via volcanic eruptions. Release into the atmosphere occurs during mining and by industries that use or make nickel, nickel compounds, or nickel alloys. Wastewater discharge from industries may be an avenue for nickel release into the environment. Release also occurs through oil-burning, coal-burning, and waste incineration. Nickel released into the atmosphere gets attached to small particles of dust and then settles on the soil through gravity. It can also be moved out of the atmosphere in rain and snows to either the soil or water bodies. Though hardly accumulate in fishes and small land animals, plants pick up and concentrate nickel in their tissues. The major source of exposure to nickel is food. Other exposure routes are inhalation, water intake, tobacco smoking, use of detergents and skin contact. The unborn and infants are exposed via fetal blood and breast milk respectively. Allergic reaction is the commonesthealth effect of nickel exposure and common reactions when skin contact is the route of exposure are skin rashes, dermatitis, and eczema. Inhalation can cause asthma, although rarely. Women are more sensitive to nickel than men and this is attributable largely to women's higher exposure to nickel via metal items and jewelries than men. High ingestion of nickel could result to stomachache, and blood, and kidneys disorder. Other severe health effects from nickel exposure include lung malfunction, cancer/prostate cancer, chronic bronchitis, and birth defects.

h. **Zinc:** It is a common element in the earth's crust; its ore is mostly in the form of zinc sulphide. It is present also in the air, water, soil, and foods. Pure elemental/metallic zinc is a shiny, bluish-white metal. It is used to make dry cell batteries. Zinc is an essential trace metal required in small amount in all animals. Powdered zinc is explosive and may burst into flames when stored in damp environment. Zinc is used to coat iron, steel, and other metals to avoid corrosion or rust and this process is called galvanization. Alloys such as bronze and brass are formed by the mixture of zinc with other metals. Zinc sulphate, zinc chloride, and zinc acetate are used for wood preservation and for producing and dyeing fabrics. Zinc compounds also find use in drug industries as ingredients for vitamin supplements, antidandruff shampoos and diaper rash ointments preparations. They are also used for paints, ceramics, and rubber production. Zinc compounds e.g., zinc sulphate, zinc sulphide, zinc chloride, and zinc oxide are commonly found at hazardous waste sites. Zinc enters the environment largely through mining activities, purification of zinc, cadmium and lead ores, coal and wastes burning, and steel production. Fertilizers and sludges release zinc into the soil, while run-off from zinc-containing soil and domestic wastewater discharge zinc into water bodies where it remains either dissolved, suspended in particulate form, or settles at the bottom. While zinc mostly remain bound to soil particles without dissolving in soil water, some amount, depending on soil type, may get to the ground water.

Zinc negatively influences the activities of earthworm and microbes in the soil thereby slowing down the breakdown of organic matter. Land animals pick up zinc by drinking contaminated water. Similarly, some fishes take in and accumulate zinc from their environment from where it enters the food chain. Zinc is largely present in the atmosphere as dust particles which are eventually deposited on water bodies and land by snow and rain. High level of zinc on land can threaten plant survival. Zinc can get to the lungs by inhaling zinc dust or fumes. Among others, automobile mechanics, construction workers, miners, smelters, and painters experience higher exposure to zinc. A short-term disease referred to as metal fume fever arises from inhaling high amount of zinc. Zinc intake much higher than the Recommended Dietary Allowances (RDAs) of 8 mg/day for women and 11 mg/day for men causes adverse health effects such as stomach cramps, vomiting, and nausea on a short-term, and causes anemia, respiratory disorders, pancreas damage, interruption of protein metabolism, and arteriosclerosis on long-term exposure (e.g., several months). On the other hand, consuming too little of zinc may pose health challenges such as appetite loss, suppressed immunity, retarded growth, decreased sense of taste and smell, slow wound healing and birth defects.

4. Hazards of Pesticide Contamination

Any substance or mixture of substances designed to destroy, repel, prevent or mitigate any pest (e.g., insects, arachnids, molluscs, rodents, nematodes, fungi or weeds), or designed for use as plant regulator, dessicant, or defoliant is a pesticide. They are designed to be hazardous and that is why, though helpful; they pose certain dangers to man, other animals and the environment in general. One can be accidentally exposed to pesticides via inhalation, skin absorption and/or ingestion and response depends on the pesticide type, pesticide amount/concentration exposed to, age, and health status of the victim. Some pesticides fit the definition and characteristics of hazardous wastes discussed above and thus are subjected to laws and regulations (which vary across nations) with regards to their handling, transportation and disposal. Generally, aside from the criteria for hazardous wastes which were discussed extensively above; hazardous pesticide waste includes any substance/material which contain any amount of pesticide that can no longer be legally used. Also included as hazardous pesticide waste are left-over spray solutions, excess pesticides, rinse water from spray equipment and containers, suspended/recalled/cancelled pesticides or collected waste pesticides during collection programs/materials generated from cleanup of pesticide leaks and spills. Hence, pesticides can become potentially hazardous wastes when the pesticide holder (i.e., registrant, dealer, distributor, or end-user) decides to discard them. Pesticides to be discarded should be disposed of as hazardous wastes. Pesticide wastes containing either arsenic, cadmium, or chromium are also regarded as hazardous wastes.

Pesticide acute poisoning cases of about 3 million, leading to some 250,000 – 370,000 deaths are annually reported. This is more severe in the developing countries (particularly more on children) where agriculture is about, if not the largest economic sector. Relationships between pesticide abuse and cancers such as leukemia and non-Hodgkin’s lymphoma, lung and prostate cancers have been established. Neurodegenerative diseases such as Alzheimer’s and Parkinson’s diseases have also been associated with pesticides. Children are particularly more susceptible to pesticide neurotoxins due to lower body weight and developing nervous and immune systems (Yimaer*et al*., 2017). Improper disposal of pesticides can cause air, soil and water pollution with immediate to long term negative impacts as, pesticides can migrate via groundwater and atmosphere to long distances. To minimize hazardous pesticide waste in the environment, more environmentally friendly pest management techniques need to be developed and adopted. The recruitment of Integrated Pest Management (IPM) strategies which advocates minimal use of synthetic chemical pesticides while promoting other eco-friendly strategies such as biocontrol, host-plant resistance/genetic control and cultural control needs more attention, particularly in the developing nations (Okrikata and Oruonye, 2013).

4.1 Classification of pesticides

Pesticides are very diverse group of substances and majorly classified on several bases such as Eldridge (2008) and Megha*et al*. (2018):

1. **Target pest and function:**

Table 2 outlines some pesticide classes which are categorized on the basis of their target organisms.

Table 2: Classification of pesticides based on target pest

Class	Target	Example
Insecticides	Insects	Cypermethrin
Herbicides	Weeds	Paraquat
Fungicides	Fungi	Thiabendazole
Avicides	Birds	Fenthion
Piscides	Fish	Rotenone
Bactericides	Bacteria	Streptomycin
Algicides	Algae	Copper sulphate
Acaricides	Mites and ticks	Dicofol
Virucides	Viruses	Ribavirin
Nematicides	Nematodes	Methybromide
Molluscicides	Snails and slugs	Metaldehyde

Others included in the list are Chemosterillants, Desiccants, Insect attractants, Insect growth regulators, Larvicides, Lampricides, Termiticides, Mammal repellents, Mating disrupters, Moth balls, Ovicides, Silvicides and Synergists.

2. Mode of entry:

On the basis of mode of entry, pesticides are classified as:

- **i.** ***Non systemic/contact:*** Target pest must come into physical contact with pesticide for pesticidal action to take place. They do not necessarily penetrate plant tissue and consequently not transported within plant vascular system e.g., Paraquat, Diquat dibromide
- **j.** ***Systemic:*** These pesticides effectively penetrate plant/animal tissues and are transported within the pest's system to trigger pesticidal effect e.g., Glyphosate.
- **k.** ***Stomach poison:*** These pesticides access the pest through mouth/digestive system. They damage the stomach of the target pest e.g., Malathion.
- **l.** ***Repellent:*** They necessarily do not kill pests but keep them away from treated area/commodity. They may also interfere with location of host by pest e.g., Methiocarb.
- **m.** ***Fumigant:*** They form toxic gases when applied. The gas kill target pest on entry via the respiratory/tracheal system e.g., Aluminum phosphide, Hydrogen cyanide.

3. Mode of action:

On the basis of mode of action, pesticides are thus categorized:

- **n.** ***Physical poison:*** Kill pest by physical effect e.g., Activated clay.
- **o.** ***Protoplasmic poison:*** Precipitates protein in pests e.g., Arsenicals.
- **p.** ***Respiratory poison:*** Inactivates respiratory enzymes of pests e.g., Hydrogen cyanide.
- **q.** ***Nerve poison:*** Inhibits impulse conduction in pests e.g., Malathion.
- **r.** ***Chitin inhibition:*** Inhibits chitin synthesis in pests e.g., Diflubenzuron.

4. Chemical nature and composition:

Being chemicals, pesticides are grouped based on the chemical nature of their active ingredients. This criterion is the most useful for pesticide scientists/researchers as it determines the efficacy, physical and chemical characteristics of a pesticide and influences the mode and rate of application as well as precautions during application. Table 3 shows the various pesticide classes on the basis of chemical nature.

Table 3: Classification of pesticide on the basis of chemical nature

Class	Main use/function	Example
1. Inorganic pesticides		
i. Arsenicals	Insecticides, herbicides	Arsenate
ii. Bordeaux mixture	Fungicides	Tetracupric + Pentacupricsulphate (Copper sulphate)
2. Organic pesticides		
i. Acetaldehyde polymer	Molluscicides	Metaldehyde
ii. Amides	Herbicides	Alachlor, Metachlor, Butachlor
iii. Carbamates	Mainly insecticides	Aldicarb, Aminocarb, Carbaryl, Carbofuran, Carbosulfan, Methiocarb
iv. Chlorinated hydrocarbons/Organochlorines	Insecticides	DDT, DDD, TDE, Endosulfan, Methoxychlor, Chlorophenoxy acids (2,4-D, 2,4,5-T, MCPA, Silvex), Cyclodienes (Aldrin, Chlordane, Dieldrin Heptachlor), Lindane
v.Dinitoaniline	Herbicides	Pendimethalin, Trifluralin
vi. Organics extracted from plants (plus laboratory analogues)	Mainly insecticides	Neonicotinoids e.g., Imidaclopirid, Nicotine, Nicotine sulphate, Pyrethrum, Red squill, Rotenone, Strychnine
vii. Organomercurials	Fungicides	Methyl mercury, Methoxyethyl mercuric chloride, Phenylmercuric acetate
viii. Organophosphates	Mainly insecticides	Dichlorvos, Monocrotophos, Fenthion, Dimethoate, Diazinon, Parathion, Malathion, Chlorpyriphos, Glyphosate
ix. Phenols	Fungicides	Trichlorophenol
x. Thiocarbamates	Herbicides	Butylate
xi. Triazines	Herbicides	Atrazine, Cyanazine, Simazine, Metribuzin

Source: Adapted from; Freedman, 2010

5. Toxicity:

On the basis of toxicity, WHO developed criteria for classifying pesticides as shown in Table 4. This classification is based on acute oral and dermal toxicity derived from pesticides LD_{50} – the pesticide dose that kills 50% of test animal when route of entry is oral or dermal.

Table 4: WHO's criteria for classification of pesticides on the basis of acute toxicity

Toxicity category		LD50 for the rat (mg/kg body weight) Oral	Dermal	Examples
Ia	Extremely hazardous	< 5	< 50	Aldicarb, Disulphoton, Phorate, Flocoumafen, Parathion.
Ib	Highly hazardous	5 – 50	50 - 200	Azinphos-methyl, Carbofuran, Dichlorvos, Zinc phosphate, Nicotine, Warfarin, Monocrotophos, Oxamyl.
II	Moderately hazardous	50 - 2000	200 - 2000	Permethrin, Imidacloprid, Paraquat, Chlordane, Cypermethrin, Dimethoate, Thiram, Chlorpyrifos, Lambda-cyhalothrin, Lindane, Metalaxyl, Pirimiphos-methyl, Tebuconazole, Sevin.
III	Slightly hazardous	> 2000		Atrazine, Butachlor, Glyphosate, Malathion.
U	Unlikely to present acute hazard	≥ 5000		Amitrole, Carbendazim, Benomyl, Mancozeb.

Source: WHO, 2009

4.2 Notable Historical Disasters Associated with Heavy Metals and Pesticides Contamination

Long-term exposure to hazardous substances, particularly pesticides and heavy metals, could pose chronic and sometimes irreversible health issues, or exacerbate existing ailments. Tables 5 and 6 summarize significantly verifiable health effects of some pesticides and heavy metals on humans or laboratory animals. Historical evidences show the risks associated with mishandling of heavy metals and pesticides and why strict regulatory procedures need to be adopted.

In mid-1950s, medical doctors in Japan started seeing many patients in the Minamata Bay area with strange central nervous diseases and exhibiting behaviors such as trembling, paralysis, stumbling, body contortions, difficulty in swallowing, sight and hearing and uncontrolled shouting. Detailed investigations showed that they all contracted mercury (methylmercury) poisoning largely through eating heavily polluted fish and shellfish from the bay as a result of mercury discharge/spillage into the bay from a neighboring industry. Aside the death of many cats, pigs, and dogs, this incident led to the death of 3,000 humans, and caused severe deformities in the fishes found in the bay (Timothy, 2001).

A related incident which also highlights the danger associated with hazardous wastes occurred at Love Canal which is situated near Niagara Falls, New York. The area which was originally designed to be a shipping lane in 1890 was converted to a hazardous waste dump site in the 1920s. In 1952, when the canal was filled up with about 20,000 tons of toxic wastes in metal drums, it was sold to the Niagara school district. An elementary school was then built there along with many other residential houses. By late 1970s, residents complained of strong odors, and presence of colored liquids and oils in the environment. Investigations showed the presence of different toxic pollutants in the air, soil, and ground water. Exposure resulted to birth defects, physical abnormalities, miscarriages, leukemia, cancers, chromosome damage, high white blood cell counts, and other illnesses. This attracted public attention with the area declared as a Federal Disaster site by the then President Carter, and the whole neighborhood was evacuated by September, 1979 with the residents carrying along longstanding health problems (Blum, 2008).

In 2007, it was reported that the French Caribbean Islands of Martinique and Guadeloupe were facing a health disaster linked to Chlordecone (an organochlorine pesticide which has insecticidal and fungicidal properties) sprayed on banana plantations. While many other countries banned its use in 1979 for health and environmental reasons, France used it legally till 1990, and eventually banned its use in the Caribbean territories in 1993. However, illegal usage continued until 2002 largely using aerial sprays thereby poisoning both land and water, including the drinking water source of the Caribbean territories. The about two decades use of Chlordecone placed 50% males at the risk of developing prostate cancer along with increasing congenital malformations and infertility among women. These effects were projected to last for about a century (Lichfield, 2007). As at 2014, it was reported that almost all adults (93 – 95% ≈ 750,000 persons) in the area still have traces of the toxic pesticide in their blood (Sieeka, 2019).

Another incident happened in India, when inhabitants of Kasaragod district of Kerala were exposed to endosulfan (a highly potent neurotoxic pesticide) aerially sprayed on about 12,000 acres of cashew orchard between 1975 and 2000 (distribution and sale was banned in the area in 2001) by the plantation owners (the State's owned "Plantation Corporation of Kerala") for pest control. The pesticide residue spread across the district and neighboring Karnataka by rain and wind with a resultant poisoning of over 9,000 persons with over 1,000 deaths (unofficial estimates puts death records at 4,000). Following a number of unusual diseases and deformities such as hydrocephalus, congenital disabilities, epilepsy, cerebral palsy, nervous system diseases, stunted growth, abortions, late sexual maturity, and mental and physical disabilities, the Centre for Science and Environment (CSE) conducted a laboratory analysis in 2001 where samples of human blood and milk, soil, fruits and vegetables, water, skin tissues, fish, cow milk and frogs were all tested, and were all found to contain high amounts of endosulfan. Scientific studies show that aside other deleterious health effects, endosulfan affects unborn children (Asha *et al*., 2012). Despite stoppage in the spraying of the pesticide in 2001, babies were still born with physical deformities, genetic disorders, and many other irreversible ailments even as at 2018 (https://ejatlas.org/print/use-of-endosulphan-in-kasragod-kerala-india). All of these historical evidences add credence for the need for proper management of hazardous wastes and to reduce, or eliminate the generation of hazardous wastes.

Table 5: Acute effects of certain hazardous wastes

Type of wastes	Nervous system damage	Gastro-intestinal system damage	Neurological system damage	Respiratory system damage	Skin damage	Death
Toxic metals						
Arsenic		X			X	X
Cadmium		X		X		X
Chromium, Copper, Nickel, Selenium, Zinc		X		X	X	
Mercury	X	X	X			X
Organic lead compounds	X	X	X			X
Pesticides						
Aluminum phosphide		X				
Carbamate insecticides	X		X	X		X
Dimethyldithiocarbamate fungicide compounds				X		
Halogenated organic pesticides	X		X	X		
Halogenated organic phenoxy herbicides					X	
Methyl bromide			X			
Organonitrogen herbicides (Paraquat and Diquat)		X				X
Organophosphorous pesticides	X		X	X		X
Rotenone		X		X		
2,4-Dichlorophenoxyacetic acid (2,4-D)	X					

X: significantly verifiable effects on humans

Source: Goldman *et al*., 1986.

Table 6: Chronic effects of certain hazardous wastes

Type of waste	Carcinogenic effects	Mutagenic effects	Teratogenic effect	Reproductive system damage
Toxic metals				
Cadmium	X			
Chromium, Copper, Nickel, Selenium, Zinc	X			
Mercury			X	
Pesticides				
Halogenated organic pesticides	O	O	O	X
Halogenated organic phenoxy herbicides	O	O	O	O
Organonitrogen herbicides (Paraquat and Diquat)	O	O	O	
Organophosphorous pesticides	O	O	O	

X: significantly verifiable effects on humans

O: significantly verifiable effects on laboratory animals

Source: Goldman *et al*., 1986.

5. Minimizing Risks Posed by Hazardous Wastes

From the beginning of early civilizations, the hazardous effects of some substances used by the people were known, but there were little or no laid down systematic procedures to deal with the issues. The advent of industrial revolution worsened the problem as health and environmental impacts of many industrial activities were hardly understood, much less quantified. This was partly because it took years for the effects to manifest, and also science and technology was still at its lowest stage of development. Today, many countries have legislations to protect their environment and populations from the effect of hazardous wastes. Despite this, soil and groundwater contamination continue to occur globally, largely due to poor and illegal waste management practices. To minimize the risks associated with hazardous wastes, proper management strategies are required. Among the options advocated for reducing the risk level of hazardous wastes are;

1. **Minimization/reduction of hazardous waste generation:**

This strategy includes modifying production process, alternative use of wastes, altering primary source of generated wastes by enhancing process technology and equipment, substituting raw materials with others with potential to generate lesser waste, reformulating or redesigning end products, reuse and recycling wastes by either using waste products as raw materials in manufacturing processes, or by reprocessing wastes to recover materials and energy

2. **Treatment of wastes before disposal:**

This involves segregating hazardous from non-hazardous wastes and then treating the hazardous wastes to render them harmless or less harmful to human and the environment. Treatment procedures can be one or a combination of:

a. Physical treatment: involves separation processes such as separating liquid from solid wastes),

b. Chemical treatment: using chemical reactions to either convert hazardous waste into less hazardous substance or reducing the volume of the waste,

c. Biological treatment: involves the use of appropriate microbes/living organisms to degenerate or detoxify hazardous wastes,

d. Thermal treatment: involves the use of incineration to destroy or reduce wastes to carbon (iv) oxide, water, and other organic substances,

e. Safe disposal of waste: This is largely through supervised or monitored landfills, incineration of final wastes, or other controlled form of disposal.

6. The Future of Hazardous Wastes

Wastes, hazardous wastes in particular, have been associated with humanity right from pre-history and will surely continue to be with us into the future. Issues related to hazardous wastes and their management will also continue to be with us as agricultural, residential, municipal, industrial, commercial, mining and recreational activities, amidst others continue to rise with rising global populations. Despite the health and environmental consequences of mishandling hazardous wastes, man has continued to dispose them indiscriminately on his surrounding with little, if any concern for the ecosystem. However, if we are to preserve our planet for the future generations, hazardous waste ought to be properly managed. Recently, nuclear technology and applications are developing rapidly with the kick off of several nuclear power plants. This should be of concern as the potential health and environmental impact of massive release of radioactive contaminants into the environment can only be imagined.

It is now known that some types of hazardous waste take so many years (decades and even more) to degrade, and for this reason, it is not in contest that hazardous waste will be with us for a very long time to come. Interestingly though, awareness about the impact of hazardous waste is rising, particularly, in the recent past. Humans are now appreciating the need to reduce the use of hazardous chemicals in agriculture and other manufacturing processes, and researchers/scientists have been in the search for safer chemicals and waste disposal strategies. Hence, the future of hazardous waste depends very largely on the successes achieved in these respect as well as in the development of more efficient recycling and reusing technologies.

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